

GRAIN LEGUMES

Leveraging legumes to combat poverty, hunger, malnutrition and environmental degradation

A CGIAR Research Program
submitted by ICRISAT, CIAT, ICARDA and IITA

03 February 2012



In collaboration with

Generation Challenge Program (GCP)

Brazilian Agricultural Research Corporation (EMBRAPA)

Ethiopian Institute of Agricultural Research (EIAR)

Indian Council of Agricultural Research (ICAR)

Turkish General Directorate of Agricultural Research (GDAR)

Dry Grain Pulses Collaborative Research Support Program (Pulse CRSP)

National agricultural research and extension systems in Africa, Asia and Latin America and the Caribbean

National and international public and private sector research and development partners

Foreword

We are pleased to present our revised proposal for CGIAR Research Program on GRAIN LEGUMES (CRP 3.5). The revision has considered the valuable suggestions from the Consortium Board and other reviewers, and reflects the substantive inputs from all partners to address the ‘must haves’ required by the Independent Science and Partnership Council (ISPC) and the Fund Council (FC).

CRP 3.5 GRAIN LEGUMES directly supports the four CGIAR System Level Outcomes and is highly complementary to other CRP targets. GRAIN LEGUMES complement the nutritional value of cereals and enable the sustainable intensification of farming systems through nitrogen fixation, extending land cover and nutrient utilization by fitting into a wide range of intercropping configurations. Grain legume cultivation directly benefits women because they are often the primary cultivators of these crops (especially in sub-Saharan Africa) as well as being employed in small-scale processing, preparation and marketing of foods derived from them.

The partners in this global alliance for grain legumes include four CGIAR Centers (ICRISAT-lead, CIAT, ICARDA and IITA), and six others who have complementary grain legume research-for-development (R4D) efforts (EIAR, EMBRAPA, GDAR, Generation Challenge Program, ICAR and USA Dry Grain Pulses CRSP).

Bringing these world-leading grain legume programs together enables us to learn much more effectively from each other than in the past, increasing our impact. We will share expertise, facilities and services that improve all partners’ capacities, efficiency and effectiveness. We will communicate more clearly and effectively with our stakeholders and with those whom we need to influence in order to achieve change on the ground.

This proposal describes how we will deliver on that promise.

William D Dar, Director General, ICRISAT

Ruben G Echeverria, Director General, CIAT

Mahmoud Solh, Director General, ICARDA

Nteranya Sanginga, Director General, IITA

Acknowledgments

The ten core partner institutions of CRP 3.5 GRAIN LEGUMES wish to offer their sincere thanks to the more than one hundred scientists and external partners who have put large amounts of time and energy into this proposal. They crossed institutional boundaries to work as a united team. They gathered data and information, and brainstormed ideas in three global meetings and in many focused sub-meetings and workshops over the course of 2010, 2011 and 2012 in order to draft, revise and refine this proposal. The effort has been well worth it, clarifying our ideas and sparking new ones that will improve our focus and direction in the coming years.

Apart from the scientists, many other staff in all the institutes (administration, finance, human resources and others) worked overtime to provide additional information and data, and to meet deadlines. Helpful suggestions have come from the members of ICRISAT's Governing Board, the CGIAR Consortium Board, ISPC, FC, as well as external experts. We thank all for making this a better proposal.

Table of Contents

FOREWORD	I
ACKNOWLEDGMENTS	II
TABLE OF CONTENTS	III
ACRONYMS & ABBREVIATIONS	V
1. EXECUTIVE SUMMARY	1
2. STATEMENT OF OBJECTIVES	5
3. JUSTIFICATION	12
4. IMPACT PATHWAY	36
5. GRAIN LEGUMES STRATEGIC OBJECTIVES	44
OVERVIEW OF GRAIN LEGUMES STRATEGIC OBJECTIVES	44
5.1 STRATEGIC OBJECTIVE 1: CONSERVING AND CHARACTERIZING GENETIC RESOURCES AND DEVELOPING NOVEL BREEDING METHODS/TOOLS FOR IMPROVING EFFICIENCY OF CROP IMPROVEMENT	48
5.2 STRATEGIC OBJECTIVE 2: ACCELERATING THE DEVELOPMENT OF MORE PRODUCTIVE AND NUTRITIOUS CULTIVARS FOR RESILIENT CROPPING SYSTEMS OF SMALLHOLDER FARMERS	61
5.3 STRATEGIC OBJECTIVE 3: IDENTIFYING AND PROMOTING CROP AND PEST MANAGEMENT PRACTICES THROUGH FARMER PARTICIPATORY APPROACHES FOR SUSTAINABLE LEGUME PRODUCTION	76
5.4 STRATEGIC OBJECTIVE 4: DEVELOP AND FACILITATE EFFICIENT LEGUME SEED PRODUCTION AND DELIVERY SYSTEMS FOR SMALLHOLDER FARMERS.....	88
5.5 STRATEGIC OBJECTIVE 5: ENHANCE GRAIN LEGUMES VALUE CHAIN BENEFITS CAPTURED BY THE POOR, ESPECIALLY WOMEN	100
5.6. STRATEGIC OBJECTIVE 6: PARTNERSHIPS, CAPACITIES, AND KNOWLEDGE SHARING TO ENHANCE GRAIN LEGUME R4D IMPACTS.....	111
6. PARTNERSHIPS AND NETWORKS	121
7. GENDER RESEARCH STRATEGY	131
8. INNOVATIONS	135
9. INTERACTIONS OF CRP 3.5 GRAIN LEGUMES WITH OTHER CRPs	143
10. GOVERNANCE AND MANAGEMENT	149
11. TIME FRAME	154
12. MITIGATING RISKS	155
13. MONITORING AND EVALUATION SYSTEM	156
14. BUDGET	162
LIST OF REFERENCES	168
APPENDICES	
APPENDIX 1. CRP 3.5 GRAIN LEGUMES INITIAL PARTNERS: CAPACITIES AND PRIORITIES.....	187
APPENDIX 2. BRIEF PROFILES OF CRP 3.5 TARGET CROPS.....	193
APPENDIX 3. CRP 3.5 GRAIN LEGUMES FOCUS REGIONS: BRIEF PROFILES.....	196
APPENDIX 4. GRAIN LEGUME DISTRIBUTION BY FARMING SYSTEMS AND REGION	203
APPENDIX 5. THE EX-ANTE ECONOMIC, NUTRITIONAL, AND ENVIRONMENTAL IMPACTS OF LEGUME R4D	208
APPENDIX 6. RELATIVE IMPORTANCE AND YIELD LOSSES (%) DUE TO BIOTIC/ABIOTIC CONSTRAINTS IN GRAIN LEGUMES IN DIFFERENT REGIONS	215
APPENDIX 7. GRAIN LEGUME REGIONAL R4D NETWORKS: BRIEF PROFILES	218

APPENDIX 8. GLOBAL PARTNERS IN CRP 3.5 GRAIN LEGUMES	221
APPENDIX 9. CRP 3.5 GRAIN LEGUMES: CURRENT BILATERAL FUNDED R4D PROJECTS	228
APPENDIX 10. ASSESSMENT OF PRODUCTION CONSTRAINTS, PROGRESS, BARRIERS TO ADOPTION AND OPPORTUNITIES IN GRAIN LEGUMES	237
APPENDIX 11. WORKPLAN FOR STRATEGIC OBJECTIVES OF CRP 3.5 GRAIN LEGUMES	244
APPENDIX 12. PARTNERSHIP OF CRP 3.5 WITH CRP 1.1 AND 1.2	268
APPENDIX 13. ROLE OF FARMERS' ORGANIZATIONS, EXTENSION WORKERS, NGOs AND SUB- REGIONAL ORGANIZATIONS AND NETWORKS	270
APPENDIX 14. PRACTICAL COMMITMENTS AND INVESTMENTS OF OTHER PARTNERS ENGAGED	275
APPENDIX 15. ANALYSIS OF TRADE-OFFS IMPLIED BY NEW EMPHASIS ON VALUE CHAINS AND LOCATION SPECIFICITY OF IPGS	276
APPENDIX 16. INTEGRATION OF THE CROP IMPROVEMENT ASPECTS WITH RESOURCE MANAGEMENT	279
APPENDIX 17. DESCRIPTION OF THE RELATIONSHIP WITH INITIATIVES LIKE TROPICAL LEGUMES I AND II	280
APPENDIX 18. CRP 3.5 LINKAGES WITH CRP 2 ON POLICIES, INSTITUTIONS AND MARKETS.....	282

Acronyms & Abbreviations

A3P	Accelerated Pulses Production Programme
AGLN	Asian Grain Legumes Network
AICRP	All India Coordinated Research Programs
AID	Analysis tracking ID
AIP	Agri-business Innovation Platform
AMDAAD	Authority of Merowi Dam Area for Agricultural Development
ARI	Advanced Research Institute
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
ASR	Asian soybean rust
AVRDC	AVRDC - The World Vegetable Center
BMGF	Bill & Melinda Gates Foundation
BNF	Biological Nitrogen Fixation
CAADP	The Comprehensive Africa Agriculture Development Programme
CBO	Community-based Organizations
CCRN	Cooperative Cereals Research Network
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical
CIARD	Coherence of Information for Agriculture Research and Development
CLAN	Cereals and Legumes Asia Network
CMS	Cytoplasmic-Nuclear Male Sterility System
COP	Communities of Practice
CORAF	Council Ouest et Centre Africain Pour la Recherche et le Developpement Agricoles
CRSP	Collaborative Research Support Programs
CRPs	CGIAR Research Programs
CSO	Civil Society Organizations
CWANA	Central and West Asia and North Africa
DARE	Department of Agricultural Research and Education (India)
DARS	Department for Agricultural Research
EARS	Ethiopian Agricultural Research System
FOs	Farmer Organizations
ECABREN	Eastern and Central Africa Bean Research Network
EIAR	Ethiopian Institute of Agricultural Research
ELS	Early leaf spots
EMBRAPA	The Brazilian Agricultural Research Corporation
ESA	Eastern and Southern Africa
FAO	Food and Agriculture Organization of the United Nations
FIGS	Focused Identification of Germplasm Strategy
FPVS	Farmer-participatory varietal selection
GBS	Genotyping-by-sequencing
GCP	Generation Challenge Program
GCDT	Global Crop Diversity Trust
GDAR	General Directorate of Agricultural Research
GIS	Geographical Information Systems
GOSM	General Organization of Seed Multiplication
GPG	Global Public Goods
GWS	Genome-wide selection

HPRC	Hybrid Parents Research Consortium
IARC	International Agricultural Research Centers
IBP	Integrated Breeding Platform
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in Dry Areas
ICIPE	International Centre for Insect Physiology and Ecology
ICM	Integrated Crop Management
ICT	Information and Communication Technology
IDM	Integrated Disease Management
IITA	International Institute of Tropical Agriculture
IP	Intellectual Property
IPDN	International Plant Diagnostic Network
IPG	International Public Goods
IPM	Integrated Pest Management
IPPPT	Improved Pulse Production and Protection Technologies
IT	Information Technology
ITC	Indian Tobacco Company
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
KM	Knowledge Management
KS	Knowledge Sharing
LAC	Latin America and the Caribbean
LIFDC	Low Income Food Deficit Countries
LLS	Late leaf spot disease
LPB	Legume pod borer
M&E	Monitoring and Evaluation
MABC	Marker-Assisted Backcrossing
MAP	Modified atmosphere packaging
MARA	Ministry of Agriculture and Rural Affairs
MARKETS	Maximizing Agricultural Revenue and Key Enterprises in Targeted Sites
MARS	Marker assisted recurrent selection
MAS	Marker assisted selection
MaviMNPV	Maruca vitrata nucleopolyhedrovirus
NARES	National Agricultural Research and Extension Systems
NARS	National Agricultural Research Systems
NCBI	National Centre for Biotechnology Information
NCDs	Non-communicable Diseases
NEPAD	New Partnership for Africa's Development
NFSM	National Food Security Mission (India)
NGICA	Network for the Genetic Improvement of Cowpea for Africa
NGO	Non-government Organizations
NGS	Next Generation Sequencing
OILFED	Oilseed Federation (India)
PABRA	Pan-African Bean Research Alliance
PAC	Program Advisory Committee
PCCMCA	Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos y Animales
PDCAAS	Protein digestibility-corrected amino acid score
PEDUNE	Protection ecologiquement durable du niebe
PIA	Program Implementation Agreement
PMU	Program Management Unit

PPA	Participant Program Agreements
PPB	Participatory Plant Breeding
PRGA	Participatory Research and Gender Analysis
PROFRIJOL	The Regional Collaborative Bean Program for Central America, Mexico, and the Caribbean
PRONAF	Projet Niebe pour l’Afrique
PRONAF-GIL	Participatory Development, Diffusion and Adoption of Cowpea Technologies for Poverty Reduction and Sustainable livelihoods in West Africa
PRS	Poverty Reduction Strategy
PTTC	Platform for Translational Research on Transgenic Crops
PVS	Participatory Varietal Selection
R&D	Research and Development
R4D	Research for Development
REMALA	Recherche et Developpement des Legumineuse Alimentaires
RENACO	Reseau de Recherche sur le Niebe pour l’Afrique de l’Ouest et du Centre
RFOs	Raffinose family oligosaccharides
RIL	Recombinant inbred lines
RMT	Research Management Team
RRFL	Rainfed Rice Fallow Land
RSAC	Regional Science Advisory Committees
SaaS	Software application as Services
SABRN	Southern Africa Bean Research Network
SADC-FANR	South African Development Community – Food, Agriculture and Natural Resources
SC	Steering Committee
SHGs	Self Help Groups
SICTA	Central American System of Integration for Agricultural Technology
SIMLESA	Sustainable Intensification of Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa
SLOs	System Level Outcomes
SMTA	Standard Material Transfer Agreement
SRF	Strategy and Results Framework
SROs	Sub-regional organizations
SRT	Strategic Research Theme
SSA	Sub-Saharan Africa
SSEA	South and Southeast Asia
TILLING	Targeting Induced Local Lesion in Genomes
TL I	Tropical Legumes I
TL II	Tropical Legumes II
TUBITAK	Turkish Scientific and Technological Council
USA	United States of America
USDA	United States Department of Agriculture
VBSE	Village-Based Seed Enterprises
WANA	West Asia & North Africa
WASA	West Africa Seed Alliance
WCA	West and Central Africa
WECABREN	West and Central Africa Bean Network

1. Executive Summary

The CRP 3.5 GRAIN LEGUMES partnership

CGIAR Research Program 3.5 GRAIN LEGUMES unites ten initial Principal **Partners**: four CGIAR centers (ICRISAT-*lead center*, CIAT, ICARDA and IITA), a CGIAR Challenge Program (Generation), four major national agricultural research systems (EIAR-Ethiopia, EMBRAPA-Brazil, GDAR-Turkey and ICAR-India) and the USA Dry Grain Pulses CRSP. All are leaders in complementary grain legume topics and regions.

The development challenge addressed by CRP 3.5 GRAIN LEGUMES will be **to apply crop improvement with related high-priority value-chain interventions to maximize the benefits that grain legumes offer to smallholder farm families, especially women, securing their food supplies, improving their nutrition, sustainably intensifying their farming systems, and increasing their incomes**. In short, leveraging legumes to benefit the poor.

These partners will link with regional grain legume networks and value chain partners to translate research-for-development (R4D) innovations into locally-attuned impacts that benefit poor smallholder farm families as well as consumers. By working together these partners will:

- Present an integrated, streamlined interface to partners in each focus region rather than the current multiple interfaces;
- Improve knowledge acquisition and sharing through comparison/contrast learning across target legume crops and systems in their distinctive regional settings; and
- Share R4D facilities and expertise to increase operational efficiency and effectiveness.

Justification

Grain legumes contribute in major ways towards all four of the CGIAR System Level Outcomes (SLOs): reducing poverty, improving food security, improving nutrition and health, and sustaining the natural resource base. Grain legumes are most important to the poorest consumers who cannot afford enough meat, dairy and fish. These poor often have little choice but to rely on inexpensive but nutritionally-imbalanced starchy diets. Legumes are the cheapest option for improving their nutrition. Their nutritional profile strongly complements that of cereals, leveraging additional value. Thus a CGIAR focus on grain legumes automatically focuses benefits towards the poorest sector of society, and also leverages additional value from CGIAR work on other crops.

Grain legumes are synergistic with cereals, roots and tubers in the farming systems of the smallholder poor farmers as well as in their diets. They diversify *and* intensify cereal, root and tuber-based systems. They *intensify* cropping systems by utilizing under-exploited system niches as rotation, double- and inter-crops. Increased cropping intensity lifts smallholder incomes and reduces risks (if one crop fails, the other can rescue the family's livelihood). Legumes also attract high market prices. Women play a major role in value-adding post-harvest activities, creating a window of opportunity to enhance the benefits that they receive.

Grain legumes also *diversify* farming systems, making them more nutrient-efficient, resilient and sustainable. An especially important and unique attribute of grain legumes is their ability to restore soil fertility through biological nitrogen fixation, substituting for costly chemical nitrogen fertilizers both for the legume and for the following crop. Legumes also break pest, disease and weed cycles of other crops, and extend soil-protective land cover.

However grain legumes face serious challenges. They have received less policy support than other commodities, leading farmers to shift them to less-productive environments. This has restrained productivity increases and investments in enabling institutions, R4D and other drivers of progress. If such policy support and investments were in place they would have increased grain legumes' productivity more rapidly, making them more affordable for the poor and expanding their environmental benefits. Concerned about production shortfalls, major grain legume producing countries such as Brazil, Ethiopia, India and Turkey are now taking significant steps to encourage grain legume production. These improvements in the enabling environment will likely magnify the impacts of CRP 3.5 GRAIN LEGUME's work.

Seed systems are a particular bottleneck. The seed industry had been reluctant to invest heavily in grain legumes due to the lower seed volumes of a larger number of crops, limited policy support, self-pollinated reproductive system, inadequate cultivar release mechanisms, and other constraints. Institutional and technical innovations to overcome these obstacles are showing promise and will be advanced further.

Despite such constraints, CRP 3.5 GRAIN LEGUMES core partners have achieved remarkable impacts in all target regions. They have helped countries to increase grain legume yields, brought destructive diseases under control, made headway against the complex problems of drought, and connected grain legumes to export markets for higher incomes. CRP 3.5 GRAIN LEGUMES partners foresee a further acceleration of progress as they unite to improve their efficiency and effectiveness.

CRP 3.5 GRAIN LEGUMES Strategic Objectives

The following six Strategic Objectives (SOs) illustrate CRP 3.5 GRAIN LEGUME's focus on crop improvement within a value chain framework, aimed at optimizing the benefits that can be obtained from the production system while overcoming obstacles elsewhere in the chain that may otherwise inhibit impact.

- **SO 1 – Genetic resources:** Conserving and characterizing genetic resources and developing novel breeding methods/tools for improving efficiency of crop improvement
- **SO 2 – Crop improvement:** Accelerating the development of more productive and nutritious cultivars for resilient cropping systems of smallholder farmers
- **SO 3 – Crop and pest management:** Identifying and promoting crop and pest management practices for sustainable legume production
- **SO 4 – Seed systems:** Develop and facilitate efficient legume seed production and delivery systems for smallholder farmers
- **SO 5 – Value chains:** Enhance grain legumes value chain benefits captured by the poor, especially women
- **SO 6 – Partnerships:** Partnerships, capacities, and knowledge sharing to enhance grain legume R4D impacts

Impact pathways and monitoring and assessment

CRP 3.5 GRAIN LEGUMES will pursue the six Objectives through a unified, monitorable, impact-oriented framework. Special attention will be paid to the drivers of change. 'Value' perceived by actors along an impact pathway or value chain is a major driver; if the value proposition of a behavioral change is favorable, impact is more likely. CRP 3.5 GRAIN LEGUMES will distinguish

between the needs of intermediate partners (e.g. NARS, seed companies, NGOs, etc.) and ultimate beneficiaries (poor smallholder families). Both are crucial for impact, but the drivers that motivate them are often different. The needs of both will be understood and addressed for each Output.

Vision

The CRP 3.5 GRAIN LEGUMES vision is to deliver R4D gains that contribute significantly to reducing poverty, hunger, malnutrition and environmental degradation for poor smallholder families in the developing world, particularly women. A measurable indicator of success will be an **increase in grain legume yields by an average of 20% on at least 20% of the planted area over ten years** in the five targeted regions (identified below), **benefiting approximately 300 million people in smallholder farm households**. Cumulative benefits of increased food production and nitrogen fertilizer saved are estimated to be **worth US \$3.0 billion** over the decade, **a six-fold return on investment, increasing food supplies by 7.1 million tons and fixing an additional 402,000 tons of atmospheric nitrogen**, plus additional value added at the post-harvest and pre-harvest stages of the value chains.

Regional and crop foci

CRP 3.5 GRAIN LEGUMES will improve the major grain legume crops that are most important to the smallholder farmers in each of five regions (listed in order of area of production by region and by crop):

- South and Southeast Asia (SSEA)
 - *Chickpea, groundnut, pigeonpea, lentil*
- Western and Central Africa (WCA)
 - *Cowpea, groundnut, common bean, soybean*
- Eastern and Southern Africa (ESA)
 - *Common bean, groundnut, soybean, faba bean, cowpea, pigeonpea, chickpea*
- Latin America and the Caribbean (LAC)
 - *Common bean*
- Central and Western Asia and North Africa (CWANA)
 - *Chickpea, lentil, faba bean*

Innovation

By bringing together major partners across crops, regions and institutions, CRP 3.5 GRAIN LEGUMES will spark cross-learning that elicits new and innovative ways of approaching the challenges outlined above. CRP 3.5 GRAIN LEGUMES' unified interface with partners is itself a major strategic innovation that will increase mutual learning and improve communications.

Research across the eight grain legume crops will generate innovative and important insights. These crops provide an unparalleled learning opportunity at the genetic, genomic, phenotypic, agro-ecosystem, value chain, regional and global levels. Cross-crop learning will improve the understanding of genetic and physiological mechanisms and control points for disease and pest resistance, drought and other stress adaptation, nutritional quality, biological nitrogen fixation, and other key traits. The sharing of facilities and testing environments will enable the partners to learn more about each crop and expand the range and impact of all these crops.

The value chain perspective will provide an innovation framework for integrating social and economic analysis with traditional strengths in crop improvement. It brings additional attention to constraints that have hobbled impact in the past, such as insufficiencies in input supplies (e.g. seed and soil fertility inputs). It will also innovate gains in value capture by the poor through enlarged, higher-value and novel markets, creating particular opportunities for women who bring special strengths to post-harvest and marketing issues.

Time frame

CRP 3.5 GRAIN LEGUMES is proposed as a ten-year program in three phases (years 1-3, 4-7 and 8-10). Milestones are presented in this proposal for the first phase.

Management

ICRISAT will be the Lead Center for CRP 3.5 GRAIN LEGUMES. Oversight will be provided by ICRISAT's Director General and its Governing Board, in consultation with an Independent Advisory Committee. A CRP Director will lead a Research Management Team including Strategic Objective Coordinators. The Research Management Team will be responsible for the overall monitoring of research outputs.

Budget

Current commitments of the CRP 3.5 GRAIN LEGUMES partners amount to US\$38.8 million in year 1. To capitalize on additional opportunities, CRP 3.5 GRAIN LEGUMES will require US\$ 48.0 million in year 2 and US\$ 52.3 million in year 3. The total CRP 3.5 GRAIN LEGUMES budget for 3 years is US\$ 139.1 million.

2. Statement of Objectives

The over-arching *research-for-development challenge* to be addressed by CRP 3.5 GRAIN LEGUMES is **to apply crop improvement with related high-priority value-chain interventions to maximize the benefits that grain legumes offer to smallholder farmers, especially women, securing their food supplies, improving their nutrition, sustainably intensifying their farming systems, and increasing their incomes.** In short: leveraging legumes to benefit the poor.

By joining forces, the partners in CRP 3.5 GRAIN LEGUMES will i) streamline and harmonize their interface with national and regional partners, ii) improve their knowledge-sharing and iii) increase their operational efficiency and effectiveness by sharing facilities, expertise, locational presence and services. The convening partners are four CGIAR centers (ICRISAT-*lead*, CIAT, ICARDA, IITA) together with major collaborating partners (EIAR, EMBRAPA, GDAR, Generation Challenge Program, ICAR, and the USA Dry Grain Pulses CRSP) that are all leaders in complementary topics and regions on these crops.

CRP 3.5 GRAIN LEGUMES defines its six Strategic Objectives (SOs) as:

- **SO 1 – Genetic resources:** Conserving and characterizing genetic resources and developing novel breeding methods/tools for improving efficiency of crop improvement
- **SO 2 – Crop improvement:** Accelerating the development of more productive and nutritious cultivars for resilient cropping systems of smallholder farmers
- **SO 3 – Crop and pest management:** Identifying and promoting crop and pest management practices for sustainable legume production
- **SO 4 – Seed systems:** Develop and facilitate efficient legume seed production and delivery systems for smallholder farmers
- **SO 5 – Value chains:** Enhance grain legumes value chain benefits captured by the poor, especially women
- **SO 6 – Partnerships:** Partnerships, capacities, and knowledge sharing to enhance grain legume R4D impacts

These six SOs directly contribute to the achievement of the four CGIAR System Level Objectives (alleviate hunger, poverty, malnutrition, and environmental degradation) by raising the stable and remunerative productivity of eight important staple grain legume food and oil crops of the poor in the focus CGIAR regions: chickpea, common bean, cowpea, faba bean, groundnut, lentil, pigeonpea and soybean (regions and crops elaborated in more detail later in this Chapter, and in Chapter 3). This will be achieved through partnerships that increase the genetic resistance of these crops to important stresses, especially diseases, insects and climatic stress, while increasing yield potential and optimizing genotype x environment interactions specific to these crops that affect biological nitrogen fixation. CRP 3.5 will also ease bottlenecks in seed systems to more effectively disseminate and achieve impact from the improved germplasm. Because grain legumes are often inter- and rotation-cropped with non-nitrogen fixing crops, their increased productivity will also raise the productivity of other crops in the system in a highly sustainable manner. Additional major gains, particularly for women farmers will be sought through the systematic diagnosis and exploitation of key priority opportunities in the input, production and post-harvest stages of grain legume value chains.

The contributions of these six SOs to the core competencies of the CGIAR that are identified in the CGIAR Strategy and Results Framework (SRF) are described in Chapter 5.

Major opportunities in brief

Below we briefly highlight some of the exciting R4D opportunities that we foresee contributing to the SOs.

Genetic resources and crop improvement

Crop improvement and allied advances, built on **more effective use of genetic diversity**, will contribute importantly to the CGIAR System Level Objectives. The impact opportunity is evidenced by numerous examples of **rapid increases in grain legume production stimulated by improved varieties and management, driven by strong market and export demand**: smallholder soybean in Nigeria (Yanguba 2009), cowpea in Nigeria (Coulibaly et al. 2010; Kristjanson et al. 2005), common bean in Uganda (CIAT 2008; David et al. 2000), chickpea, common bean and faba bean in Ethiopia (Dar et al. 2010; ICARDA 2008; Rubyogo et al. 2011), chickpea in southern India (ICRISAT 2010), pigeonpea in Tanzania (Shiferaw et al. 2007; Shiferaw et al. 2008a), short-duration pigeonpea in India (Bantilan and Parthasarathy 1999), groundnut in Malawi (Simtowe et al. 2010) and lentil in northern India (Aw-Hassan et al. 2009, Aw-Hassan et al. 2003, Materne and Reddy 2007).

Disease resistance will be a prime target for further gains in CRP 3.5. Diseases are a major point of vulnerability for grain legumes, and **large value gains have already been achieved through disease resistance** against *Fusarium* wilt, *Aschochyta* blight, a range of foliar fungal and bacterial diseases, and several viruses (Bantilan and Joshi 1996; Gaur et al. 2007; Morales 1994; Moyo et al. 2007; Singh et al. 1997). Yet much still remains to be achieved. Biotechnology will be particularly useful for combating diseases, particularly for diseases that lack sufficient levels of resistance in the cultivated species (e.g. the production of aflatoxins by the fungus *Aspergillus flavus*). Additional sources of resistance in germplasm collections will be made accessible by capitalizing on rapidly-improving, more affordable genetic and genomic tools. Many of the tools and lessons are applicable across crops, adding efficiency and effectiveness through a cross-crop innovation platform approach.

Increasing yield is a central objective (Specht et al. 1999). Poor small-scale grain legume producers currently operate well below the yield levels that are obtainable with improved varieties and management. Yield under farmer field conditions is a result of numerous interacting traits, including genetic yield 'potential' (itself a complex of traits) as well as genetic adaptation to soil, climate, pest, disease, and other stresses and to management practices, all of which may change over time (Alene and Manyong 2007). To that extent it is somewhat artificial to consider breeding for traits as isolated yield components; their benefits are often synergistic. Crop improvement integrates desirable attributes for a target production environment.

The value of vegetative matter (leaves, stems/haulms) as livestock feed may have been underestimated in the past. A tradeoff versus vegetative matter yield ('haulm' or stalk yield) may not be inevitable, since legumes can increase photosynthesis rate in response to increased sink demand (Kaschuk et al. 2009). Plant type improvement may also unlock yield gains by genetically increasing the sink strength of reproductive organs as they develop. Small amounts of nutrient amendments, water harvesting, breeding for improved symbiosis with *Rhizobium* under environmental stress and other small-scale appropriate management interventions can synergistically interact to **ease binding constraints to biological nitrogen fixation (BNF), triggering large productivity responses** in a highly cost-efficient manner (Giller 2009; Kumar Rao et al. 1995; Wani et al. 1995).

The definition of heterotic groups and hybrids also holds enormous potential (~30-40% yield gains). CRP 3.5 will build on recent breakthroughs in pigeonpea (Saxena and Nadarajan 2010) to also explore hybrid potential in faba bean and soybean.

In addition to quantity of yield, CRP 3.5 GRAIN LEGUMES will attend to **the nutritional quality** of that yield, especially **increasing micronutrient content** and exploring opportunities in protein and oil quantity/quality, vitamins and countering anti-nutritional factors. In particular, the knowledge and methodology advances in increasing iron and zinc content in bean, enabled by the HarvestPlus

Challenge Programme as part of CRP 4 will be leveraged to other grain legume species and regions, raising the returns on past R4D investments. Vitamin A enhancement forms an interesting longer-term opportunity for grain legumes through both conventional breeding and genetic engineering approaches (Kotecha 2008; Stein 2006). Breeding for aflatoxin resistance has made little headway to date, but the new tools of biotechnology may open new opportunities. Strategies other than breeding for reducing mycotoxin contamination will be led by CRP 4. (Also see box article 'Spotlight on Nutrition' at the end of Chapter 3).

Crop and pest management

Grain legumes are strategically prominent in the CGIAR's quest for **sustainable intensification options**, because of their capacity to biologically fix atmospheric nitrogen partially substituting for chemical fertilizer (Herridge et al. 2008). Opportunity in this arena will be exploited through partnership with the N2Africa project, which relies on CRP 3.5 and others to provide germplasm that it (N2Africa) assesses for ability to increase BNF in grain legumes across Africa (www.n2africa.org). R4D contributions by CRP 3.5 GRAIN LEGUMES such as increased stress resistance (drought, low soil P, and others) and adaptation to a wider range of *Rhizobia* will generate large impacts by stimulating nodulation and N fixation. Drought diminishes BNF, but potential has been identified to breed for higher BNF drought tolerance in soybean (Sinclair et al. 2007). Gains in these areas will also trigger yield increases for the crops that follow the grain legumes in the cropping cycle (Adu-Gyamfi et al. 2007; Bado et al. 2006; Jeranyama et al. 2007). Increased productivity of grain legumes will spur their **wider inclusion as intercrops, relay crops and rotation crops in non-leguminous cropping systems, sustainably intensifying those systems** on existing farmland (Kimaro et al. 2009; Singh et al. 1996).

"Adaptation to environmental stress in the legume/rhizobial symbiosis is poorly understood and there is a strong need for detailed plant physiology research in this area to support breeding efforts to enhance BNF." – K. Giller (2009)

Drought, heat and other types of environmental stress are major constraints within the grain legume systems of the poor, which are mostly rainfed with few soil-ameliorating inputs. **Drought adaptation is the fine art of optimizing production with a limited amount of water, rather than breeding for isolated 'drought tolerance' traits** (Vadez et al. 2011). Conservative use of water during the early vegetative stages, leaving enough moisture in the soil to complete grain development, is important (Zaman-Allah et al. 2011). Water use traits that limit transpiration when the evaporative demand is high, and others that also concern plant hydraulics such as the aquaporin cell membrane proteins appear to be important under certain drought conditions and merit further investigation (Sadok and Sinclair 2010); they will be investigated in chickpea and other legumes including at the gene expression level. **Heat tolerance at flowering** is seen as a major opportunity for progress, and one especially important for climate change-proofing the grain legumes. Research on heat stress mitigation by application of nitrogen fertilizers (Upadhyaya et al. 2011) may have potential application across legume species.

Specialized and costly drought screening facilities and skills will be shared across partners to increase CRP 3.5's collective efficiency and effectiveness. For example, cowpea, pigeonpea and chickpea are highly drought-tolerant; learning from the body of research and screening tools already developed for those crops can contribute to improve the drought tolerance of more drought-sensitive crops such as common bean and soybean.

Insects are major constraints for grain legumes, but development of insect resistant cultivars has been challenging. Wider use of genetic resources, accelerated and made more effective through the use of new molecular breeding methods could generate breakthroughs not foreseen at the present time. Genetic engineering to deploy Bt insect resistance genes holds enormous potential but faces formidable policy and consumer acceptance obstacles. The largest impact will likely be in the area of **controlling pests of stored grains**, because storage provides an opportunity for integrating improved

storage management with genetic resistance. In the production stage, R4D will focus on pod-borer insects such as *Helicoverpa* that have proven difficult to contain through plant breeding. **Integrated pest management advances** hold considerable promise, but sustainable delivery systems for transmitting knowledge and new types of bio-pesticides are challenging (Grzywacz et al. 2005; Ranga Rao and Gopalakrishnan 2009).

Seed systems

Improving seed systems is a major priority for CRP 3.5 and is therefore the subject of an in-depth box article at the end of this chapter. CRP 3.5 GRAIN LEGUMES believes that **seed system constraints can be significantly eased** through several concrete strategies (see box article, and Strategic Objective 4 in Chapter 5). Effort in these areas is especially strategic because once seed flows, the impacts of a whole range of genetic advances flow to farmers.

Value chains

A value chain perspective helps align crop improvement with farmer priorities and motivations. Farmers produce grain legumes because they perceive different kinds of value to be gained, such as food, fodder, income, and soil fertility enhancement among others. Identifying i) the value associated with these products, ii) how that value is created (processes within the value chain), and iii) the actions of institutions involved helps researchers identify and target the most impactful opportunities, as well as bottlenecks to achieving impact (Shiferaw et al. 2008b). Recognizing the importance of these dynamics, the CGIAR's SRF states that "*As a System Level Outcome, reducing rural poverty will require research to develop and validate specific agricultural investments... including improved value chains and markets.*" (SRF para. 69).

"Perhaps most exciting to me is an idea that Bill Gates, Howard Buffett and others have supported boldly. What if, instead of looking at the hungry as victims... we view them as the solution, as the value chain to fight hunger? When poor farmers are given a guaranteed market, their yields have gone up two-, three- four-fold. They figure it out."

Josette Sheeran, Executive Director, World Food Programme
(http://www.ted.com/talks/josette_sheeran_ending_hunger_now)

For example, AGRA states that "African farmers who sell surplus harvest routinely receive only 10 to 20 percent of the price of their products". Women's incomes in West Africa can be enhanced by improving cowpea flour processing, a target of CRP 3.5 principal partner Dry Grain Pulses CRSP (Lowenberg-DeBoer and Ibro 2008) which may also benefit from breeding for particular storage and milling characteristics in CRP 3.5. Additional overlooked opportunities may lie in areas such as soil fertility services (e.g. improving BNF for soil nitrogen enrichment) and livestock feed enhancement. Studies suggest that significant income gains await from breeding more nutritious haulms (stalks) to enrich cereal straw fodder in cowpea (Grings et al. 2012) and groundnut (Nigam and Blummel 2010; Thannamal 2011).

By integrating socio-economic with biophysical analysis of grain legume commodity systems, **CRP 3.5 will utilize value chain analysis as an aid in assessing its priorities and likely impacts benefiting smallholder farm families, diagnosing constraints in impact pathways, and identifying new opportunities, particularly for women.** By providing a better understanding of smallholder grain legume value chains it will complement, as well as benefit from the value chain learning that will emerge from the farming system and methodological investigations of CRPs 1 and 2.

Value chains are by their nature 'innovation platforms', i.e. partnerships to innovate and thus add value to the food economy. By stimulating novel partnerships with key value chain players, CRP 3.5 will also pioneer in relation to the SRF's challenge that "*...the linear view of the innovation process has been replaced with an innovation system view of the world, where a much more diversified and complex universe of public and private actors come into play... significantly expanding the demands*

that national and international institutions need to confront...” (SRF para. 33).

Partnerships

CRP 3.5 will catalyze major innovation in grain legume R4D partnerships. By bringing four CGIAR Centers together with six regional and global partners across eight legume crops, **regional interfaces with partners will be greatly streamlined**, improving communication, R4D efficiency and effectiveness. Regional networks for different crops will be harmonized and integrated where possible. **Centers will explore and exploit opportunities to share facilities, operations and expertise** for greater efficiency and economies of scale. As mentioned previously, the value chain approach will reveal opportunities for **more diverse innovation platform partnerships** bringing unfamiliar but synergistic institutions together from the public, private and community sectors to add value to grain legume chains.

Vision of success

Our vision is to achieve R4D gains that contribute meaningfully to reducing poverty, hunger, malnutrition and environmental degradation for poor smallholders, particularly women in the developing world. A measurable indicator of success will be an **increase in grain legume yields by an average of 20% on at least 20% of the targeted area by the tenth program year, benefiting approximately 300 million people in farming households**. This yield increase will be achieved through both yield stability and yield level gains through improved disease and pest control, agro-ecosystem adaptation, responsiveness to modest inputs, and smallholder-appropriate soil fertility enhancement that especially increases biological nitrogen fixation. We estimate the cumulative benefits of this R4D gain over the ten year project duration, including grain value and fertilizer substitution value across low income food deficit countries to be **worth US \$3.0 billion** over the period, **a six-fold return on investment** (Chapter 3 and Appendix 5). In addition to this monetary value, we expect major benefits for the poor through improved food and nutritional security (**an extra 7.1 million tons of grain, including 2.1 million tons of protein**) and **fixing an additional 402,000 tons of atmospheric nitrogen**, plus additional value added at the post-harvest and pre-harvest stages of value chains.

Target regions

CRP 3.5 GRAIN LEGUMES will target five priority regions that have been historically addressed by the CGIAR, namely (in order of grain legume hectareage) **South and Southeast Asia (SSEA), West and Central Africa (WCA), Eastern and Southern Africa (ESA), Latin America and the Caribbean (LAC) and Central and West Asia and North Africa (CWANA)**. The farming systems in which grain legumes are cultivated in these regions are described and quantified in Chapter 3.

Within these five regions, CRP 3.5 GRAIN LEGUMES will apply a second prioritization criterion, namely the FAO definition of **low-income food deficit countries (LIFDCs)** described in detail at <http://www.fao.org/countryprofiles/lifdc.asp>. This criterion identifies the poorest, hungriest countries of the developing world most in need of the CGIAR’s help and least likely to have strong alternative suppliers of grain legume R4D. For example the large-scale commercial soybean and common bean producing areas found in Argentina, Brazil, China, the USA and other well-endowed and strongly emergent economies within the developing world lie outside the LIFDC. The LIFDC list currently includes 39 countries in sub-Saharan Africa, twelve in South and Southeast Asia, six in Central Asia and the Caucasus, five in Oceania, four in West Asia/North Africa, three in Latin America and the Caribbean, and one in Europe.

As a third prioritization criterion, CRP 3.5 GRAIN LEGUMES will not work in *all* LIFDCs but rather on select **region x crop targets where the largest numbers of very poor people live and cultivate large areas of grain legumes are cultivated and the probability of success is high**. Where well justified, CRP 3.5 GRAIN LEGUMES will also make a few case-by-case exceptions to extend beyond the LIFDC countries.

Specific region x crop targets following these guidelines are identified in Chapter 3. While focusing on these geographic targets, CRP 3.5 GRAIN LEGUMES will remain mindful of its comparative advantage as an international institution to ensure that its programs generate international public goods that complement and reinforce, rather than duplicate the contributions of its partners at local, national and regional levels.

Target crops

CRP 3.5 GRAIN LEGUMES will improve the grain legume crops that are the most widely grown by poor smallholders in each of the five focus regions' LIFDCs. Analyses of FAO crop area data led CRP 3.5 GRAIN LEGUMES to identify eight highest-priority crops (in order of sown hectareage): **groundnut, soybean, chickpea, cowpea, common bean, pigeonpea, lentil, and faba bean**, as elaborated in more detail in Chapter 3. Detailed profiles of these crops are given in Appendix 2.

SEEDS OF SUCCESS

CRP 3.5 pursues a vision of adoption of improved varieties on 20% of the grain legume area by the tenth year of the program. To achieve this we must overcome difficult challenges to adoption. Exemplifying the challenge, a 23% higher-yielding drought tolerant variety of groundnut, ICGV 91114 released in Andhra Pradesh, India in 2002 had spread to only 3.2% of the groundnut area in the Anantapur locality (the world's largest concentrated area of groundnut production) by 2008-09 (Birthal et al. 2011). All improved groundnut varieties combined occupied only 6% of the total area. Similarly a study of the adoption and impact of improved pigeonpea varieties in Tanzania showed that about 16% of the farmers had fully adopted improved varieties, 9% cultivated both improved and local varieties, and 73% continued to plant only local varieties (Shiferaw et al. 2007). A survey of chickpea adoption in four districts of Ethiopia revealed that only 18% of farmers grew improved varieties (Dadi et al. 2005). And in lentil, improved varieties were adopted on 12% of the area in Bangladesh and 30% of area in Pakistan (Aw-Hassan et al. 2003). Only 15% of the bean-producing households in Mozambique were reported to have adopted improved bean cultivars (Lopes 2010).

Seed system bottlenecks are the major immediate constraint in raising the adoption of improved grain legume varieties (Bishaw et al. 2009, Phiri et al. 2000, Sperling et al. 1996). There are several reasons for this: (i) numerous, diverse species each requiring separate seed production and handling systems for lower volumes of sale; (ii) Insufficient policy incentives: grain legumes compete for the attention of seed companies against crops that receive stronger policy support; (iii) Institutional constraints: public institutions for varietal release and seed multiplication often lack the capacity to efficiently test, release and multiply new varieties of large numbers of crops, and consequently give priority to the fewest high-volume crops; (iv) Self-pollinated reproductive system of most grain legumes (except pigeonpea, faba bean) enables farmers to re-use their own or their neighbor's seed instead of buying fresh seed each year, reducing incentives for the private seed sector; (v) Low seed-to-seed multiplication ratio and rapid loss of viability in a few legume crops, particularly groundnut and chickpea; and (vi) Insufficient farmer awareness of the benefits of new varieties.

For example on items i-iii, Bishaw et al. (2009) surveyed six CWANA countries and found that the volume of formal-sector grain legume seed production amounted to only one percent of the volume of cereal seed produced. Public-sector seed production has not been able to meet the demand for new varieties and for initial quantities of high-quality seed. On item vi, farmers' knowledge of improved varieties was found to be strongly correlated with adoption rate for pigeonpea in Tanzania (Shiferaw et al. 2007) and for improved chickpea in Ethiopia (Dadi et al. 2005).

Imaginative approaches are making headway against these obstacles. The PABRA, Tropical Legumes II and USAID Seeds projects have supported in-depth baseline studies to understand the constraints in different grain legume crops/regions and innovations to overcome them (e.g. Coulibaly et al. 2010 and others at www.icrisat.org/impi-tl-2, www.icrisat.org/tropicallegumesII/ and www.icrisat.cgiar.org/icrisat-rrp2-wasa-wca).

CRP 3.5 GRAIN LEGUMES will accelerate the adoption of improved grain by enhancing farmers' awareness through a range of strategies. Involving farmer groups in participatory varietal selection (PVS) will enable them to assess the performance of improved varieties in their fields and growing conditions and choose the varieties that they prefer; this approach is being applied in the Tropical Legumes II project (<http://www.icrisat.org/tropicallegumesII/>). CRP 3.5 GRAIN LEGUMES will also organize field days, farmers' fairs, training programs and will use electronic and print media to spread the word.

Efficient and sustainable seed systems will be established by building capacities in the public seed sector, by working with the private seed sector to overcome constraints to their engagement in legume seed production, and by fostering linkages between formal and informal (farmer/traditional) seed systems. Successful approaches identified through Tropical Legumes II and WASA will be scaled out to additional crops/regions.

In sub-Saharan Africa...

Novel seed distribution mechanisms offer promise against this bottleneck. CIAT initiated studies of local seed systems more than 20 years ago in Rwanda. They found that farmers, particularly women were willing to purchase small seed packets of 100-200 grams each to experiment in small plots on their own farms. This small pack model was further explored and systematized in the Tropical Legumes II project, involving national programs and the private sector. It has been quite successful in Malawi (Phiri et al. 2000, Chirwa et al. 2007) and Kenya.

In the Kenya case the national seed program of KARI connected with Leldet Seed Company and CIAT/PABRA to test the marketing of the small packs. A company pickup truck traveled to villages on market days and announced the sale of samples of new varieties from the back of the truck with a loudspeaker. The truck was often mobbed by enthusiastic farmers seeking access to the new varieties; many were women. Leldet became convinced that this was a significant market opportunity. The cost charged per gram of seed for these small packs is in fact higher than for conventional large bags so profitability is maintained, yet the absolute cost of the seed pack is well within reach of poor women (less than US\$ 0.13/ 100 g) and provides enough seed for a homestead cultivation area. As improved varieties become known through this mechanism the company hopes that this will stimulate further demand. Four more PABRA countries are now experimenting with the small-pack approach.

A second approach pursued with KARI (Kenya) is the revolving seed loan program. Local agencies receive initial seed through purchases or grants and together with the farming community identify farmers to be loaned that seed. After harvest farmers return one to three times the amount of seeds to the service providers/organizations. Upon receiving the returned amount the service providers identify additional beneficiaries on a similar loan arrangement. The revolving loan continues for three to four seasons until the variety becomes widespread.

A related model is to revolve cash earned from sales of the seed, rather than revolving the seed itself. Donors put up the initial cash to establish the seed multiplication capacity, and that cash revolves back following seed sales. ICRISAT is catalyzing this nonprofit model for groundnut and pigeonpea in Malawi in close partnership with NASFAM.

Community-based seed systems offer yet another opportunity. From 2007 to 2010 such a system was established in the Dosso region in Niger, enabled by the Tropical Legumes II project. Farmers and small-scale seed producers were trained in seed production and small-scale business management and marketing. The national research program INRAN was tasked to supply breeder seed to the community-based organizations (CBOs). This was very successful. After 4 years, CBOs produce about 65% of the total certified seed produced in Niger (Republic of Niger 2011). Seed from small-scale farmers is now in demand by many NGOs. FAO also purchases seed stocks for emergency reserve.

Another CBO success occurred in disseminating root rot resistant beans in the highlands of southwestern Uganda (Opio 1999). Bean-dependent communities were going hungry due to losses from this disease complex, but the narrow ecological niche occupied by this farming system generated insufficient seed volume to interest the formal seed sector. The Nyamabale Bean Seed Producers (one of the farmer groups that had evaluated the root rot tolerant lines) stepped in to fill the gap, registering as a community-based seed producer with support from NARO and the National Agricultural Advisory (NAADS). By 2009 this CBO was producing 15 tons of seed annually of resistant varieties that had been released just three years earlier.

In Southern/Southeastern Asia...

The Punjabrao Deshmukh Krishi Vidyapeeth (PDKV) model originating from Punjabrao Deshmukh Agriculture University at Akola, Maharashtra in India overcomes the seed bottleneck by helping farmers to grow their own. This capitalizes on the fact that most grain legumes are strongly self-pollinating, so outcrossing is not an issue even on small plots. Farmers are provided with free starter seed and production guidelines. Starting with 2 kg of groundnut, a farmer multiplies enough to cover one hectare in three years. For example in Namakkal district in Tamil Nadu where most farmers save their own groundnut seed for the next cropping season this model is vigorously being followed to achieve the rapid spread of newly-identified groundnut variety ICGV 87846. Initiated for this crop by Punjab Agricultural University in 2003, enough seed is distributed to sow 0.4 ha for 270 farmers in 30 villages.

For crops like pigeonpea where outcrossing risk requires larger seed production fields in isolation, village-level seed growers' cooperative societies have been formed. These societies are linked to the formal seed sector. A 'One Variety-One Village' concept is followed in order to maintain the required minimum isolation distance of 300-500 m between varieties.

In Central/West Asia and North Africa...

Fostered by ICARDA, village-based seed enterprises (VBSEs) are owned and managed by farmers in Afghanistan, Algeria, Morocco, Tunisia, Iraq, and Pakistan. Village farmers are provided with essential facilities (mobile cleaners, storage facilities and others) and trained in seed production and business management. They are linked to formal sector institutions (e.g. R4D and seed companies). They are monitored and evaluated for their profitability and sustainability. VBSEs form a network at provincial levels for facilitating flow of information for seed marketing and experience sharing. In Afghanistan over 2003-2006 VBSEs earned a net profit of US\$3.1 million from cereal and grain legume seed provided to about 154,000 farmers.

3. Justification

Why Do Grain Legumes Matter?

In early 2011, the CGIAR approved a new Strategy and Results Framework (SRF) that identified four apex System Level Outcomes (SLOs) to serve as guiding principles to steer the objectives and activities of the CGIAR Research Programs (CRPs). Therefore we begin this Justification with a brief overview of how grain legumes are relevant and important to achieving the SLOs.

Reducing rural poverty: **Farmers both consume and sell grain legume crop products, granting them flexibility to optimize their livelihood strategy** according to household food needs and market conditions (Shiferaw 2007; Lowenberg-DeBoer and Ibro 2008). Grain legume crops deliver poverty-fighting income by yielding premium-valued grains, oil, pods, peas, leaves, haulm, and press-cake that are in high demand locally, in urban centers and in export markets for human food and for livestock fodder and feed. A wide range of processed products from these raw materials add further value and generate important income-earning opportunities for poor people, especially women.

Securing food supplies: Grain legumes are often fitted into underutilized niches in farming systems and thus **increase total food production per unit land area for land-constrained smallholders. By increasing crop diversity they reduce food supply risks** from environmental shocks and hazards. For example, later-sown legumes often escape drought or disease that occur at times that devastate other crops, rescuing the farm family's food supply. The use of legume haulms to improve fodder quality contributes to the productivity of the animals that provide the poor with draft power, milk, meat and money.

Nutritious, healthy food: **Grain legumes are rich in protein, oil and micronutrients** such as iron and zinc. Their amino acid profiles complement those of cereals, such that consuming them together raises the nutritional effectiveness of the cereal-dominated diets of the poor. High iron and zinc content is especially beneficial for women and children at risk of anaemia; genetic elevation of mineral content in beans has been shown to improve child health (Haas et al. 2011). Omega-3 fatty acids are scarce in the cereal-dominated diets of the poor but are present in significant amounts in soy oil; they are essential for cognitive development in young children and protect against inflammatory diseases. Due to high nutrient content and palatability, pastes made from a base of groundnut ("plumpy'nut" by Nutriset and others in Africa) and chickpea (the World Food Programme's "wawa mum" in Asia) are distributed by famine relief agencies for the emergency feeding of severely malnourished or starving children. Legumes are also low in glycemic index, reducing obesity and diabetes risk. They also contain bioactive compounds that show evidence of helping to combat cancer and heart disease. (For a fuller discussion please see the 'Spotlight on Nutrition' box Item at the end of this chapter).

Sustainable intensification: Grain legumes are well adapted to inter-, relay-, double- and rotation-crop niches in farming systems, **intensifying land productivity in a sustainable way**. They biologically fix nitrogen, thus i) meeting much of their own N requirement while ii) also leaving significant amounts of N in the soil for following crops and iii) reducing fertilizer costs for cash-poor smallholders while further iv) reducing fossil fuel greenhouse gas emissions by substituting for chemical N fertilizer. By moderating N flushes through the gradual release of N from decaying root biomass they can improve overall N use efficiency in farming systems compared to chemical N-only strategies (Crews and Peoples 2005; Nyiraneza and Snapp 2007). They also break weed and disease cycles in rotations, and extend the duration of protective land cover (vegetation protecting the soil from erosion). They further increase the effective capture, productive use and recycling of water and nutrients, such as end-of-season residual moisture and fallow moisture in rice-legume systems. Their fodder also enriches nitrogen-limited livestock diets, enhancing the sustainability benefits of crop-livestock mixed farming systems.

Area, production, yield, value

While the benefits of grain legume cultivation and consumption are congruent with the SLOs, are they large enough to matter?

Taken collectively, **the dry grains of the eight prioritized legume crops of CRP 3.5 attract US\$24 billion in market value at the farm gate per annum in the LIFDCs**, on par with maize or wheat (Table 3.1). Value is an integrative indicator reflecting the sum total of the attributes that people seek from crop grains. Value paid for a ton of grain also represents investment into the value chain to grow, process and deliver the next crop, thus indicating the scale of investment by the marketplace into a commodity. Part of that investment reaches the poor farm households that cultivate these crops, impacting the SLOs as well as motivating them to further improve production in order to increase their gains. Thus **value** may be a more informative metric for cross-crop comparisons than simple gravimetric mass, i.e. tons of production.

Total area of production of the eight focus grain legumes also exceeds that of maize or wheat. However production by gravimetric weight (tons) is less, because the average grain yields of grain legumes are only about one-third to one-half those of the cereals (except for faba bean). The reasons for these yield differences are discussed later in this chapter. As mentioned above, from a development strategy point of view, value and nutritional yield may be more relevant than gravimetric yield. For example, the protein content of the pulses (grain legumes eaten mainly as human food) is 2-3 times higher, and for the oilseeds (soybean, groundnut) is 3-4 times higher than in the cereals (Kimaro et al. 2009; Messina 1999).

Table 3.1. Area, production, yield and value of grain legumes in Low Income Food Deficit Countries (LIFDCs, as per FAO¹)

Crop	Area (million ha)	Production (million tons)	Yield (t/ha)	Producer price (US\$/ton)	Value of production (US\$ billion)
Chickpea	9.2	6.7	0.73	585	3.9
Common bean	6.5	4.5	0.69	624	2.8
Cowpea	11.7	5.5	0.47	403	2.2
Faba bean	0.7	1.2	1.63	500	0.6
Groundnut (in shell)	17.0	18.3	1.01	450	8.2
Lentil	1.9	1.2	0.64	548	0.7
Pigeonpea	4.3	3.5	0.81	592	2.1
Soybean	11.6	12.3	1.06	305	3.7
Total	62.8	53.2			24.2
Maize	45.1	99.4	2.20	210	20.9
Wheat	50.0	131.9	1.32	213	28.1
Rice	90.4	328.9	3.29	236	77.6

¹Source: FAOSTAT. For production data, 2008 values are shown; for price data the 2000-2008 average is shown. FAO definition and listing of Low Income Food Deficit Countries (LIFDCs) is at www.fao.org/countryprofiles/lifdc.asp

Demand trends

Akibode and Maredia (2011) provide the most recent comprehensive overview of production, trade and consumption trends of seven of the eight grain legume crops that are the focus of CRP 3.5 (except groundnut) based on FAO data. Per capita net availability of grain legumes across the developing world, an imperfect but useful indicator of **per capita consumption climbed from 7.30 to 7.94 kg between 1995-2007, a 9% increase**. Regional analysis of 2007 FAOSTAT data (the most recent available) indicates per-capita food supply of pulses of 12.7 kg/capita/year in Latin America and the Caribbean, 8.8 kg in Eastern and Southern Africa, 8.2 kg in West and Central Africa, 7.1 kg/capita-year in South and Southeast Asia, and 4.8 kg in Central and West Asia/North Africa (Roberto Telleria, ICARDA from FAOSTAT data). The portion these crops represent in the total diet is typically measured in kilocalories consumed per capita per day. Since the mid-1990s total calories consumed per capita in the developing world have risen by about 6%. The contribution of cereals to this caloric intake has declined, but (in agreement with rising per capita consumption) the pulse share has remained steady (in sub-Saharan Africa and South/Southeast Asia) or increased (Latin America and the Caribbean, Central and West Asia/North Africa) (Akibode and Maredia 2011).

Akibode and Maredia (2011) suggest that long-term (multi-decadal) *global* per capita consumption of grain legumes (and also for cereals) will probably decline as wealth and urbanization enable people to consume costlier livestock-based protein and convenience foods. However, as indicated in the SRF and SLOs, the target beneficiary group of the CGIAR is the poor of the developing world, rather than the global population as a whole. Those developing-world poor who are unable to afford livestock products will remain dependent on grain legumes for a significant portion of their dietary protein and other nutrients. Akibode and Maredia (2011) conclude that **grain legumes will remain crucially important as “poor person’s meat”**. Thus the benefits of grain legume R4D will naturally accrue to the poorest peoples who are the prime target of the CGIAR SLOs.

FAOSTAT data are unfortunately not stratified by income class, which would aid in delineating consumption trends of the poor - the CGIAR’s prime target. A rough approximation is to compare poorer vs. less-poor countries. Akibode and Maredia (2011) indicate that **many of the poorest countries in the world derive the highest proportion of their total dietary protein from grain legumes (10-20% or more)**, e.g. (in descending order): Burundi (55%), Rwanda (38%), Uganda and Kenya (20%), Comoros, Haiti and Eritrea (18%), Nicaragua and Cuba (16%), Niger, Ethiopia, Malawi, Angola, Tanzania (14-15%), Mauritania, Sierra Leone, India, Brazil, Trinidad and Tobago, Mozambique, Cameroon (12-13%), DPR Korea, Guatemala, Mexico, Togo, Belize, Paraguay and Botswana (10-11%). These authors state that grain legumes provide 7.5% of total protein intake in the developing world, three times higher than the 2.5% proportion found in the developed world.

Income-stratified consumption data *are* available in India, the world’s largest pulse consumer and producer, from the National Sample Survey Organization (NSSO). They reveal that caloric contribution of pulses to the diet of the very poor increased by 6% during 1993-2004 (Akibode and Maredia 2011). The poorest strata in India spend more on grain legumes than on meat and animal products, while the reverse is true for the less-poor strata. Across strata, from 1990 to 2007 per capita consumption of pulses increased from 11.4 to 12.9 kg/capita (FAOSTAT). Added to meeting the needs of increased populations, this resulted in a total consumption increase of 2.2 million tons.

Demand for human consumption of grain legumes in India is expected to further strengthen over the current decade (Parthasarathy Rao et al. 2010; Birthal et al. 2010; Kumar et al. 2009). Using food characteristic demand system (FCDS) methodology to analyze NSSO household level consumption data from 2004-05, Kumar et al. (2009) found that **income elasticity for grain legumes is solidly positive** for all income classes, clearly outpacing cereals, **indicating that the poor would purchase relatively more grain legumes if extra income were available to them** (Kumar et al. 2009). They projected per capita grain legume consumption by the rural population in India for the period 2011 to 2022 to increase by 9%, compared to no increase in cereal consumption. Recently (16 July 2011,

Foundation Day Lecture) the Director General of the Indian Council for Agricultural Research (ICAR) projected an annual demand growth of 3.1% for pulses for the 2011-2027 period, far outpacing the 1.3% demand growth expected for cereals (Ayyappan 2011).

“That the consumption of milk, eggs, meat and fish for the lowest income distribution group is still very low in India implies that next to cereals, pulses still remain the main source of protein for the poorest segment of both rural and urban India. This observation is applicable to many other countries in the world.” - Akibode and Maredia (2011)

Due to high population growth rates, Africa and the Middle East are projected to have the strongest growth in food demand and trade over the coming decade (Alene 2012). For oilseeds such as soybean and groundnut, population growth will boost demand for vegetable oils for food consumption and rising incomes will increase demand for protein meals from oilseed presscake for use as livestock feed.

Supply trends

Akibode and Maredia (2011) note **a rebound in grain legume production and consumption since the mid-1990s**, with production gains outstripping population growth (1.8% vs. 1.3%). In the developing world, area sown increased by 10%, yields by 12% and production by 24% since that time. More than half of the increase in production in the developing world occurred in sub-Saharan Africa.

Yet this progress has still not been sufficient to meet growing demand over the past fifteen years, so developing countries are compelled to import an increasing proportion of their grain legume requirement (Akibode and Maredia 2011). For example if current trends continue in West and Central Africa, cowpea demand will grow faster than supply (2.68% per year vs. 2.55%) during 2010–2030, with Nigeria, already a large net importer, exhibiting the largest demand-supply gap and consequent importation requirement (Alene et al. 2012). Africa is also projected to face a soybean production deficit of 1.7 million tons by 2020 (Alene et al. 2012). Pulse imports worldwide have been increasing since the mid-1990s, particularly by India, exceeding the growth rate of global production. A total of 6.7 million tons of pulses worth US\$4.5 billion were imported in 2006-08, a substantial outlay of scarce foreign exchange (Akibode and Maredia 2011).

As a result of these production shortfalls, Clansy (2009) foresees **continuing increases in imports to fill the grain legumes supply-demand gap** globally, particularly in sub-Saharan Africa due to that region’s rapid population growth. Akibode and Maredia (2011) estimate that even if area sown to grain legumes continues to increase at the same rate as in the past decade (0.37%/year), **yields will still need to grow at a rate 50% faster than the current 0.4% per annum average in order to meet projected demand growth to 2020.**

India is the world’s largest producer and consumer of pulses (pulses are the non-oilseed grain legumes). Produced mostly by smallholders, India generates about one-third of the developing world’s total pulse production, and one-quarter of the world total. Reddy (2004; 2009) and Reddy et al. (2010) forecast that India’s domestic supply will lag behind demand by 9%-26%, depending on scenario outcomes. Pulse imports to India increased from 350,000 t in 2001 to 2.7 million t in 2008 (FAOSTAT). Concerned about demand continuing to outstrip supply, India is taking aggressive steps to foster increased grain legume production, such as raising minimum support prices and launching the Accelerated Pulses Production Programme (A3P), described in more detail later.

Major emerging economies such as China and India as well as some countries in North Africa, the Middle East, and South Asia are not able to meet their vegetable oil needs from domestic production and will need to import (Alene et al. 2012). If past trends continue, Africa is projected to face a soybean production deficit of 1.7 million tons by 2020 and Asia will be in deficit by 60 million tons.

A painful consequence for the poor of shortfalls in pulse production has been **increasing prices** in

recent years (Akibode and Maredia 2011; Chandrashekhar 2011; Prensa Libre.com 2012). Grain legumes attract approximately 2-3 times higher prices than cereals on a worldwide average basis (2000-2008 average data - Table 3.1). High prices limit the ability of the poor to buy the quantities that they desire ('desire' as indicated by income elasticity data discussed earlier). By constraining consumption high prices can risk shifting the diets of the poor towards less nutritious configurations - a caution issued from a recent international conference on "Leveraging Agriculture for Improving Nutrition and Health" (IFPRI 2011).

High prices resulting from production shortfalls are attributable to the low productivity of these crops, which results from low input usage (especially seed, fertilizer, irrigation), and cultivation on marginal rainfed lands (Joshi 1998). These factors are a result of the low level of policy support and investment (subsidies, price supports, services, etc.) provided to grain legume producers in comparison with other crop commodities such as the major cereals, as described earlier. Akibode and Maredia (2011), Joshi (1998) and Rao et al. (2010) indicate four reasons for the slower yield growth in grain legumes: i) low input use, ii) shift into marginal growing areas, iii) less policy support than other commodities, and iv) limited R4D and dissemination of improved technology. They note that only 25% of the grain legume crop area in the developing world is high input/irrigated, compared to 60% of the cereal area. Only 6% of fertilizer in sub-Saharan Africa is used on grain legumes, compared to 26% for maize and 11% for wheat/barley (Bumb et al. 2011). As a consequence of this unfavored policy status, **global average yields of grain legumes are one-third to one-half as large as those of cereals, and are increasing at a slower rate (0.4% per annum, compared to 1.5% for cereals since the mid-1990s).**

Adapting to this reality, the priority assigned to stress resistance breeding (drought, heat, insects, diseases, nutrient-depleted soils, short-season niches) has been relatively high in grain legumes since the Green Revolution. Breeding for maximum yield potential has been less relevant since the expression of high yield potential is constrained by these stresses.

In summary, **the slow pace of growth in production and yield of grain legumes over recent decades can largely be attributed to less policy and institutional support compared to other commodities, causing a shift of cultivation to less productive environments and lower use of inputs such as fertilizer, irrigation and improved seed. Breeding programs have therefore placed priority on selecting for adaptation to the stresses of marginal environments rather than on yield potential under non-limited conditions.**

Alignment with the priorities of regions, nations, farmers and development investors

CRP 3.5 is attentive to the priorities assigned to grain legumes within the agricultural development agendas of its partner regions and countries. Priority-setting information is not readily available for all countries, but the examples below from available sources indicate typical perspectives, issues, constraints and opportunities.

West and Central Africa

CORAF/WECARD is the regional agricultural research organization representing the priorities of the nations of West and Central Africa. Their Strategic Plan (2007-2016) ranks groundnut third in priority among all crops in West and Central Africa in terms of research benefits foreseen (US\$3.4 billion), and second in the Sahel zone. It emphasizes the opportunity to access export markets with this crop, improving varieties and processing technologies. The pulses collectively contribute 8.7% of agricultural GDP growth in the region.

Development investors (donors) carefully weigh their choices in prioritizing their interventions. The Bill and Melinda Gates Foundation is one of the largest philanthropic investors in agricultural R4D today, and has chosen to make major investments in grain legumes, specifically groundnut, cowpea, bean and soybean in Sub-Saharan Africa (Gates Foundation 2011). Two Gates Foundation-supported projects on grain legumes that are central to CRP 3.5 are Tropical Legumes I and Tropical Legumes II.

In addition to the Gates Foundation, TL I is supported by the European Commission, the UK's Department for International Development [DFID] and the World Bank.

TL I is executed by the Generation Challenge Program, which is a core partner in CRP 3.5. It focuses on developing advanced genomic tools such as molecular markers to improve the stress tolerance, particularly to drought, of groundnuts, cowpeas, beans and chickpeas. TL II focuses on breeding improved cultivars and improving grain legume seed systems. Three countries are prioritized by TL II in West and Central Africa: Burkina Faso, Ghana, Mali, Niger and Nigeria (along with others listed later for Southern and Eastern Africa, and in India). TL II will increase the productivity and production of legumes and the income of poor farmers by an average of 15 percent across all nine of its target countries by 2020, with improved varieties being adopted on 30 percent of the total area planted by some 57 million poor farmers.

The N2Africa project is another major initiative supported by the Gates Foundation. Its aim is to raise biological nitrogen fixation (BNF) by about 50 kg/ha on average, approximately doubling the average grain yields of four major legume crops: groundnut, cowpea, soybean, and common bean - in eight countries in sub-Saharan Africa. In West and Central Africa, three countries are targeted: Ghana, Nigeria, and the Democratic Republic of the Congo. The project focuses on testing different legume varieties with different Rhizobium strains to find the most BNF-productive matches for particular environments, followed by training and dissemination of seed inoculation technology. CRP 3.5 contributes diverse crop germplasm for testing that is essential to the success of this project.

A third major investment initiative in the West and Central Africa region (and other regions) is the USAID-sponsored Feed the Future program (Feed the Future 2010). In Ghana, its strategy is to transform commodity value chains for high impact on nutritional, gender equity and poverty issues. It prioritizes soybean along with rice and maize, especially in the northern part of the country. To maximize nutritional impact, Feed the Future integrates food production and processing approaches with behavioral changes.

Eastern and Southern Africa

ASARECA is the unifying regional association for national R4D systems in Eastern and Central Africa. ASARECA 's Strategic Plan 2006-2015 ranks oilseeds (mainly groundnut) as #1 among all commodities in forecasted contribution to widely-distributed (i.e. reaching a large number of farmers) agricultural GDP growth in that region. They also state that "pulses have relatively high current and expected future demand in the region."

Ethiopia has been a standout performer over the past decade in increasing the production of grain legume pulses for export (IFPRI 2010). Legumes are the third-largest export crop category (following coffee and sesame), with about 140,000 tons exported in 2007/08 earning the country US\$90 million (in addition to local consumption). The major species produced are faba bean, pea, chickpea, common bean and lentil. About 60-90% percent of the pulse crop is consumed on-farm, so they play a food security role as well as a cash-earning role. Pulses account for about 13 percent of cultivated land and 15 percent of protein intake in the country. IFPRI states that pulses are a "significant contributor to the economic and social development of Ethiopia" and notes their ability to reduce the fertilizer requirement for the subsequent cereal crop, concluding that "diversification by rotating staple cereal production with pulses is an important income opportunity."

The Government of Ethiopia has been strongly supportive of the development of pulse value chains for export. IFPRI (2010) sees potential for doubling these exports and recommends investment in a robust extension system, seed systems, and access to irrigation. They flag an opportunity for realizing gender equity benefits, because women are primarily responsible for planting, harvest, postharvest value addition, and marketing of these crops. Priority needs are the increased use of inputs (e.g. fertilizer and improved seed) to improve productivity, improved linkages between producers and exporters, transparent market price systems, and a promotive business environment.

SADC's new agricultural research subsidiary body, CCARDESA has not yet produced a crop prioritization for the Southern Africa sub-region, but national policies in Malawi, Mozambique and Zambia are informative. Malawi's 2011-2015 prioritized strategy (Agricultural Sector-wide Approach) emphasizes both food security based on maize self-sufficiency, and nutritional security based on diversification into legumes, horticultural crops, livestock and fish (Malawi Ministry of Agriculture 2011). Improving dietary diversification for vulnerable groups specifically targets "promoting consumption of enriched foods in complementary feeding programmes and maternal nutrition and among people living with HIV and affected by AIDS through the use of soy beans, pigeon peas, and groundnut as key ingredients." Reflecting these priorities, these crops are now eligible for the national Farm Input Subsidy Program. Malawi's strategy further notes that fertilizer subsidies for maize consume more than half of the Ministry of Agriculture's budget and that legumes can help substitute for some of that fertilizer requirement through biological nitrogen fixation.

The third component of Malawi's priority agenda is risk management for food stability, particularly against market gluts and climatic shocks. Crop exports are seen as key to managing market risks including transition away from overdependence on tobacco exports. Groundnut, soybean and pigeonpea are priority alternatives being supported through government programs. In addition to export income, local production of oilseeds provides import substitution. Vegetable oil is in high demand, and the use of nutritious presscake (the residue that remains after oil extraction) as poultry feed substitutes for costly fishmeal feeds. The Export Strategy is also being assisted by Irish Aid; a preliminary report presented at a drafting workshop in mid-January 2011 ranks groundnut among the first two priority export targets for the near-term future. Improving seed systems for groundnut and soybean is a priority element.

The National Smallholder Farmers Association of Malawi (NASFAM) is in agreement with these priorities and is actively engaged in partnerships with CRP 3.5. In their current strategic plan they have prioritized groundnut and soybean as alternative cash crops to tobacco for smallholder farmers. NASFAM's strategy is to connect smallholder farmers to markets to sell nutritious high-value crops in order to raise their incomes while also improving household health. ICRISAT has assisted in this aim by providing aflatoxin-testing technology to meet EU export quality standards.

NASFAM also places priority on sustainable farming methods and risk management against droughts and climate change. To highlight just a few examples, in collaboration with ICRISAT, ICRAF, and Malawi's Department for Agricultural Research (DARS) in the Ministry of Agriculture and Food Security, and with support from the Alliance for a Green Revolution in Africa (AGRA), NASFAM is implementing a 3 year soil fertility project entitled 'Increasing benefits of smallholder farmers from improved soil fertility through integration of pigeon peas, groundnuts and conservation agriculture in maize production systems in Malawi'. And in response to increasingly short and unpredictable rainfall seasons, which may be a harbinger of climate change, ICRISAT, DARS and other research institutions are developing varieties of groundnut and pigeonpea that are suitable for shorter seasons. ICRISAT contributes the diagnosis, breeding and on-station variety testing while NASFAM leads in the on-farm testing of promising varieties, farmer capacity-building and dissemination of results. Breeding and variety testing involves the full participation of smallholder farmers, whose growing conditions, priorities, preferences and seed delivery system practices were the subject of the diagnostic studies. NASFAM is also innovating in weather risk insurance; having demonstrated its feasibility it is now deploying it with groundnut and soybean as two out of seven priority crops.

“In recent years, tobacco, which is the main cash crop grown by most smallholder farmers in Malawi, has continued to face challenges that are making the crop less and less profitable for farmers. During the Association Assessments carried out in April 2011 as part of the Strategic Development Plan III process, groundnuts and soya beans came out as the next best cash crops to tobacco. It will however be necessary to manage total production well in order to avoid over-supply which can lead to reduced prices, and to engage in value-addition in order to attract higher prices.”

- National Smallholder Farmers Association of Malawi (NASFAM) Strategic Development Plan III (2011-2016)

USAID’s Feed the Future strategy prioritizes legumes in Malawi. Praising that nation’s prioritization plan for its wide stakeholder ownership, Feed the Future concurs on the main issues facing the country, particularly its overdependence on a single crop (maize, > 50% of dietary calories) and need to diversify its exports beyond tobacco, seeing the diversification of crops and diets as a strategy to address both issues. Legumes take the spotlight; Feed the Future’s main agricultural production focus is “Invest in high potential legume and dairy value chains” which it justifies based on providing broad income, gender and nutrition impacts, embodying a clear business case, providing opportunities for innovation and leveraging USAID resources.

In Mozambique, after considering 25 commodity options spanning the cereals, root crops, legumes, fruits, livestock, dairy, fisheries and forestry, Feed the Future chose oilseeds (soybean, sesame and groundnut), cashews and fruits as their priorities. Their decision was based on these commodities’ importance to income-generating value chains that benefit improved nutrition, supported by targeted research and technology innovation. Feed the Future considered the main constraints in oilseed value chains to be the lack of smallholder access to improved seed and other inputs, and weak market linkages. It will build on the Gates Foundation’s support to soybean production by linking soybean farmers to processors and markets.

In Zambia, Feed the Future notes high rates of under-nutrition and child stunting alongside micronutrient deficiencies associated with overreliance on maize in the diet, disproportionately supported by subsidies. Feed the Future places its largest commodity value chain investment in legumes and oilseeds (38%, vs. 19% for vegetables and 10% for maize). Their rationale for legumes and oilseeds as a priority is based on potential for productivity growth, nutritional value/dietary role, and impact on women (women play a major role in production, marketing and trade of legumes and oilseeds). They also note legumes’ synergistic integration with maize in farming systems, and potential for value addition and trade. Key intervention areas are value addition and processing, and promoting consumption to enhance nutrition and dietary balance.

In Uganda, bean (for nutrition) is one of three Feed the Future priorities, alongside maize (for food security) and coffee (for growth). Two-thirds of the population grows beans, and this crop is both accessible to the poor and vulnerable as well as being synergistic in farming systems with maize and able to capitalize on similar post-harvest infrastructure. High zinc/iron beans hold important potential.

The Gates Foundation-supported Tropical Legumes projects described earlier for WCA are also active in ESA. TLII is working in five ESA countries: Ethiopia, Kenya, Malawi, Mozambique, and Tanzania - to accelerate and expand the delivery of more productive grain legume varieties through improved seed systems and related assistance.

Also in the Eastern and Southern Africa region, Malawi, Mozambique, Kenya, Rwanda and Zimbabwe are priority targets of the major Gates Foundation-supported N2Africa project described earlier. This project aims to dramatically raise the biological nitrogen fixation of legumes and consequently the yields of grain legume crops, and of the following crops that benefit from the residual N left in the soil by the legumes.

South and Southeast Asia

India is the world's largest consumer and producer of grain legumes (one-quarter of world supply; one-third of the developing world's supply). The large and growing gap between production and consumption in India was described earlier, and is of great concern to the country's leaders. To address the growing supply-demand gap, India began aggressive steps to foster increased production of pulses in 2007 by launching the Accelerated Pulses Production Programme (A3P) within the umbrella of National Food Security Mission (NFSM). Funded at a level of US\$360 million over the first four years (2007-2011), the crops supported were chickpea, pigeonpea, urad bean, mung bean and lentil. A3P's target is to increase annual pulse production by 2 million tons (over its 15 million ton/annum baseline) by 2011-2012 through a large program of demonstration, training, and input and services provision to 1,000 localities in 14 states. After stagnant growth the first three years the target was achieved in 2010/11, with 17.3 million tons produced due to increased area sown and favorable weather. Strong prices due to the growing supply-demand gap may also have motivated farmers to increase plantings (Chandrashekhar 2011). As a result of the bumper crop, prices have moderated by 25-40%, providing relief to poor consumers. Based on the success of the program it was expanded starting in 2010-11 through a \$65 million dollar supplement to create 60,000 "Pulses and oilseeds villages". These villages are being provided with tractors and tillage machinery to be let out on a 50% subsidized contract basis for land preparation to expand the cultivation of pulse crops.

The Bill & Melinda Gates Foundation-supported Tropical Legumes projects (TLI and TLII, described earlier) are also assisting India to increase pulse production. Among the legumes, the Gates Foundation places priority on chickpea and groundnut in India (Gates Foundation 2011).

USAID's Feed the Future program prioritizes pulse crop value chains along with rice, maize and vegetables in Nepal, the poorest country in South Asia (and 13th poorest country in the world). Nepal has very high rates of stunted (49%) and underweight (39%) children under the age of five. Average landholdings are just 0.5 hectare in size; 75% of income is spent on food yet dietary diversity is limited. Prioritization was based on Nepal's own priority crops for investment, high unmet demand for the crop, high potential for increasing production, a significant role in human nutrition, and large numbers of smallholders growing these crops. Interventions will focus on high value agricultural transformation, nutrition and hygiene, and the integration of vulnerable groups.

Latin America and the Caribbean

SICTA (Central American System of Integration for Agricultural Technology) is the regional organism coordinating agricultural research among seven countries in Central America. SICTA prioritizes the maize-bean system as an important value chain to be strengthened through technological innovation (<http://redsicta.org/redesNacionales.html>). Likewise, the Generation Challenge Program highlights the maize-bean system as a priority to be targeted in efforts to address drought, malnutrition and poverty.

In Honduras, one of the USAID Feed the Future's eight priorities is to increase the productivity of the two main grain crops, bean and maize. They foresee a 2.5-fold yield increase through improved practices. Besides improving food security in this impoverished country, this will free up agricultural land for cultivating higher-value export crops such as vegetables, fruits and coffee.

Feed the Future in Nicaragua prioritizes beans along with coffee and horticulture based on the following criteria: already a priority of the country's government, largely smallholder-based, nutritionally important in diets, high export potential, high potential for production gains, and potential to employ women in processing.

Another impoverished country in the region is Guatemala. Increased prices for beans have been punishing the poor for the last four years, according to newspaper reports (Prensa Libre.com 2012). Guatemala, Haiti, Nicaragua, and Honduras participate in the Bean Technology Dissemination

Project aiming to reduce these countries' dependence on bean imports. This project is convened by the Dry Grain Pulses CRSP supported by USAID and aligned with Feed the Future.

Central and West Asia and North Africa

Wheat and cotton are by far the most important crops in Syria, but the government also sets producer prices for lentils and chickpeas as well as for barley, sugar and tobacco (Westlake 2001). Morocco's Ministry of Agriculture and Fisheries has declared food legumes, particularly faba bean to be priorities for research and development (MAPM 2007, 2010).

The International Assessment of Agricultural Knowledge, Science and Technology for Development report (IAASTD 2009) states that grain legume consumption in the region has increased as animal products have become more expensive due to high costs of feeds in the region. It urges that legumes also be included in CWANA cereal-based farming systems in order to improve the sustainability and productivity of the farming system.

The importance of diversity in crops, diets and livelihoods of the poor

A lesson that emerges from the preceding discussions is the value that **diversity** delivers through grain legumes. Diversity is a key asset of CRP 3.5 that constitutes 'business un-usual' relative to sole-crop R4D. By uniting four CGIAR Centers' work on eight crops and partnering with world-leading institutions beyond the System, the CGIAR gains an unprecedented opportunity to more deliberately investigate and exploit the uses and benefits of crop and dietary diversity. Numerous specific opportunities for cross-crop research and partnership are described elsewhere in this proposal, such as in 'Why a Consortium Research Program on Grain Legumes?' (also in Chapter 6 on 'Partnerships and Networks', and in Chapter 8 on 'Innovations'.

The stakeholder views presented earlier highlight the priority roles they see for grain legumes as a means to diversify overly-cereal dependent farming systems and diets, as well as to increase market opportunities and incomes. The USAID Feed the Future strategy papers make this case on a particularly wide scale across three continents (Africa, Asia, Latin America). In its Malawi strategy paper, Feed the Future lists a prime risk as "Low diversity and inadequate supply of nutritious foods available for consumption (e.g., maize > 50% of energy supply)"; in its Mozambique strategy it lists the first priority as "Invest in income-generating value chains that benefit improved nutrition (oilseeds, cashew, fruit)"; and in its Ghana strategy it prioritizes "Increase small-scale household production of diverse nutritious plant and animal foods." Similar statements support its priority choices for Nepal, Nicaragua, Uganda and Zambia, all utilizing grain legumes as important to diversification strategies. NASFAM's strategy in Malawi is particularly insightful and specific in strategies for assisting its farmers in achieving diversification.

"In addition to maize self-sufficiency, diversification of smallholder farming systems can increase food availability... once farmers reliably achieve food security, they rapidly explore other, potentially more profitable, livelihood options (both on- and off-farm). This further diversification helps reduce the vulnerability of households to unexpected shocks."

- Malawi Ministry of Agriculture 2011 - Malawi Agricultural Sector Wide Approach: A Prioritized Agenda

Diversity also delivers widely acknowledged farming system benefits. Diverse farming systems are usually more resilient (Walker and Salt 2006) and flexible. If one crop fails due to drought or disease, another that escapes these hazards may rescue the farm family's food supply and income. Crops with diverse phenological patterns are often ecologically complementary and make more efficient use of system resources (nutrients, water, solar radiation and others), as in maize-pigeonpea intercropping in Eastern and Southern Africa and Latin America/Caribbean, and sorghum and millet relay cropping with cowpea in the Sahel. They also enable a more efficient spreading of labor use over the cropping season and the dry season, and supply a steadier source of food and income over

the calendar year.

Consideration of the roles of the eight grain legumes proposed in CRP 3.5 in farming systems, regions and livelihoods leads to the conclusion that they are not duplicative. Each fits uniquely well to important agro-ecosystems, dietary demand and market value chains that are relevant to and important for the CGIAR mission and SLO targets. There would be no feasible crop that the CGIAR could persuade the populations of East Africa and Latin America to substitute for bean; the Sahel for cowpea; the CWANA region for faba bean, lentil and chickpea; and South Asia for chickpea, groundnut, pigeonpea and lentil. All of these crops have also extended their reach to additional continents. Soybean is relatively new to Africa but has gained a strong foothold in and commitment from key countries across the continent, and holds uniquely advantageous nutritional, yield and value chain attributes that will contribute importantly to the SLOs.

Diversity also provides a very rewarding starting point for scientific investigation. We can only learn from differences. Compare/contrast learning is a powerful approach at all levels: gene, genome, genotype, phenotype, agro-ecosystem, value chain, region, and globally. Legumes are by far the most diverse family of flowering plants (Doyle and Lucknow 2003). Cultivated species within the CRP 3.5 ambit are distributed at considerable genetic distance across the largest subfamily, the Papilionoideae. Yet genomic advances are enabling scientists to map homologous genes and gene regions among them. This means that genetic learning from one legume species, particularly the well-studied soybean, can yield valuable information about the other, less-researched legumes in CRP 3.5's portfolio (Gepts et al. 2005). The potential value of such cross-learning is immense. With partners CRP 3.5 will be positioned to gain insight on fundamental questions about the traits that make soybean high-yielding and exceptionally nutritious; cowpea, pigeonpea and chickpea especially drought-tolerant; pest and disease resistance mechanisms; and other key game-changing questions.

“Bringing the genomic and biological knowledge in reference legumes to bear on other food and feed legumes of major economic importance, including cool-season pulses (e.g. pea, lentil, and chickpea), warm-season food legumes (e.g. peanut and common bean), and forage legumes (e.g. alfalfa and clover) represents a major scientific opportunity. Each legume presents unique features of economic and scientific interest.” – Gepts et al. (2005)

In sum – crop, dietary, and income diversity delivered by grain legumes are powerful assets of great importance to CGIAR stakeholders that CRP 3.5 is ideally positioned to exploit.

Priority setting among grain legume regions, crops, and farming systems

Priority regions

As mentioned in Chapter 2, CRP 3.5 GRAIN LEGUMES will place its greatest emphasis on regions containing the largest numbers of poor and malnourished grain legume producers and consumers. As guided by the CGIAR SRF and as reflected in the data of Table 3.2, highest priority will be assigned to South and Southeast Asia (SSEA) and sub-Saharan Africa, the latter consisting of two regions: West and Central Africa (WCA) and Eastern and Southern Africa (ESA). Two additional regions will also be addressed; although their poverty/hunger indicators are lower, they contain important pockets of poverty along with well-established CGIAR capacities and are located in important centers of grain legume genetic diversity. They are Latin America and the Caribbean (LAC) and Central and West Asia/ North Africa (CWANA).

Table 3.2. Population and poverty indicators by region

Indicator	SSEA	WCA	ESA	LAC	CWANA	Total
Rural population (millions)	1,477	243	273	122	213	2,328
Urban population (millions)	832	192	112	467	321	1,924
Number of poor (<US\$ 1 per day, millions)	443	121	85	45	46	740
Number of stunted children (millions)	62	13	11	5	3	94
Grain legume area (million ha) ¹	40.6	19.4	10.6	3.1	2.6	76.3
Number of beneficiaries in farm households (million) ²	149	82	38	22	13	304
¹ 2008 crop area from FAOSTAT						
² Number of beneficiaries per region estimated using a four-step process: i) dividing the total legume area in a region by the average farm landholding (from FAO 2010) in that region; then ii) dividing that number by 0.20 on the assumption that on an average, farm households grow legumes on about 20% of their cropped area (FAOSTAT estimates 14% of cropped area is cultivated to grain legumes in LIFDCs); then iii) multiplying by average number of household members per farm (obtained from Bongaarts 2001); then iv) multiplying that number by 0.20 to downsize for 20% adoption rate of CRP 3.5 grain legume innovations by the tenth year of the program.						

Priority crops per region

Within these five regions CRP 3.5 GRAIN LEGUMES will focus on the grain legume crops that are grown over the largest areas by smallholders in LIFDCs in the five regions. FAO crop area data were used to identify the leading eight candidate grain legumes worldwide. Their cropped areas were then disaggregated by region.

In addition to sown area, key additional decision-making criteria were:

- Emphasize crops with at least 500,000 ha and preferably over 1 million ha cultivated in each region;
- Emphasize crops that, though important to the poor, have received lesser investment from the public and/or private sectors due to a range of policy and market failure issues;
- More crops addressed in the ESA region because of that regions' exceptional variation in edaphic, topographic and climatic parameters, necessitating a wider range of grain legume crops to suit its agro-ecosystem conditions and meet farmer needs; and because of strong recent growth in income-earning export markets for several grain legume crops; and
- Exclude soybean in SSEA despite large hectareage due to high capability of alternative suppliers of R4D attracted by the crop's commercial potential

The above priority-setting focuses the cropped area to be addressed by CRP 3.5 GRAIN LEGUMES down to 61 million ha out of the 76.2 million total ha of these eight crops sown in LIFDCs across the five regions (last two rows of Table 3.3). Shaded cells in the table are the priority crop/region targets for CRP 3.5.

Table 3.3. Planted area (million ha) of eight major grain legume crops in LIFDCs by region (excluding large-scale commercial plantings)^{1,2}

Major grain legumes	SSEA	WCA	ESA	LAC	CWANA	Total
Chickpea	10.9	0	0.5	0.1	1.2	12.6
Common bean	0.3	1.5	4.8	2.7	0.3	9.6
Cowpea	0.4	9.2	0.5	0	0	10.1
Faba bean	0	0	0.6	0.1	0.4	1.1
Groundnut	9.6	8.0	2.9	0.2	0.1	20.8
Lentil	1.9	0	0.1	0	0.6	2.6
Pigeonpea	4.6	0	0.5	0	0	5.1
Soybean	12.9	0.7	0.7	0	0	14.3
Total area per region for all eight legumes	40.6	19.4	10.6	3.1	2.6	76.3
Prioritized area (shaded)	27.0	19.4	10.5	2.7	2.2	61.8

Poverty and beneficiary breakdown by crop and region

Table 5.3 in Appendix 5 combines and extends the disaggregation of Tables 3.2 and 3.3 by crop x region and also adds a breakdown of foreseen benefits from CRP 3.5 (benefits are explained in the Value Proposition section later in this chapter).

Advancing the priority setting process in CRP 3.5

The prioritization choices made by CRP 3.5 to date have been substantial. To ensure focus on the poorest, hungriest areas of the world, an independently-defined (by FAO) subset of only the neediest countries was adopted, the Low Income Food Deficit Countries (LIFDCs). The original set of 13 target crops proposed in the first version of the proposal was cut nearly in half, to eight. Among the remaining eight, and within LIFDCs, only farming systems with substantial grain legume hectareage grown by large numbers of poor and hungry people have been prioritized. Within that focused portfolio, further considerations of alternative suppliers of R4D were used to exclude certain large cropped areas even though they are farmed by smallholders, namely for soybeans in SSEA and LAC, and common beans in South America. Another major grain legume of the Asian poor, mung bean was excluded at the suggestion of the CGIAR based on domain issues. Many of these choices were difficult and not without controversy.

An additional challenge in priority-setting has been the reality that the majority of CRP 3.5 activities are ongoing, some with special project funding. They reflect past priority-setting exercises and are commitments to partners and investors that CRP 3.5 institutions are obligated to fulfill. Furthermore those priorities are well-informed by three decades of R4D expertise on grain legumes, and have gained crucial support from partners and stakeholders that are essential to their success. It would not be realistic or even responsible to disregard these commitments and launch a fully *de novo* priority-setting initiative. The re-examination of priorities will be an ongoing task that includes continuous dialogue with partners to build consensus on new targets. CRP 3.5 will keep its stakeholders onboard, while not settling into a comfort zone that rejects any change. Change will be

evolutionary rather than revolutionary; yet CRP 3.5 will encourage well-justified changes in R4D directions, and will take risks on some potentially game-changing topics despite their unpredictable probability of success.

With those basic considerations in mind, CRP 3.5 management will institute a rigorous, well-defined, regular and ongoing process of re-examining its priorities prior to each annual workplanning process. Experts in priority-setting will be engaged including those from ICRISAT's Impact Assessment Office who assist CRP 3.5 on a continuing basis (see chapter 10 on Management Arrangements).

Priority-setting will begin by deliberating and deciding upon a set of criteria against which different candidate activities will be evaluated. Ideally, those evaluations would be based on full and precise datasets for all those criteria. Experience teaches us that this is rarely the case, even for the simplest criteria. For grain legumes in the developing world, and particularly in Africa, data gaps are vast. Detailed, geo-referenced baselines for poverty, malnutrition, gender issues, farming systems, farmer motivations and decision-making, and other crucial criteria are inadequate or non-existent. Much information is anecdotal at best. This situation needs urgent rectification, and CRP 3.5 is heartened to see development investors such as the Bill and Melinda Gates Foundation and others supporting projects to improve this situation. Those initiatives have already influenced CRP 3.5's priority setting, e.g. using preliminary information from the Tropical Legumes II project baseline studies and information from the ICRISAT Village Level Studies, recently reinvigorated through Gates Foundation support. In addition, CRP 3.5 will use value chain analysis to quantify the benefits of different R4D options in order to improve priority-setting (as introduced in Chapter 2 and fully elaborated in chapter 5).

Although improved data will help considerably, priority-setting will also always need to include difficult-to-quantify considerations such as potential contributions to the global scientific knowledge base, institutional comparative advantages, alternative suppliers, improving human well-being and others. Seasoned judgment as well as improved datasets will be required. However judgment is more susceptible to human error and differences of perspective.

A particular challenge in applying judgment to non-quantifiable criteria is the minimization of bias. On the one hand, effective priority setting requires involving the experts that are most knowledgeable about the options on the table. On the other hand, those same experts are often emotionally invested in the options that they know best and perhaps depend upon for their career fulfillment. In theory, disinterested parties should be brought into the process to eliminate such bias; in practice, disinterested parties usually lack the hands-on knowledge needed to make informed judgments.

There is no perfect solution to this dilemma, but certain techniques can help to moderate the impacts of bias on the prioritization process. One is to counteract individual biases through collective judgment. A related and quite useful technique, often reducing conflict, is to compare all the options pairwise, taking collective judgment on which option is the winner vs. the loser for each head-to-head comparison. If 20 options are on the table, for example this technique involves 190 unique comparisons $[n(n-1)/2]$. The advantages of this technique include i) rather than a complex quantification of absolute priority based on insufficient data, the question becomes simple and relative: "Which of these two options is a higher priority?" and thus easier to agree upon and justify; and ii) given the large number of small discrete judgments involved, it is more difficult to 'game' this process in order to bias its outcome. Often these 'matchups' elicit discussions that reveal the weaknesses of the 'losing' option, enabling the proponents to improve them. Once the 190 comparisons have been made, the number of wins is counted for each option, resulting in a rank priority order. CRP 3.5 will explore techniques such as this in its annual priority-setting exercise.

Priority Farming Systems

Improved cultivars must be adapted to the farming systems for which they are targeted. This section describes the farming systems where the eight priority grain legumes are grown in the five target regions. Summary tables are shown here; full table breakouts by region, by crop and by farming system including poverty are in Appendix 4. Additional descriptions of the focus crops and regions are in Appendices 2 and 3, respectively.

The analysis is based on farming systems as defined by Dixon and Gulliver (2001) applied to FAOSTAT crop distribution data. Expert judgment was invoked to clarify some crop area statistics, particularly to estimate the *Phaseolus vulgaris* common bean component at 330,000 ha in SSEA (in FAOSTAT bean is a lumped category including numerous other grain legumes).

Grain legumes collectively occupy a significant portion of LIFDC farming systems (which by definition exclude large-scale commercial soybean and bean areas). **The eight CRP 3.5 crops collectively occupy 14% of the total cropped area, a larger area than maize (9%) or wheat (11%).** They are mostly grown by smallholders as mixed, rotation, relay and/or inter-crops with staple cereals or roots/tubers. The diversity of grain legume species (eight receive focus in this CRP) provides a rich resource of adaptive traits, enabling smallholders to fit them into a wide range of climatic, edaphic, topographical and farming system settings. Complex mixed systems are common in subsistence settings, while a transition towards monocropping often emerges as connections to high-value commercial markets develop.

“It is impossible to provide a succinct summary of the various cropping patterns involving legumes around the world. There are important instances where they are planted as a major sole crop, often as a component of a rotation, but many more examples involve various types of intercropping, mixed cropping and relay cropping, taking advantage of complementarities in growth habits and farm labour profiles.” – Tripp (2011)

South and Southeast Asia (SSEA)

Table 3.4 Grain legumes farming systems of South and Southeast Asia (SSEA)

Farming System	Total crop (ha)	Pulses (ha)	Groundnut (ha)	Soybean (ha)
Rice	24,990,147	1,388,935	404,018	3,207
Rice-wheat	78,250,745	5,463,072	425,669	312,564
Highland mixed	7,295,799	653,366	42,685	22,593
Rainfed mixed	73,828,571	11,442,518	3,456,211	5,700,620
Dry rainfed	12,754,535	1,365,997	699,514	395,620
Pastoral	5,079,272	534,150	459,987	1,067
Sparse (arid)	2,887,987	338,256	24,509	58

Clarification note: Following conventional practice, in these summary area tables the term ‘pulse’ refers to grain legumes mainly used for direct human consumption, as contrasted to other grain legumes used both as oilseeds and as foodstuffs (groundnut and soybean).

Extent of cultivation: SSEA is the largest producer of grain legumes among the CRP 3.5 priority regions. Groundnut, soybean, chickpea, and pigeonpea dominate legume production in SSEA (Table 3.4 and Appendix 4). FAOSTAT data on common bean area are misleading; common beans occupy a relatively small area estimated at 330,000 hectares. Grain legumes occupy up to 28% of the crop area in vast, poor rainfed mixed systems found across the region. These systems are commonly

plagued by low soil fertility and low input usage. Dry rainfed (India) and pastoral systems (India and Pakistan) follow in importance of relative area, accounting for 19 and 20% of cropped area. The extensive and fertile Indo-Gangetic Plain straddling India and Bangladesh is dominated by rice-wheat cropping systems; although grain legumes are grown on several million hectares these occupy only a small fraction of total cropped area (as indicated earlier, policies and subsidies since the Green Revolution have created economic pressures that compelled the grain legume area to shift elsewhere (Joshi 1998). Lentil is important in rice-wheat systems, rainfed mixed systems and highland mixed systems in India, Nepal, Pakistan and Bangladesh.

Relevance to poor smallholders: SSEA holds the world's largest concentration of poverty with 600 million people earning less than \$2 per day and childhood malnutrition is rampant. Poverty is mainly in rural smallholder areas where grain legumes are grown and consumed (and are especially important in protein contribution to the diets of the very poorest – see Demand section earlier). Soybean in SSEA will be excluded from CRP 3.5 attention despite its large area of smallholder cultivation due to the existence of alternative suppliers attracted by its industrial potential.

Relevance to priorities and capacities of major partners: Governments in the region prioritize increasing grain legume production to counter large imports. They also see legumes as part of the solution for improving the sustainability of rice-wheat systems. Some NARS are strong (e.g. India) but the sheer scope of poverty in this region is overwhelming. ICAR (India) is a principal partner in CRP 3.5. The regional research body APAARI and the CLAN network re key regional partners. The CGIAR can add significant value to partnerships to accelerate progress against hunger and malnutrition.

West and Central Africa (WCA)

Table 3.5 Grain legumes farming systems of West and Central Africa (WCA)

Farming System	Total crop (ha)	Pulses (ha)	Groundnut (ha)	Soybean (ha)
Irrigated	478,998	167,911	306,764	4,323
Tree crop	748,814	376,603	289,833	82,378
Forest based	543,001	90,544	399,223	53,234
Highland perennial	150,169	120,811	26,802	2,556
Highland temperate mixed	122,597	76,892	42,170	3,535
Root crop	2,630,653	983,902	1,241,758	404,993
Cereal-root crop mixed	5,356,803	2,507,703	2,701,935	147,165
Maize mixed	64,863	34,661	30,186	16
Agro-pastoral millet/sorghum.	5,592,174	3,118,536	2448,939	24,699
Pastoral	3,381,721	2,920,200	458,067	3,454
Sparse (arid)	758	718	40	0
Coastal artisanal	380,948	295,407	63,081	22,460

Extent of cultivation: Cowpea, groundnut, soybean and common bean are grown over the largest areas (Table 3.5 and Appendix 4). Priority will be placed on the predominant areas (Table 3.5) viz. cowpea predominates in pastoral and agro-pastoral millet/sorghum systems, and groundnut in

cereal-root crop mixed and root crop based systems (with significant overlap). Groundnut, known as a ‘woman’s crop’ in WCA, contributes more than 50% of their farm income in many areas. Soybean is emerging strongly in the root-crop and cereal root-crop systems. Beans are primarily found in the cereal-root crop mixed, root crop, and tree crop systems (with coffee and cocoa in Togo and Cameroon).

Relevance to poor smallholders: The systems listed above are overwhelmingly poor smallholder-cultivated and rainfed. Collectively the five farming systems above are occupied by more than 65% of the region’s poor. Cowpea areas are severely drought-stressed. Little or no fertilizer is applied except in maize-based systems; groundnut may benefit from some residual nutrients from maize.

Relevance to priorities and capacities of major partners: National partners are in considerable need of strengthening although there is variation between countries. Strategic partnerships with regional bodies AATF, CORAF, FARA and WECABREN are vital. They place a high priority on these grain legume crops.

Eastern and Southern Africa (ESA)

Table 3.6 Grain legumes farming systems of Eastern and Southern Africa (ESA)

Farming System	Total crop (ha)	Pulses (ha)	Groundnut (ha)	Soybean (ha)
Irrigated	102779	25018	77691	70
Tree crop	48518	36263	11555	700
Forest based	15359	9598	5761	
Rice-Tree crop	114862	81397	33465	
Highland perennial	1564188	1365967	119452	78769
Highland temperate mixed	680762	618330	50173	12259
Root crop	1303224	896344	405434	1446
Cereal-root crop mixed	610971	186995	423839	137
Maize mixed	4028415	2562837	1129386	336192
Large commercial	324941	56031	64265	204645
Agro-pastoral millet/sorghum	537818	221615	292793	23410
Pastoral	958854	695720	263076	58
Sparse (arid)	12049	1100	10546	403

Extent of cultivation: ESA is the most diverse region in terms of agro-ecologies and therefore requires attention to the largest number of grain legume crops among the five CRP 3.5 focus regions. In terms of area cultivated, common bean is the most important followed by groundnut, while soybean, faba bean, chickpea, cowpea, and pigeonpea are important in smaller concentrated areas (Table 3.6 and Appendix 4). Beans are important in highland perennial systems, maize-mixed systems and root crop systems. The maize mixed and root crop based systems together contain the largest area of grain legumes, in addition to beans including groundnut, pigeonpea, soybean and cowpea; followed by the pastoral and agro-pastoral systems. About 200,000 ha of soybean are large-scale commercial that will not receive priority in CRP 3.5. Faba bean and chickpea are important in Ethiopia, Sudan and Eritrea especially in highland temperate mixed, maize mixed and pastoral systems.

Relevance to poor smallholders: The maize mixed system, a priority for several grain legumes (above) accounts for about 30% of the ESA region's poor. Since economic 'structural adjustment' in the mid-1990s input use has fallen sharply, especially fertilizer and improved seed, constraining yields. Drought is a constant threat for poor smallholders who lack access to irrigation. Ethiopia's highland temperate mixed system is another large pocket of poverty. Per capita consumption and percent of dietary protein derived from legumes is among the highest in the world in several ESA countries (Burundi, Rwanda, Uganda, Kenya, Tanzania, Eritrea).

Relevance to priorities and capacities of major partners: Key regional partners are FARA, ASARECA and AATF. EIAR (Ethiopia) is a principal partner in CRP 3.5. Bean partners are networked through PABRA.

Latin America and the Caribbean

Table 3.7 Grain legumes farming systems of Latin America and the Caribbean (LAC)

Farming System	Total crop area (ha)	Pulses (ha)	Groundnut (ha)	Soybean (ha)
Irrigated	4,127,335	500,912	25,324	40,954
Coastal plantation mixed	16,347,448	1,408,428	106,779	209,760
Intensive mixed	14,453,159	1,047,626	78,549	3,466,539
Maize-Beans (Mesoamerica)	8,035,324	1,027,895	38,202	5,668
High altitude mixed (central Andes)	1,813,688	197,632	5,619	54,066
Dryland mixed	7,075,572	1,875,486	18,369	745,438

Extent of cultivation: Major systems for beans are dryland mixed, coastal plantation mixed, maize-beans, intensive mixed, extensive mixed, and irrigated (Table 3.7 and Appendix 4).

Relevance to poor smallholders: Dryland mixed, coastal plantation mixed, maize-beans, and intensive mixed systems contain the largest numbers of poor smallholder farmers in LAC. Beans are the most important grain legume in the region. The dryland mixed system is prominent in northeast Brazil and Mexico, featuring 34% poverty incidence, 37% of the total legume area; 23% of dietary iron in this area is obtained from beans. The maize-bean system in Central America is of special concern because of high incidence of childhood stunting (36%) and because it is a homologue to the mixed maize system of East Africa. Irrigated and extensive mixed have relatively fewer poor, and include considerable commercial production of beans so will not be a priority for CRP 3.5. A possible role in high altitude mixed (N. Andes) will be explored due to large numbers of poor.

Relevance to priorities and capacities of major partners: Beans are a dietary staple across the region and therefore a high priority for NARS. Brazil (EMBRAPA) is a principal partner in CRP 3.5. Capacity is decreasing in Central American NARS and requires strengthening; the emergency situation in Haiti requires special attention.

Table 3.8 Grain legumes farming systems of Central and West Asia and North Africa (CWANA)

Farming System	Total crop (ha)	Pulses (ha)	Groundnut (ha)	Soybean (ha)
Highland mixed	6,879,756	495,357	631	42,646
Pastoral	4,202,538	457,515	5,434	29,880
Sparse (arid)	2,146,328	298,342	790	16,324

Extent of cultivation: Pastoral and sparse (arid) systems host the largest proportion of grain legumes, accounting for 12 and 15% of cropped area respectively (Table 3.8 and Appendix 4). Highland mixed systems contribute to 8% of the grain legume area. Chickpea is mainly grown in the highland mixed system in Iran and Morocco, the small scale cereal-livestock and horticulture system in Turkey, the rainfed mixed system in Morocco and Syria, and in both the dryland mixed and pastoral systems in Iran and Syria. The major lentil areas are the horticulture mixed and small scale cereal-livestock system in Turkey, the dryland mixed and the rainfed mixed systems in Syria, Iran and Morocco. The major faba bean systems are the dryland mixed systems of Morocco, Syria, Tunisia and Algeria, the pastoral systems of Egypt, Morocco, and Syria, and the rainfed mixed system of Morocco and Tunisia.

Relevance to poor smallholders: Most poor are in the pastoral, highland mixed, rainfed mixed and dryland mixed systems. Cereal-livestock and horticulture mixed have fewer poor with greater participation of commercial production operations.

Relevance to priorities and capacities of major partners: Limited capacity in most of the NARS partners; strategic partnerships with Turkey (a CRP 3.5 principal partner), Iran, Syria and Morocco.

Value proposition for CRP 3.5

To quantify the return on investment in CRP 3.5, the present value of gross **benefits from a 20% yield increase over 20% of the crop area** in the focus regions and farming systems identified in Tables 3.3-3.8 by the tenth year of the program. Benefits were assumed to begin flowing after a 3-year investment period (i.e. in year three); the accrual of these benefits over the remaining seven years was simulated on a regional basis using an economic surplus empirical model for an open economy. Full details of the methodology are provided in Appendix 5.

The 20% yield increase estimate is an outcome of yield gap analysis by CRP 3.5 CGIAR center grain legume experts (Chapter 5, Table 5.3.1 and Appendix 6). Average *actual* yield in the target regions across the target legume crops (not weighted for area differences) is 0.91 t/ha (FAOSTAT). The experts estimated that a *realizable* yield with improved cultivars and optimum management on smallholder farms would be 2.63 t/ha (Table 5.3.1). The difference, 1.72 t/ha is the yield gap. The experts estimated that across crops an average 35% of that gap could be closed by farmers who adopt both improved cultivars and optimum management. This corresponds to 0.6 t/ha gap closure (0.35 x 1.72) which is a 66% increase from the current actual yield level (0.6/0.91). However the experts recognized that optimal management would be difficult for most small-scale farmers to achieve, despite the vigorous efforts of R4D and the development community. They estimated that about half of the 66% gain will probably not be realized for that reason, reducing their *plausible* gain to 33%. Recognizing that this plausible 33% gain would be the maximum achieved in year ten, with the seven prior years building from the baseline yield to ultimately reach that point, they recommended that an average 20% yield gain figure be used for the 10-year *ex ante* analysis.

The 20% area adoption estimate was also derived from expert opinion. As described previously (see Seeds of Success box article in Chapter 2), the adoption of improved cultivars of grain legumes is

often hampered by seed system bottlenecks and in the past has often languished in the 0-20% range for decades. On the other hand, success cases of adoption well in excess of 20% have been documented, some as high as 90% when seed systems receive vigorous focus (see ‘Seeds of Success’ box article at the end of Chapter 2, and ‘Our Track Record’ section later). Recognizing that CRP 3.5 will put a stronger emphasis than ever before on overcoming seed system bottlenecks, supported through major projects such as Tropical Legumes II and several others, the experts felt confident that adoption will build to at least the 20% level by the tenth year. The ex-ante analysis assumed a logistic diffusion curve pattern to reach that adoption level over the ten-year period (Appendix 5).

Two kinds of monetary benefit from the total increase in grain production were estimated: the **additional value of grain produced, and nitrogen fertilizer saved** due to BNF. The results (Table 3.9 and Appendix 5) indicate cumulative benefits of US\$2.8 billion for the grain value component and US\$271 million for the fertilizer savings component, for a **total of US\$3.03 billion in benefits**. Assuming an average annual CGIAR investment of US\$50 million over the ten years (\$500 million total) to generate these benefits, a **six-fold return on investment** is indicated over the period. As elaborated in the full table in Appendix 5, food availability will increase by 7.07 million tons and protein availability will increase by 2.12 million tons, and an additional 402,000 tons of atmospheric nitrogen will be fixed.

These projections do not include monetary evaluation of the substantial but difficult-to-quantify benefits to livelihoods resulting from improved household food security and nutrition (particularly for women and children). Nor do they include environmental benefits additional to fertilizer savings such as the value of breaking disease cycles, the value of increased yields of following crops due to soil fertility enhancement, nor the value of improved land cover and erosion protection. They also do not include benefits that will continue to accrue from these R4D investments beyond the tenth year of the program.

Table 3.9 Net present value of 20% yield increase on 20% of grain legume area over ten years (summarized from Appendix 5)

Region	Present value of gross benefits (US\$ million)								
	Chickpea	Common bean	Cowpea	Faba bean	Groundnut	Lentil	Pigeonpea	Soybean	Total
SSEA	305	0	0	0	759	51	191	0	1,306
WCA	0	81	186	0	316	0	0	27	610
ESA	19	205	11	0	121	0	26	20	402
LAC	0	262	0	0	0	0	0	0	262
CWANA	94	0	0	31	0	50	0	0	175
Total	418	548	197	31	1,196	101	217	47	2,755

Why a Consortium Research Program on Grain Legumes?

CRP 3.5 GRAIN LEGUMES partners have been working independently on grain legumes for decades. Why join forces now?

Improve our interface with partners

At present all four CRP 3.5 Grain Legume CGIAR Centers interface independently with partners on different crops at global, regional and sub-regional scales. Partners find this confusing and burdensome. Many have a single, often under-resourced office or program handling all legume crops. They feel overwhelmed by the multiple interfaces that they are expected to maintain and meetings they are expected to attend with numerous external institutions. Streamlining and

harmonizing this interface will significantly improve the effectiveness and efficiency of communication, collaboration and advocacy. To give just one of many important examples, evidence to inform decision-makers as they seek greater regional harmonization of seed policies will be far more compelling and effective if presented across crops by solid regional R4D partnerships speaking with a unified voice.

Cross-learn in priority R4D domains

Important learning can be gained by sharing expertise across crops, regions and partnerships. Grain legume crops are genetically related and therefore exhibit synteny at the genetic and genomic levels and consequently functional similarities at physiological and phenotypic levels. Studies of these comparisons/contrasts offer a potential gold mine of useful learning. Can the high drought tolerance of cowpea and chickpea teach us how to enhance these traits in common bean and soybean? Can the high BNF capability of soybean, groundnut, chickpea, lentil and faba bean indicate ways to improve that trait in other grain legumes? How can high-yielding features in soybean teach us ways to improve yield in low harvest-index (highly vegetative) legumes? Beyond the crop production stage, many other cross-lessons could be learned about partnership innovations, successes/lessons in collective action in value chains, opportunities for novel products and markets, and others.

Share expertise and facilities

Centers have established specialized, costly facilities and expertise for different activities and in different regions. By joining forces they can share these assets to leverage higher value from them. To name just a few complementary strengths (see **Appendix 1** for a fuller exposition), CIAT has high capacity in geospatial mapping, seed systems, nutrition and disease diagnostics; GCP partners in molecular and functional genetics; ICAR in locational testing in the main grain legume zone of India; ICARDA in geospatial targeting, seed health, seed systems and rhizobium R4D; ICRISAT in root studies for drought tolerance, rapid-throughput genomics, and public-private partnerships; and IITA in host-rhizobium interactions, post-harvest processing, value chain analysis and advocacy.

CRP 3.5 GRAIN LEGUMES will provide a mechanism for generating added value through cross-sharing these strengths. Some specific opportunities that will be explored during the CRP timeframe (2012-20) include:

- Sharing ICRISAT's drought and root phenotyping field facilities,
- Sharing CIAT's drought screening field facilities in Tanzania and Malawi,
- Sharing BNF and Rhizobium research facilities at ICARDA,
- Joint research at CIAT on mechanisms that trigger the shift from vegetative to reproductive stage,
- Applying ICARDA's Focused Identification of Germplasm Strategy (FIGS), the GCP's reference set and ICRISAT's core and mini-core approaches to improve the likelihood of finding traits of interest in germplasm collections,
- Utilizing the molecular genomics facilities for legumes at ICARDA and ICRISAT,
- Multi-crop phenotyping for salinity screening using high-throughput hydroponic systems at ICARDA, and
- Doubled haploid production technology at ICARDA.

Our track record

Despite the constraints facing grain legumes described earlier, CRP 3.5 GRAIN LEGUMES partner institutions have achieved impressive impacts in important production systems, as illustrated by the twelve success cases below.

Climbing bean in Rwanda and Eastern and Southern Africa

Largely as a consequence of 25 years of research by CIAT and national partners, Rwanda has gone from hunger-inducing shortages of beans to producing surpluses for export. Consumers in the Great Lakes Region of Eastern and Central Africa eat beans at one of the highest rates in the world, around 60 kg per capita per year. Climbing bean varieties had been adapted only at high elevations in the country. CIAT introduced germplasm capable of tripling yields in mid-altitude environments. Within a few years, adoption rates reached 90% in the target areas (David et al. 2000). Today the Rwandan research program has matured and is producing its own improved varieties for home consumption and for high-end markets. Farmers are harvesting 2-4 tons per hectare, well above averages for other parts of Africa.

Drought tolerant beans poised for impact in Nicaragua and Rwanda

In 2000, CIAT plant breeders in Colombia made drought tolerance the centerpiece of their efforts to improve small-seeded Meso-American bean types farmers grow in difficult environments. Many of these lines have now been released in Nicaragua and Rwanda (three are pending release in Malawi). These materials represent the first drought-resistant bean varieties developed and released for the warm tropics (Beebe et al. 2008). Farmers recognize the difference; in Nicaragua they pointed out how the new variety uniformly fills its seeds under drought. In Malawi, on farm trials demonstrated a yield advantage of over 50% (TL II 2011). This highlights the potential for farmer participation in selection as more attention is focused on abiotic stress in the face of climate change.

High returns on cowpea research in Africa

The net present value of benefits from investments in cowpea research and extension convened by IITA over a 20-year period is estimated at upwards of US\$ 1.09 billion with an internal rate of return ranging between 50–103 percent (Kristjanson et al. 2002).

Emerging market-oriented pigeonpea enterprise in Northern Tanzania

Fusarium wilt-resistant, seasonally-adapted varieties of pigeonpea adopted on 25,000 hectares in northern Tanzania have tripled yields and created a thriving export market, producing an additional 1.3 tons per hectare or 33,000 total extra tons - delivering approximately US\$33 million in extra value to impoverished farmers (Shiferaw et al. 2007; Shiferaw et al. 2008a). Usually intercropped with maize, pigeonpea also increases the resilience and productivity of that vital cereal crop through biological nitrogen fixation and natural weed control.

World's first hybrid grain legume: pigeonpea in India

ICRISAT and Indian partner's creation of the world's first hybrid variety of a food legume, pigeonpea is on the cusp of major impact (Saxena and Nadarajan 2010). These CMS (cytoplasmic male sterile) hybrids increase yield by an average of 33% in on-farm trials, adding about US\$400 to net income per hectare. They are expected to revolutionize the production of this high-protein 'poor people's meat' crop across India, Myanmar and China in the coming years.

Chickpea earning export income for Ethiopia

Improved varieties from the CGIAR combined with effective extension by the national program EIAR in East Shewa Zone of Oromia region, Ethiopia are increasing chickpea yields by 90% (2003-05 average compared with 2008) and a 40% increase nationwide (Dar et al. 2010). Total production doubled to 312,000 tons from 2003-05 to 2008, multiplying chickpea export earnings 26-fold, from US\$1 million in 2004 to US\$26 million in 2008.

Drought & heat-tolerant chickpea in southern India

Earlier-maturing, heat tolerant high-value chickpea varieties from ICRISAT, particularly JG11 have more than doubled yields, from 600 to 1400 kg/ha in Andhra Pradesh state, India, stimulating a fourfold increase in sown area from 160,000 to 630,000 hectares (ICRISAT 2010). The added value of

grain is US\$69 million annually reaped by 6 million people in rural farm households.

Winter chickpea takes hold in CWANA

Research on winter chickpeas by the Syrian national research program and ICARDA created the elements for significant increases in production of this important crop (Mazid et al. 2009). Until recently, farmers in CWANA avoided winter sowing to reduce the risk of severe winter weather and *Ascochyta* blight disease. Improved winter varieties have now been widely adopted, particularly by poorer farmers. Yield increases compared with spring-sown chickpea ranged from 33 to 61 percent and net farm income rose by US\$220.

New groundnut (peanut) variety spreading in the world's largest groundnut cultivation area

In Anantapur, India where over 50% of farm income comes from groundnut. The new variety ICGV 91114 from ICRISAT increases yield by 23% and is more drought tolerant with higher-value large seeds, more uniform harvest maturity, disease tolerance and greater palatability of haulms (straw) for livestock. An estimated additional 42,000 t of groundnut is being produced annually, worth US\$3.7 million to 30,000 farm households (150,000 people). Net income from this crop increases by 35% on the average 1.5 ha groundnut field area per farmer, worth \$110 extra US dollars. Cows fed with these haulms also produce 11% more milk. Impact is projected to increase to 35% of the 0.75 million hectares of groundnut in Anantapur by 2020 (Birthal et al. 2011).

Lentil boom in South Asia and Ethiopia

Over the last 30 years South Asian lentil production has doubled, reaching 1.27 million tons. The increase is due equally to productivity growth and area expansion. The driving factor is farmer adoption of short-duration, disease resistant varieties developed by ICARDA in partnership with India, Nepal, and Bangladesh (Aw-Hassan et al. 2009; Aw-Hassan et al. 2003). Annual economic gains are estimated at US\$ 30 million in Bangladesh and US\$ 42 million in Nepal. Impact is also reported in Ethiopia with a 150% increase in production and 73% increase in area under cultivation.

Spotlight on Nutrition

The CGIAR Strategy and Results Framework (SRF) declares the alleviation of under-nutrition to be one of the four System Level Objectives, raising this issue to the top level of the Systems' agenda for the first time. Under-nutrition problems are particularly common in populations that consume less than 2000 kcal/capita/day, which includes most of the poorest populations that subsist largely on the least expensive root and grain food sources (Welch and Graham 2000). Such poor populations often obtain more than 50% of their dietary energy from cereals, roots and tubers because these are the least expensive foods, unknowingly inducing a nutritional imbalance ("hidden hunger" – IFPRI 2011a). Grain legumes offer important opportunities for improving dietary nutrition, as described below.

Micronutrients

Iron deficiency is the most widespread nutritional problem, affecting between 4 and 5 billion people (SCN, 2004) with 1.62 billion suffering the extreme state of iron deficiency anemia (WHO 2008). The prevalence of anemia among children is 69% in Africa, 66% in South Asia, 47% in the Eastern Mediterranean, and 29% in the Americas (WHO, 2008; while noting that not all anemia can be attributed to iron deficiency). Legumes are sources of important minerals, especially iron and zinc (Welch and Graham, 2000). Mexican school children consuming high iron beans exhibited improved iron status compared to those consuming beans with average levels of iron (Haas et al. 2010). Iron-rich beans for Africa are being bred through the HarvestPlus Challenge Programme.

Protein

Generally, populations that source over 50% of their protein from cereals, roots and tubers – as is the case for most of the poor in the developing world - are plagued by protein malnutrition, especially in populations subject to high levels of infection (Ghosh et al, 2012; Pellet 1996). Legumes contain 2-4 times more protein than cereals (i.e. 8-12% vs. 20-40% with soybean the highest), so dietary supplementation with legumes can significantly alleviate protein deficiency.

This opportunity is even more compelling when protein quality is considered. Low lysine content relative to human amino acid balance is the limiting constraint in cereal-dominated diets. Legumes are superior sources of lysine, thus increasing the biological value of the combined protein. The current WHO-endorsed index for protein quality is the protein digestibility-corrected amino acid score (PDCAAS). Experts recommend that foodstuffs of at least 70% PDCAAS score should be consumed (Michaelsen et al. 2009). The PDCAAS values of cereals are around 35%, indicating their

low protein quality when consumed in isolation. Grain legume PDCAAS ranges from 45-93% with soybean the highest in quality. By combining cereals with legumes in the proportions of 70/30 (weight/weight), this PDCAAS threshold can usually be reached or exceeded (this will vary across cereal/legume species and the desirable amino acid spectrum will also depend on the age and health of the consumer) (Ejigui et al. 2007; Michaelsen et al. 2009).

Milk is an excellent protein source, but the cost of protein from milk powder is 5-10 times higher per unit weight of protein than the cost of protein from cereals or legumes (Michaelsen et al. 2009). If the low protein quality of cereals is improved by combining them with legumes as discussed above, the cereal-legume combination provides a nutritionally acceptable protein at one-fifth or less the cost of the same amount of protein sourced from milk. (Nevertheless milk is a nutritionally superior food, especially for children, whenever it can be afforded). Humanitarian organizations provide a vitamin-enriched maize-soy flour blend (UNIMIX, 30% maize:40% beans, 10% milk powder, 10% oil, 10% sugar) to moderately-malnourished children (Michaelsen et al. 2009); home-based mixes have also been proposed such as sorghum/groundnut (Oumarou et al. 2005) and pearl millet/soy (Ali et al. 2009).

Fats (oil)

Fat is energy-dense, thus valuable in increasing energy intake when appetites are reduced as is common with malnourished people. Fat shortages in the diets of the very poor are of increasing concern (Michaelsen et al. 2009). Cereals provide very little fat, but two grain legumes stand out: groundnut (40% oil) and soybean (22%). Oil creates the viscosity of peanut butter, contributing to its highly preferred taste and increased intake by the poor; along with high protein content, this is a major reason that groundnut is a main ingredient (25%) of the most popular ready-to-use therapeutic food (RUTF) formula administered by the World Food Programme and others for severe childhood malnutrition. Michaelsen et al. (2009) suggest that in addition to breast milk fat, at least 20-25% of dietary energy in complementary foods fed to very young children should be sourced from fats; for those not consuming breast milk, 35-45% of dietary energy sourced from fat is recommended. Fat is also important for the absorption of fat-soluble vitamins such as vitamins A, D and E.

Increasing attention is being paid to the balance of essential fatty acids within food sources. Shortages of omega-3 (alpha linolenic) acid is of especial concern, because it is insufficient in most plant foods and the poor have difficulty affording fatty fish sources; the body cannot synthesize alpha-linolenic acid and deficiencies, particularly when young can impede brain and cognitive development, and are associated with inflammatory diseases. Cereals are insufficient in omega-3 fatty acids, whereas soy oil is a good source (Michaelsen et al. 2009).

Yet another fat-related issue is the balance between omega-9 (oleic, monounsaturated) and omega-6 (linoleic, polyunsaturated) fats. A high O/L ratio increases shelf life, an important issue under tropical conditions of grain and processed product storage.

Vitamins

Vitamin A enhancement of sweet potatoes, maize, cassava and rice has been advanced through the HarvestPlus Challenge Program but has not been tackled for grain legumes. Vitamin A is fat-soluble and in principle its enhancement should be feasible the oil-rich legumes groundnut and soybean as well. Besides increasing the capacity of the seed to hold soluble beta carotene, the consumption of oil occurs automatically when groundnuts are eaten so that chances for absorption in the gut are maximized.

Anti-nutritional compounds

The most important compound interfering with nutrient uptake in the gut is phytate, both for cereals and legumes (Michaelsen et al. 2009). Iron, zinc, and phosphorus availability is reduced in the diets of cereal and legume consumers by phytate. Soaking, sprouting and fermenting legume grains stimulate the production of phytase enzyme which breaks down phytate, improving nutrient availability. Biotechnology may find ways of reducing phytate activity and/or increasing phytase activity in the future (Raboy 2007).

Obesity, cancer, heart disease and HIV/AIDS

The SRF also calls attention to the growing issue of chronic diseases associated with calorie-rich but nutrient-poor diets (Burslem 2004 and Tanumihardjo et al. 2007). Grain legumes exhibit low glycemic index thus reducing the risk of obesity and diabetes (Foster-Powell K. et al. 2002). Grain legume consumption also has positive effects on colon and breast cancer (Correa 1981; Hangen and Bennink 2003; Thompson et al. 2008) and cardiovascular disease (Kabagambe et al. 2005). Preliminary tests with HIV/AIDS victims fed grain legumes shows an increase in cell counts of CD4 cells, a primary element of the immune system (M. Bennink, personal communication).

4. Impact Pathway

Impacts of agricultural research and development involve a multitude of partners, institutions and other external factors. To ensure a focus on impact, CRP 3.5 GRAIN LEGUMES research and development activities will be guided by an impact pathway framework. It is a description of the process by which the research inputs will lead to outcomes and ultimate impacts. The three major processes in the impact pathway include the development and delivery of outputs, effective partnerships in achieving outcomes, and engagement of smallholder legume farmers in Asia, Africa, and Latin America that will lead towards impacts.

The overall impact pathway of CRP GRAIN LEGUMES is illustrated in Figure 4.1. It highlights the six strategic objectives as major areas of R4D investments and provides a detailed presentation of the main outputs, research and development outcomes, and impacts¹. The implementation of the strategic objectives leads to outputs that are the products of partnership between CG centers, ARI's and NARES partners, including the private sector. The implementation of the strategic objectives is linked, and are mutually reinforcing (see Fig. 5.2). Better availability and utilization of genetic resources contributes to more efficient breeding programs that generate a steady flow of improved varieties. Improved varieties will give greater benefits where they are disseminated through improved seed systems. Improved varieties, crop management practices, better seed systems, and integrated nutrient and pest management are all complementary innovations that allow grain legumes to be intensified by smallholder farmers for greater production and productivity. Farmers will be able to capture a greater share of the higher production through participation in value chains at appropriate entry points. Value addition and processing technologies will enable higher value capture by the smallholder farmers particularly women. Innovative partnership models will be developed and piloted to empower stakeholders along the value chain.

The research outcomes generated from the outputs will feed into development outcomes. As illustrated in Figure 4.1., changes in behavior, practices and capacities by the immediate users of the outputs is a necessary step for achieving the development outcomes/impacts. For example, development partners will adopt better seed systems to ensure timely availability, accessibility and affordability of improved seeds. As well Agri-Business incubators (ABI) will speed up the commercialization of value added products. Farmers' involvement in participatory varietal selection (PVS) will facilitate the selection of improved varieties that fit in their fields and growing conditions and socio-economic environment. In addition to PVS, field days, farmers' fairs, training programs and use of electronic and print media will further enhance awareness, access to knowledge and empower farmers. Researchers will receive feedback information from intermediaries and end users. This in turn will be translated into mid-term corrections or redirection of research targets and outputs.

CRP GRAIN LEGUMES will achieve its impacts through six interdependent and linked strategic objectives. The knowledge and technologies developed through the Strategic Objectives will be shared with all the stakeholders periodically in order to update and enhance the uptake process and finally the impacts. Participation in the value chains will ensure higher benefits. The innovation platform ensures free flow of information and delivery systems among all stakeholders working towards the common goal. These outcomes in turn will contribute to: (i) increased incomes; (ii)

¹ The description of the impact pathways for each of the objectives is provided in Chapter 5 on Strategic Objectives. Each strategic objective includes products/outputs (e.g. genetic and genomic resources, improved grain legume varieties, crop management technologies, value added products, processing, post-harvest technologies, information exchange, capacity building tools, etc.) with linkages to different research outcomes.

improved food security; (iii) improved health, nutrition; (iv) and reduced environmental and resource degradation.

Adoption is a pre-condition for impacts. The major determinants of adoption and impact of grain legume technologies by farmers include: farmers' access to information and awareness of improved varieties and crop management technologies; availability and accessibility to new technologies (seed and inputs); market access and opportunities (performance of input and output value chains); and access to credit and other policies to enable farmer investment in new technologies. Effective research-for-development partnerships and linkages in the impact pathway—as defined in Table 4.1—will ensure that various development partners will facilitate farmer access to information and innovations to stimulate adoption and scaling up of successful innovations.

A few case studies on adoption constraints and success stories of adoption and impacts in grain legumes are given below. (Also see **Appendix 10** on Assessment of Production Constraints, Progress and Barriers to Adoption). A scoping study conducted on the impacts of food legume research in the CGIAR by Tripp (2011) indicated that the uptake and impact of legume technology is less well documented than is the case for some other major staples because of several factors related to the relative importance of legumes and the mechanisms for promoting legume technology and particularly the limitations of national seed systems for diffusing new varieties. The scoping study concluded that the adoption of modern varieties of grain legumes is low in most cases.

A study by Bhatia et al. (2006) indicated that farmers' knowledge of improved technologies is a significant factor in explaining the level of adoption. Similar results were observed for groundnut varieties in West Africa (Ndjeunga et al. 2008), pigeonpea varieties in Tanzania (Shiferaw et al. 2008a), and cowpea varieties in Nigeria (Kristjanson et al. 2005). Various social and economic factors such as farmers' preferences, risk perceptions, and access to inputs and markets were noted in Ndjeunga and Bantilan (2005). In addition to lack of awareness to improved varieties, the absence of an adequate seed system was found as the most serious bottleneck for the diffusion of new legume varieties (Sperling et al. 1996; Phiri et al. 2000, Tripp 2011). Bishaw et al. (2009) reiterated that the combination of poor public-sector performance and lack of private-sector interest has led to a void in seed supply systems that needs to be filled.

The near absence of formal seed production for many legumes has meant that new varieties face greater challenges. The idea that 'a good new variety sells itself' is only very partially true for legumes. New legume varieties do spread from farmer to farmer (Grisley and Shamambo, 1993; Kormawa et al, 2004; Alene and Manyong 2006b), and grain markets, which are a very important seed source for many legumes, can help dissemination of a new variety (Jones et al. 2001; Tripp et al. 1998; David, 1997). Participatory methods have now been advocated since they are supposed to improve relevance and adoption of technologies (Chamango 2001; Snapp et al. 2002).

Despite the above cited constraints, there are some successes in the adoption of improved cultivars and technologies of legumes across crops/regions. One of the successful examples is from the Tropical Legumes-II project where inadequate availability of seed was identified as a major constraint in adoption of improved cultivars by farmers in sub-Saharan Africa and India. The project partners put high emphasis on improving seed systems. Nearly 93,000 metric tons seed of groundnut, common bean, cowpea, chickpea, pigeonpea, soybean was produced across target countries during 2007-2010. This amount is enough to plant an estimated 2 million ha, equivalent to about 1 million smallholder households. <http://www.icrisat.org/tropicallegumesII/pdfs/BTL4-2011.pdf>). Strengthening of both formal and informal seed systems was the key factor for enhancing availability of quality seed in TL-II project countries.

There are several other examples where concerted efforts of research and development organizations have enhanced the awareness of farmers about improved cultivars and the strengthening of seed systems led to rapid adoption of improved cultivars leading to impacts on crop productivity. A few examples are listed below, to indicate the lessons learnt and how these can enhance adoption and impacts in CRP GRAIN LEGUMES.

- Short-duration chickpea varieties developed through ICRISAT-Indian NARS partnership were adopted in >90% of the area within a period of 10 years in Andhra Pradesh state of India. The chickpea area in Andhra Pradesh was 163,000 ha during 1999-2000 and 90% of this area was under a 4-decade old desi chickpea variety Annigeri. During the past 10 years (1999-00 to 2008-09), the chickpea area has increased from 163,000 ha to 628,000 ha and production has increased from 95,000 tons to 884,000 tons. The increase in productivity from 580 to 1400 kg/ha during this period is most remarkable (ICRISAT 2010). The availability of high yielding, short-duration and heat tolerant varieties suited to short-season environments of Andhra Pradesh; knowledge empowerment of the farmers about improved varieties and improved production technologies; and strong partnership of research institutions with public seed sectors and farmers/farmers' groups were the key factors for high adoption of improved chickpea cultivars in Andhra Pradesh.
- The adoption of improved chickpea varieties developed through partnership of ICRISAT and Myanmar NARS has been very rapid in Myanmar. During 2004-05, these improved varieties covered about 82% of total chickpea area. The short-duration kabuli chickpea variety Yezin 3 (ICCV 2) was the most popular variety grown in about 55% of area. The adoption of improved varieties and improved crop production practices has led to remarkable increase in chickpea yields and production in Myanmar. During 1995-96 to 2004-05, the chickpea area in Myanmar increased by 23.5% (from 166,000 to 205,000 ha), production increased 2.6 times (from 92,000 t to 239,000 t) and yields almost doubled (from 588 to 1171 kg ha⁻¹) (Than et al. 2007). Availability of short-duration high yielding varieties well-adapted to short-season environments of Myanmar and farmer-to-farmer exchange of seed facilitated by researchers and developmental agencies are the key factors for rapid adoption of improved chickpea varieties in Myanmar.
- The strategy of producing and selling small seed packs of new bean varieties in Malawi has been quite successful in improving smallholder farmers' access to seeds of new bean varieties (Phiri et al. 2000, Chirwa et al. 2007). The small seed packs sold fast because they were affordable, making it easy to reach many farmers in the rural communities. Farmers were willing to try new varieties with minimal investment. The common bean seed system was further adopted under Tropical Legumes II project. The improved varieties reached over 1 million farmers with small pack seed distribution during the last three years in Ethiopia (ca. 465,000) and Kenya (ca. 637,000) <http://www.icrisat.org/tropicallegumesII/pdfs/BTL4-2011.pdf>. The key factors for success include: (1) affordability (in terms of cost) and accessibility (in local markets and shops) of seed, (2) increased awareness of improved varieties, especially targeting women, (3) assured seed quality (certified and/or truthful label seed), and (4) involvement of private sector seed companies and local traders where it created business opportunities.

- A project supported by IFAD and implemented by ICARDA in collaboration with national programs in Egypt, Sudan and Ethiopia focused on enhancing adoption of improved cultivars and production technologies of faba bean, chickpea and lentil. Adoption levels varied widely, within and between countries, between different technologies, and between different components of a 'package'. Most farmers tended to adopt specific components (particularly improved variety, sowing method, and pest control) rather than the complete package. But there was substantial adoption of complete packages in areas with relatively higher-input or intensive agriculture. The ICARDA-IFAD project made substantial impacts on crop productivity, food security, farm income and poverty in each of the target countries. (ICARDA, Impact Brief No.3, 2008). Key elements of success included enhanced collaboration of researchers with extension personnel in each country, increase in seed availability by research organization, and creating awareness of the role of food legumes in crop rotations and in household nutrition.
- A new drought and Ascochyta blight tolerant kabuli chickpea variety, Gokce, developed by ICARDA, in collaboration with Turkish national scientists, was adopted by Turkish farmers. In most areas where wheat, barley, and other crops have failed, chickpea variety Gokce's yield was high. As adoption of cv. Gokce expanded, the average yield of chickpea in Turkey increased from 860 kg per hectare in 2000 to 1070 kg per hectare in 2006. Chickpea is now grown in about 600,000 hectares in Turkey. The availability of quality seed of drought tolerant variety due to seed multiplication efforts by the Exporters' Union Seed and Research Company (ITAS) were the drivers of success for wider adoption and impacting farmers' income (New Agriculturist: <http://www.new-ag.info/07/05/brief.php>; African Agriculture: http://www.africanagricultureblog.com/2007_09_01_archive.html.)
- Research on winter chickpeas technology by the Syrian national program and ICARDA was responsible for significant increases in production of chickpea (Mazid et al. 2009). A study in early 2006 indicated that improved winter chickpea varieties have been widely adopted (ranged from 33% to 61% across all provinces), and most farmers have also adopted some components of the recommended crop management package. Growing winter chickpea varieties with improved farming practices was more profitable than with traditional practices leading to an increase in farm income by US\$220 per hectare. The success of the technology is attributed to the availability of Ascochyta blight and cold tolerant varieties and the General Organization of Seed Multiplication (GOSM), Syria enhanced the awareness and seed availability through mass media and extension services.

There are also examples of successes in enhancing adoption and realizing impacts of improved crop and pest management practices of grain legumes. Major success has been achieved in Senegal with the introduction of 'triple bag storage', using PICS (Purdue Improved Cowpea storage) several layers of thick plastic bags to minimize the damage by bruchids (Boys et al. 2007). The method is also being promoted in other West African countries (Moussa et al. 2009). Examples of legume IPM programs include those for cowpea in Benin (Nathaniels, 2005), groundnut and cowpea in Uganda (Bonabana-Wabbi 2002), pigeonpea and groundnut in India (Tripp and Ali 2001), chickpea in Nepal (Pande et al. 2005), and common beans in Nicaragua.

CRP3.5 is designed to address the above cited constraints and build on lessons learned from successes. Fueled by the drivers of change, the proposed impact pathway will accelerate the adoption of improved technologies and innovations by increasing farmers' awareness, improving access, availability and affordability of quality seed. Improved grain legume value chains will lead to enhanced local capacity to manage production and market risks and generate new opportunities for employment. Focused gender and capacity building activities will lead to increased national capacity for technological and institutional innovations and accelerated translation of outputs to impact. These will progressively lead to economy-wide social and environmental impacts that contribute to sustainable intensification, poverty reduction and food security in the face of population growth and climate change.

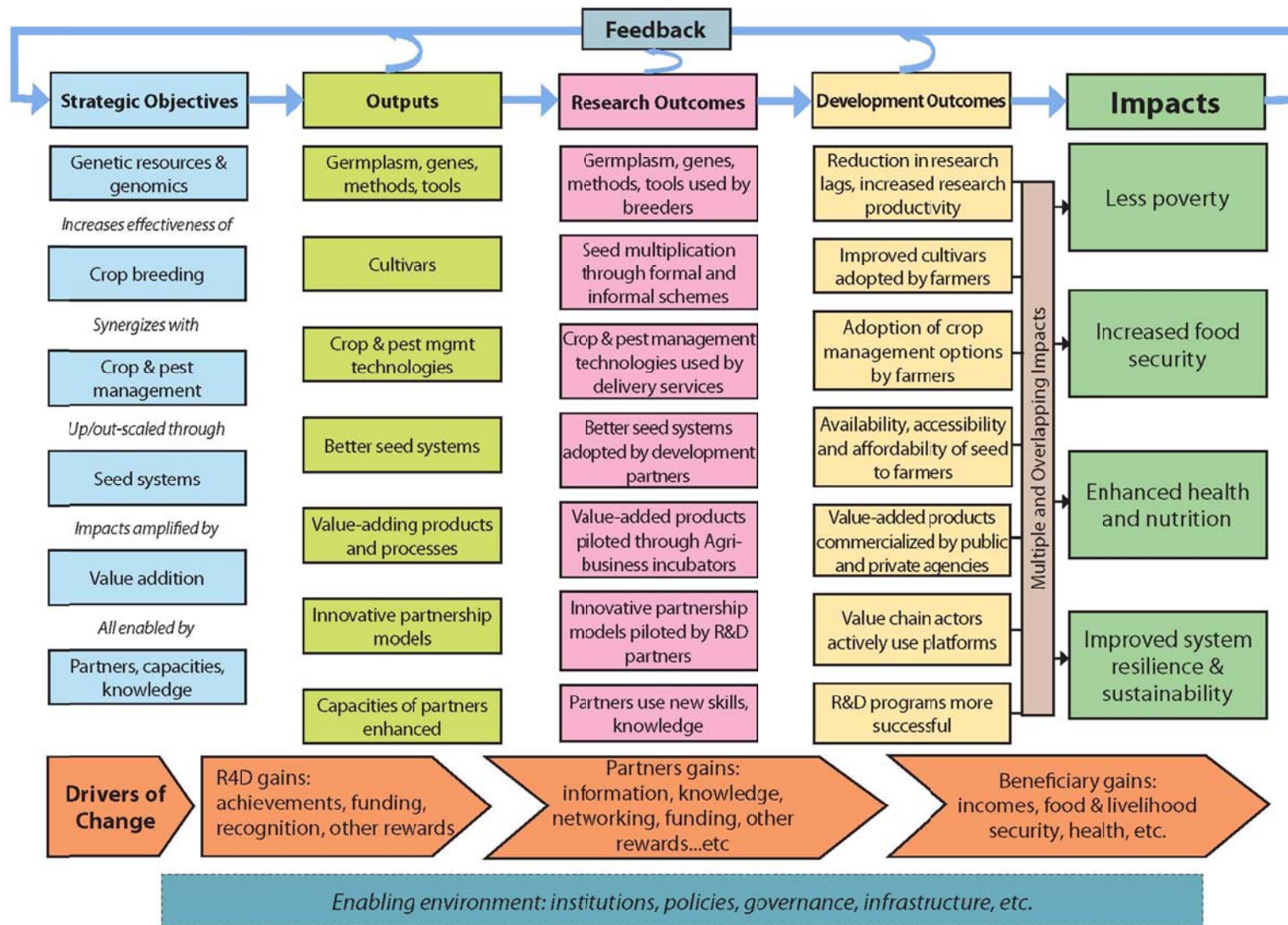


Figure 4.1. CRP 3.5 Grain Legumes Overall Impact Pathway

Table 4.1. CRP 3.5 GRAIN LEGUMES impact pathway - translating outputs into outcomes and impacts

OUTPUTS (Products of GRAIN LEGUMES investments)	OUTCOMES (Conditioning factors for primary impacts)	PRIMARY IMPACTS (Adopter level changes)	UPSCALING (Conditioning factors for secondary impacts)	SECONDARY IMPACTS (Economy-wide changes)
<p>New varieties and improved seed systems</p> <ul style="list-style-type: none"> • Trait-specific germplasm • Efficient breeding methods • High yielding varieties • Dual-purpose (food/feed) varieties • Pest and disease resistant varieties • Drought tolerant varieties • Heat tolerant varieties • Nutritious varieties 	<ul style="list-style-type: none"> • NARS partners adapt the new varieties to local conditions • NARS, NGOs, and CBOs integrate new variety information and make it available to farmers • Community-based seed producers (linked to seed companies) produce improved seed • Private sector as well as public programs provide fertilizer and other complementary inputs • Farmers adopt new varieties 	<ul style="list-style-type: none"> • Increased yields • Area expansion • Increased production • Reduced cost of production • Increased marketable surplus • Diversified diets • Reduced vulnerability (risk) from disease and pest attack • Increased profitability 	<ul style="list-style-type: none"> • Strategic public investments in market infrastructure to induce private sector participation in input supply • Increased participation of community-based seed producers that are linked to seed companies for production and wider diffusion of new varieties • Improved market opportunity for farmers • Information flow and knowledge and demand creation through extension • Up-scaling of new varieties across impact target domains through public and private sector partners 	<ul style="list-style-type: none"> • Increased production for home consumption and food security • Increased farm household income • Reduced vulnerability to drought as well as pest and disease pandemics • Increased adaptation to climate change • Improved nutritional security for women and children • Increased supply and reduced food prices that increase real incomes and make food more affordable to the poor • Employment and income(owing to Increased production) generation • Reduced poverty
<p>Improved management practices for system resilience</p> <ul style="list-style-type: none"> • Integrated pest management • Integrated soil fertility management • Improved crop management 	<ul style="list-style-type: none"> • NARS partners adapt improved crop management practices • Extension systems demonstrate recommended practices for adoption by farmers • Seed producers, agro-dealers, and credit agencies provide farmers with access to seed, fertilizer, and other inputs 	<ul style="list-style-type: none"> • Increased yields (e.g. closing the yield gap) • Reduced pest pressure • Improved land quality • Reduced input use (labour, fertilizer, pesticides, etc.) • Reduced cost of production (e.g. from reduced fertilizer use owing to crop rotation) • Increased marketable surplus • Increased profitability 	<ul style="list-style-type: none"> • Improved market opportunity for farmers • Access to credit to catalyse farmer investment in IPM & soil fertility management • Wider delivery of key inputs (fertilizer, inoculants, etc.) by the public and private sectors • Strategic public investments in market infrastructure to induce private sector participation in input supply 	<ul style="list-style-type: none"> • Increased production for home consumption and food security • Increased farm income • Increased system resilience (e.g. reduced land degradation and pest and disease pandemics) • Increased supply and reduced food prices that increase real incomes and make food more affordable to the poor • Reduced poverty

OUTPUTS (Products of GRAIN LEGUMES investments)	OUTCOMES (Conditioning factors for primary impacts)	PRIMARY IMPACTS (Adopter level changes)	UPSCALING (Conditioning factors for secondary impacts)	SECONDARY IMPACTS (Economy-wide changes)
<p>Value chains, institutional innovations, and policy advocacy</p> <ul style="list-style-type: none"> • Processing and storage methods for product quality and safety • Knowledge of end-user preferences and product demand through participatory evaluation of alternative technologies and products involving the actors along the value chain • Approaches to more inclusive value chain development (e.g. collective marketing, PPP mechanisms, etc.) • Advocacy strategies for influencing policy and creating demand for grain legumes and grain legume products 	<ul style="list-style-type: none"> • A range of efficient legume processing and storage technologies evaluated and adapted by NARS, NGOs, and private sector partners • NARS and private sector partners apply knowledge of end-user preferences and product demand to meet end-user preferences, and to determine the market size for new products • NARS, NGOs, and other agencies adapt alternative mechanisms for value chain development for achieving both equity and competitiveness • Government agencies and NGOs access and use information and tools contained in promotional materials to launch awareness programs for grain legumes and products • Farmers and other actors along the value chain adopt household level as well as industrial processing and storage technologies 	<ul style="list-style-type: none"> • Diversified diets and improved nutrition for actors adopting improved post-harvest and processing technologies • Better producer/farm gate prices owing to increased market access and more efficient value chains involving lower marketing margins • Increased and more stable household incomes for farmers as well as other actors along the value chain 	<ul style="list-style-type: none"> • Expanded market outlets/opportunities for grain legumes and grain legume products • Strategic public investments in market infrastructure to induce private sector participation in storage, product development, and marketing • Increased access to business finance (e.g. microfinance institutions) for the development of small and microenterprises • Information flow and awareness/demand creation through product promotion using popular media 	<ul style="list-style-type: none"> • Improved food security (owing to improved storage and reduced losses) • Improved nutrition security (owing to diversified diets and improved nutrition) • Increased employment and income generation (owing to increased postharvest storage and product development activity) • Lower consumer prices for grain legumes (owing to more efficient value chains involving lower marketing margins) • Reduced poverty

5. GRAIN LEGUMES Strategic Objectives

CRP 3.5 GRAIN LEGUMES is focused on integrated legume improvement (that includes enhanced use of genetic resources and novel breeding methods/ tools, and efficient seed systems), cropping systems (improved crop, pest and disease management), and post-harvest technologies (improved harvest, storage, processing, value-addition and markets); and involves active collaboration with other CRPs such as CRP1.1, CRP 1.2 (production systems), CRP 5 (land and water management), CRP 2 (policies, market access and prices), CRP 4 (nutrition and health), and CRP 7 (climate resilience), as depicted in Figure 5.1.

Overview of GRAIN LEGUMES Strategic Objectives

In order to deliver the desired outcomes and impacts, CRP 3.5 GRAIN LEGUMES is organized around six Strategic Objectives that are interrelated (see Figure 5.2). Genetic/genomic resources/tools and novel breeding methods developed in Strategic Objective 1 will provide inputs to Strategic Objective 2 to produce higher yielding and more nutritious grain legume cultivars; and developing sustainable crop and pest management practices (Strategic Objective 3). Information on value addition opportunities in Strategic Objective 5 will help Strategic Objective 2 to refine breeding objectives to develop cultivars with market preferred traits to ensure rapid adoption. Strategic Objective 2 and Strategic Objective 3 will provide inputs for Strategic Objective 4 on developing efficient seed production and delivery systems.

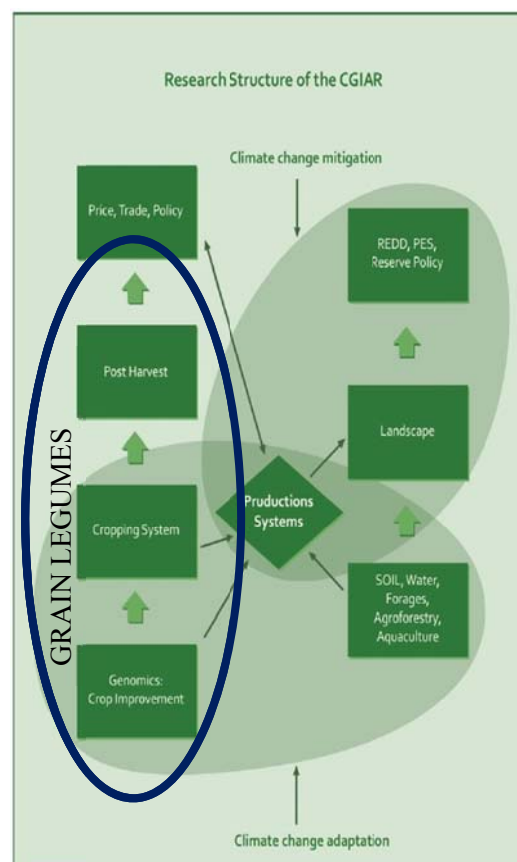


Figure 5.1. Focus of GRAIN LEGUMES in the overall research structure of the CGIAR (figure borrowed from CGIAR Strategy and Results Framework)

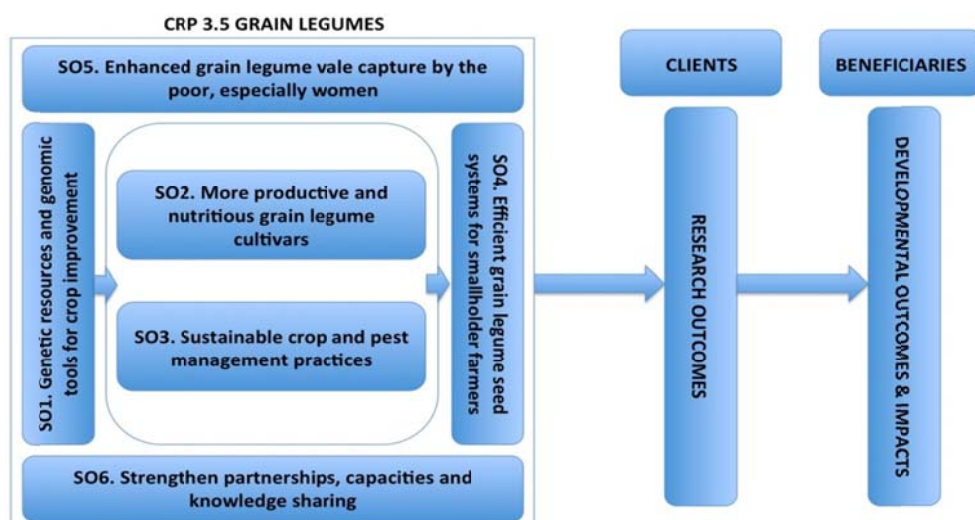


Figure 5.2. Linkages among Strategic Objectives, research and development outcomes and impacts

Strategic Objective 4 (improved seed delivery and adoption) will be monitored by Strategic Objective 5 to assess its impact on the poor (especially women). Strategic Objective 6 is a crosscutting input to the other five Objectives, but has its own identity in order to ensure that these crucial partnerships, capacity building, knowledge sharing and innovation platforms work receives high visibility and is carefully monitored and assessed.

A comprehensive assessment of past research was undertaken to identify constraints and barriers to adoption, and opportunities for future research (see Appendix 10 for the detailed report). The proposed workplan under various Strategic Objectives consider the lessons learnt and way forward for grain legumes R4D, for technology development, assessment, and facilitating adoption for impacts.

A brief overview of the Strategic Objectives is given below. Full descriptions of each are given later in the Chapter. Detailed workplans for the Outputs under each of the Strategic Objectives is given in Appendix 11.

5.1 Strategic Objective 1: Conserving and characterizing genetic resources and developing novel breeding methods/tools for improving efficiency of crop improvement

This Objective will collect, assemble, conserve and make available well-characterized genetic resources of common bean, chickpea, cowpea, groundnut, faba bean, lentil, pigeonpea and soybean for research and development by global partners; and develop novel breeding tools and methods to assist crop improvement scientists for enhancing the efficiency and reducing time to develop new cultivars. One of the major activities will be developing phenotyping platforms and screening of germplasm to identify lines that possess greater resistance to abiotic and biotic stresses, especially traits that will be important for adaptation to climate change.

Major outputs

- 5.1.1: Grain legumes genetic resources collected, conserved and made available to researchers globally.
- 5.1.2: Genetic resources characterized, evaluated and documented for unique traits/genes related to nutritional value and adaptation to current and future stressful environments.
- 5.1.3: Novel and efficient breeding methods/tools for cultivar development established and shared.
- 5.1.4: Novel genes/traits accessed/mobilized/incorporated through wide hybridization/genetic engineering to broaden the genetic base of grain legumes.

5.2 Strategic Objective 2: Accelerating the development of more productive and nutritious cultivars for resilient cropping systems of smallholder farmers

Using the enhanced genetic diversity from Strategic Objective 1, elite breeding lines and cultivars with high yield potential, greater yield stability (due to improved resistance to stresses) and with enhanced nutritional and commercial value will be developed. Special emphasis will be on using improved genomic tools and Integrated Breeding Platforms. These elite lines will be shared with partners for further selection, evaluation and possible release by NARS to the farmers in different farming systems across the five priority regions in the CRP.

Major outputs

- 5.2.1: Elite lines/cultivars with at least 25% higher yield potential than the best available cultivars developed for different production systems.
- 5.2.2: Elite lines/cultivars with enhanced resistance/tolerance to key biotic and abiotic stresses and resilience to climate change developed.
- 5.2.3: Improved germplasm better targeted to smallholder niches using GIS and other novel methods.

- 5.2.4: Elite lines/cultivars with enhanced nutritional composition and end-user preferred traits developed.
- 5.2.5: Elite lines/cultivars with enhanced nutrient use efficiency, high N₂ fixation potential and other traits for system efficiency developed.

5.3 Strategic Objective 3: Identifying and promoting crop and pest management practices for sustainable legume production

This Objective will develop integrated crop and pest management options that can alleviate the yield reducing constraints, thus stabilizing and increasing legume yields in the farmers' fields. These include improved BNF by providing efficient rhizobium strains, enhanced nutrient and water use, weed management and integrated pest management practices. Much of the research will be carried out collaboratively with CRP 1.1, CRP 1.2 and CRP 5 in different farming systems and agroecological conditions.

Major outputs

- 5.3.1: Strategies to optimize Biological Nitrogen Fixation by legumes developed and promoted.
- 5.3.2: Methods to increase legume productivity and profitability through increased resource use efficiency developed, tested and promoted.
- 5.3.3: Tools and protocols for more effective insect pests, disease and weed management developed, tested and promoted.
- 5.3.4: Potential strategies for increasing legume production in response to climate change identified and tested.

5.4 Strategic Objective 4: Develop and facilitate efficient legume seed production and delivery systems for smallholder farmers

The focus of this Objective is to facilitate efficient and equitable seed production and delivery so that the smallholder legume farmers, especially women, have access to quality seed of preferred varieties at the right time and at an affordable price. We will empower the development partners with improved knowledge and technologies to strengthen the decentralized seed system and to integrate formal and informal seed systems, involving public and private sector, NGOs, self-help groups and farmers themselves to ensure sustainability of seed systems. In collaboration with CRP2, we will support the development of favorable pro-legume seed policies at the regional and national level that will ensure sustainable seed access to women, poor and vulnerable farmers.

Major outputs

- 5.4.1: Decentralized seed systems enhanced through systematic diagnosis and implementation of appropriate models.
- 5.4.2: Capacity of public and private sector in legume seed systems strengthened.
- 5.4.3: Enabling seed policies for legume seed systems based on thorough analysis of current arrangements.
- 5.4.4: Framework for national seed security for vulnerable regions and households (poor and women) developed.

5.5 Strategic Objective 5: Enhance grain legume value chain benefits captured by the poor, especially women

This Objective will characterize grain legume value chains in order to i) identify, quantify and develop value addition opportunities for the poor and especially women, particularly post-harvest and II) to provide a knowledge base and framework for CRP 3.5 monitoring, assessment and priority-setting. Both institutional and technological opportunities will be sought. Treating value chains as innovation systems, this Objective will engage non-traditional partners that are key to overcoming longstanding obstacles in the delivery and impact of improved grain legume technologies and policies.

Major outputs

- 5.5.1: Enhancing grain legume value chains for the poor, especially women.
- 5.5.2: Institutional innovations to engage poor farmers with input and product markets identified and piloted.
- 5.5.3: Post-harvest technologies/practices and value-added products benefiting women identified and promoted.
- 5.5.4: Drudgery and cost-saving small-scale machinery for grain legume processing identified or developed.

5.6. Strategic Objective 6: Partnerships, capacities, and knowledge sharing to enhance grain legume R4D impacts

This Objective will foster improved partnerships enabling environment required for the CRP to succeed. In large, multi-country, and multi-institutional projects such as CRP 3.5 GRAIN LEGUMES, partnerships are vital, as no single institution can accomplish the task. Its outputs are in support of, and executed seamlessly with, the other five Objectives. Capacity strengthening is also critical to ensure that all partners have the skills required to conduct the planned research. Under these circumstances, knowledge sharing mechanisms and innovation platforms have a major role to play, and advances in ICT can be harnessed effectively to benefit the grain legumes community.

Major outputs

- 5.6.1: Partnership models to enhance grain legume R4D impacts identified and implemented.
- 5.6.2: Enhancing capacities of women and men for grain legume R4D innovation.
- 5.6.3: Knowledge sharing platforms for grain legumes crops strengthened.

5.1 Strategic Objective 1: Conserving and characterizing genetic resources and developing novel breeding methods/tools for improving efficiency of crop improvement

5.1.1 Rationale and description

Strategic Objective 1 will collect, assemble, conserve, document and make available well characterized genetic resources of common bean (CB), chickpea (CP) cowpea (CW), groundnut (GN), faba bean (FB), lentil (LN), pigeonpea (PP) and soybean (SB), as International Public Goods (IPG) for research and development. Novel breeding methods and tools will be developed and shared to improve the efficiency of legume improvement programs globally.

Genetic diversity is critical for any successful breeding program and genetic resources are important sources of such diversity, and also important sources of traits that permit continued yield increases under climate change scenarios; as materials may have evolved under some of the harshest conditions (Gepts 2006).

The CGIAR has excelled at collecting, conserving, and distributing genetic resources globally as IPGs. The four CGIAR centers – CIAT, ICARDA, ICRISAT, and IITA – conserve more than 133,000 accessions of the eight grain legumes targeted in this CRP. These centers have provided globally over 1.9 million samples of over 118,000 accessions to the scientists working in these centers and researchers in more than 140 developing and developed countries (Table 5.1.1). CGIAR centers have strong institutional linkages with the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) and use the standard material transfer agreement (SMTA) to provide materials for research and development. These large collections are safeguarded at each Center and many have been, or are being, placed in long-term storage in the Global Seed Vault at Svalbard, Norway. Genebank management systems are in place at each Center, but opportunities for more integrated approaches exist (e.g. the USDA's GRIN Global system, crop registries). CRP3.5 GRAIN LEGUMES will provide an opportunity to better integrate with other national and regional legume genebank networks.

Table 5.1.1. Germplasm collections in the CGIAR genebanks and global distribution

Crop	Accessions conserved		Germplasm distribution				
			Outside the center			Within the center	
	Total Accessions	Number of countries	Number of samples	Number of accessions	Number of countries	Number of samples	Number of accessions
Common Bean	30,617	110	418,762	29,086	103	310,171	21,524
Chickpea*	34,085	71	226,894	29,917	89	285,172	31,059
Cowpea	16,805	102	40,539	11,945	99	24,001	8,782
Faba bean	9,419	74	63,789	9,129	43	40,669	8,895
Groundnut	15,445	92	98,763	14,426	95	96,065	12,594
Lentil	11,643	80	103,197	11,167	52	56,100	10,242
Pigeonpea	13,632	74	70,498	10,773	112	84,146	8,050
Soybean	1,749	25	3,425	1,633	24	2,889	1,582
Total	133,395	-	1,025,867	118,076	-	899,213	102,728

* ICRISAT conserves 20,267 chickpea accessions, ICARDA conserves 13,818 accessions; 26,281 accessions unique and 7,804 common in both centers.

Even with such large collections, breeding programs globally (including IARCs and NARS) have so far used less than 1% of germplasm accessions available in the genebanks (Upadhyaya et al. 2006, 2011), mostly due to inadequate data and information on characterization on economic traits to help breeders select accessions of interest in the large germplasm collections. In CRP3.5, the four CGIAR centers plan to reverse this trend – by improving the availability of sets of germplasm that represent the diversity contained within the entire collections. Recently, the “Focused Identification of Germplasm Strategy” (FIGS) is being used in crops with robust geographical data sets. FIGS employs information about the environment from which germplasm accessions are collected to predict in-situ selection pressures. The strategy has proven successful at capturing very low frequency adaptive traits such as salt tolerance, insect pests and disease resistance (Bayuelo-Jiménez et al. 2002; Bhullar et al. 2009; El-Bouhssini et al. 2009, 2010). Core collections (consisting of about 10% of an entire collection), mini-core collections (consisting of 10% of core or 1% of entire collections) and reference sets (Upadhyaya and Ortiz 2001, Upadhyaya et al. 2008; Mahalakshmi et al. 2007) have been used to identify sources of resistance to diseases, tolerance to drought and other abiotic stresses and enhanced quality traits (Tohme et al. 1995; Upadhyaya et al. 2009). Molecular genotyping with SSRs has been completed for 1000 to 3000 accessions in most of the legume species (Upadhyaya et al. 2008, Upadhyaya et al. 2011; Varshney et al. 2010) and opportunities now exist to do a larger number of assays with less-expensive high throughput sequencing and more comprehensive genetic markers such as SNPs (Varshney et al. 2009a). As sequencing costs continue to decline, whole genome sequencing of significant number of accessions will be feasible, providing even more detailed discrimination and identification of diverse subsets (Varshney et al. 2009b). Such large data resources have required appropriate information systems. While systems like SINGER (SINGER.cgiar.org) have provided initial germplasm information as IPGs, newer and more robust information systems must be employed to adequately handle the large amount of information produced

Phenotyping is critical to fully appreciate diversity and identify useful sources for crop improvement.

Focused Identification of Germplasm Strategy (FIGS)

As plant breeders are challenged to produce new varieties that can deal with the impacts of climate change and other emerging production constraints, they will be increasingly forced to look within genetic resource collections for novel genes. However, the question is how breeders rationally choose a subset of germplasm to screen from genetic resource collections that contain several thousands of accessions; given that it is not economically or logistically feasible to screen them all for a specific suite of traits. Focused Identification of Germplasm Strategy (FIGS) is an approach to assist plant breeders and other genebank users looking for a target trait property. The principle of this approach is to use agro-climatic information, generated by Geographic Information Systems, or other types of information, to describe the environments from which genetic resources were originally collected. This in turn gives a rational basis upon which to select best-bet subsets from global plant genetic resource collections that will maximize the chances of finding the desired traits in a manageable set of genotypes and thus greatly enhancing the efficiency and timeline associated with gene discovery.

Mini-core collections for genetic resources

Continuous progress in plant breeding depends on the discovery of new sources of genetic variation with beneficial traits and their judicious use in crop improvement programs. Although large number of germplasm accessions (over 118,000) of eight grain legume crops (beans, chickpea, cowpea, faba bean, groundnut, lentil, pigeonpea and soybean) targeted in this CRP have been conserved in four CGIAR genebanks, only a small proportion (<1%) has been used in developing cultivars. This is mainly due to inadequacy of reliable information for traits of breeder's interest that show high genotype x environment (GxE) interactions, and require replicated multilocation evaluation to identify parents. Development of small sized subsets representing the diversity of entire collections is needed to enhance the use of germplasm in crop improvement. Developing representative core (10% of the entire collection) and mini-core (10% of core or 1% of the entire collection) collections has been suggested as a means to enhance the utilization of germplasm (see details in the main text). Mini-core collections of chickpea, pigeonpea, faba bean, cowpea, and groundnut have been developed and evaluated by scientists at CGIAR centers and NARS partners. New sources of genetic variation for various traits such as resistance/tolerance to diseases and insect-pests, drought, salinity, low temperature tolerance and for agronomic and quality traits have been identified. The utilization of these new sources of variation in crop improvement programs would have a great impact in developing improved high yielding cultivars with a broad genetic base.

Use of germplasm subsets has been successful in various species and for several important traits. High-throughput phenotyping offers opportunities to screen much larger numbers, and when combined with molecular fingerprinting, can provide trait-marker associations. Opportunities to coordinate efforts across centers in the CRP are high.

Information systems are key to provide global public access to all characterization data. Geo-referenced genetic resources can be the common denominator for all genotypic and phenotypic data in the future. Databases need to contain highest-quality, comprehensive and dynamically curated data on germplasm.

Where diversity is lacking for critical traits in cultivated species, tapping wild relatives can be employed. Wide-hybridization offers opportunity to introduce diversity from wild relatives (Upadhyaya 2008) and to create novel diversity in polyploidy species such as groundnut (Mallikarjuna et al. 2010). Molecular tools will provide effective methods to evaluate and follow such introgressed segments in breeding programs (Glaszmann et al. 2010).

Genetic engineering provides opportunity to create novel materials containing new and/or greatly improved characteristics of economic importance. Methods for successful transformation are available for several species and GM soybean has been deployed globally (James 2010). Safety and public acceptance are important issues that must be considered before moving forward. NARS need to take the lead to assure public acceptance of genetically engineered crops.

Finally, breeding programs must consider using much larger amounts of data in deciding what are the best materials to continue with. Accuracy of the field data is critical, and quality control/assurance is important in assuring the most cost-effective program possible. Information systems that efficiently collect data in the field, curate and centralize secure data storage and analysis, and provide rapid access to the results for decision-making, are critical. The Generation Challenge Program is spearheading the development of such a system (Ribaut et al. 2010).

5.1.2 Priority setting

The priority for desired traits will be set by Strategic Objective 2. However, the priority for genetic resources will be to enhance the utilization of genetic resources in crop improvement. Developing mini-core and reference sets in crops where such sets are not available and their multilocation evaluation or use of FIGS in selecting useful germplasm will be a key activity. The aim would be to provide the plant breeders with trait-specific germplasm along with reliable information, so that the germplasm materials can be effectively used by them. The information on genotypic and phenotypic diversity of the trait-specific germplasm will be useful to enhance the use of diverse parents to breed cultivars with a broad genetic base. Assembly/collection of germplasm from the high priority areas based on gap analysis will be undertaken for conservation and utilization (Rysavy et al. 2009; Ramírez-Villegas et al. 2010). Availability of genomic resources and use of modern breeding methodologies vary from minimum (e.g. LN, FB) to maximum (e.g. SB). In majority of the legume crops (GN, CP, CB, CW and PP), several international initiatives such as the Generation Challenge Program have helped develop such genomic resources (Glaszmann et al. 2010). Therefore, priority will be given to develop molecular markers and genetic maps in less-studied species such as LN, FB, and GN by establishing and using high-throughput genotyping platforms. While the genome sequences of SB are already available, and that of CB should be available shortly, efforts will be made to develop genome sequences in species like CP, CW and PP.

Most of the grain legumes have a narrow genetic base (Sonnante et al. 1994), and levels of resistance to some biotic and abiotic constraints are low. Priority will be to introgress useful genes from wild relatives into the cultivated germplasm (GN, PP, CP, and LN) through wide hybridization techniques. Further, in cases where no variability for these traits exists in the available germplasm, or is difficult to breed through traditional methods, germplasm enhancement through the use of genetic engineering will be adopted. Identifying novel genes/traits and assessing their suitability as

candidate genes for genetic engineering options will be important for future grain legume breeding programs.

5.1.3 Impact Pathway

This objective will generate a number of diverse outputs, including genetic and genomic resources, information resources, and enhanced capacity of partners. These outputs will result in several research outcomes such as data integration and web based information dissemination, web based systems for germplasm requests, communities of practice (COP) such as those that the GCP is promoting for sharing molecular tools to be developed under Output 5.1.6.3, and germplasm networks, either existing or to be formed, that will ultimately lead to the intended impacts of reducing poverty and hunger, enhancing livelihoods in a gender equitable manner, and reducing environmental degradation (See Figure 5.1.1).

The primary users of the output of this objective are geneticists, breeders and plant protectionists (Strategic Objective 2) to use them in breeding programs, to understand the mechanisms of resistance/tolerance to biotic and abiotic stresses as well as to identify molecular markers for deployment in breeding. Applications of the developed genomic tools and modern breeding approaches will shorten the breeding cycles and eventually lead to development of superior cultivars (Strategic Objective 2) that will be adopted by farmers through active involvement of extension specialists and NGOs. This objective will contribute to more productive and stable farming systems with increased productivity and income, improved health and resilience to climate change. The mechanisms to achieve this will include building capacity of partners, conducting joint research to integrate closely in the delivery processes and networking on a continuous basis for sharing knowledge.

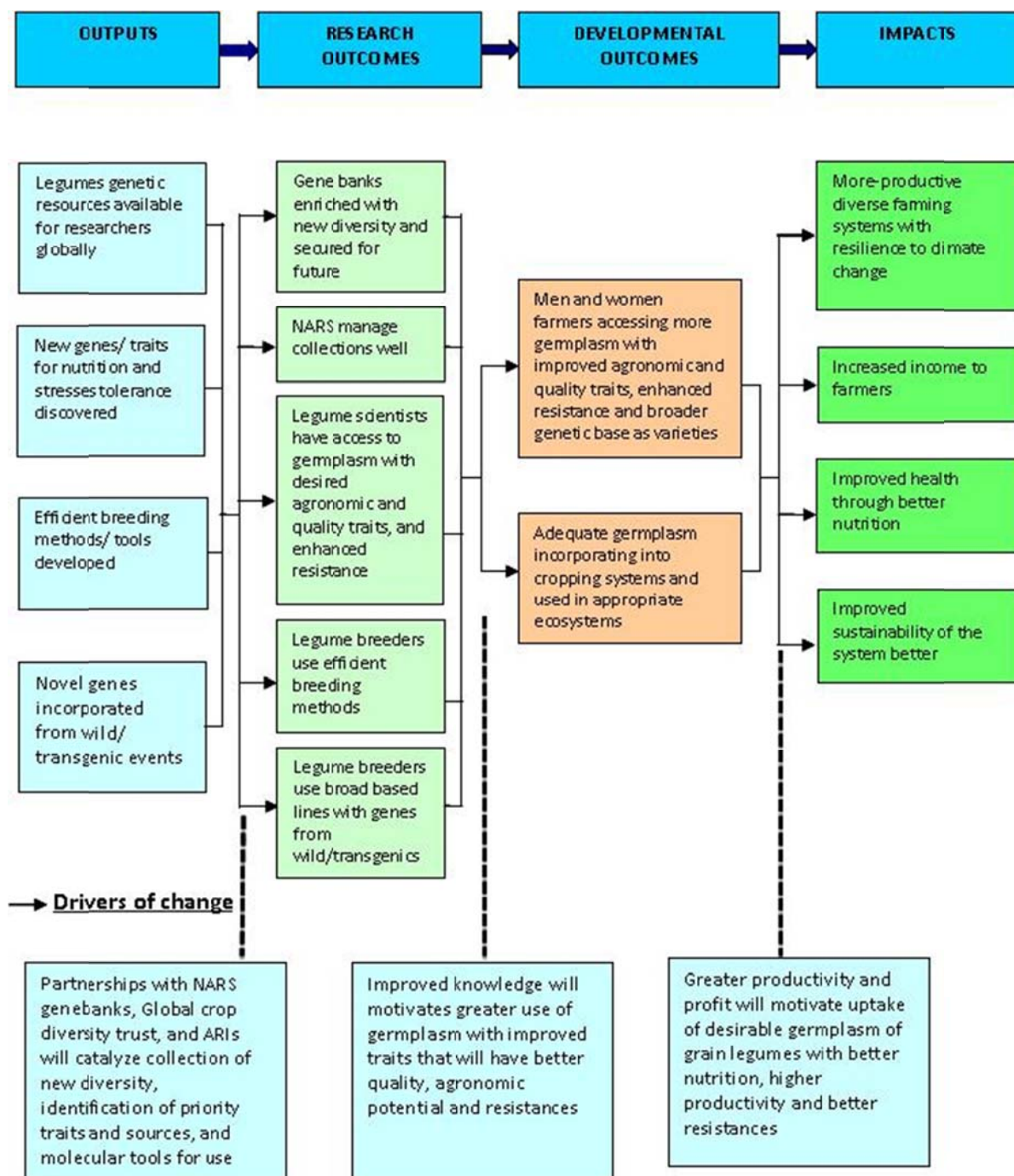


Figure 5.1.2. Impact pathway for Strategic Objective 1

5.1.4 Key partners and their role

Activities in this objective require clear roles and responsibilities and a strong interaction among the CGIAR Centers and with national and regional partners. Availability of germplasm for users depends upon readiness of countries to collaborate and share unique collections not available in the CGIAR centers and making resources available for characterization/evaluation, regeneration, documentation, long-term conservation, and distribution of germplasm to the users. Further, identification of trait-specific germplasm accessions will involve research efforts among scientists from different disciplines within and between centers, NARS, and ARIs. Partnership with NARS will assist in identifying gaps in the collections and means to fill such gaps, evaluation of germplasm sets

such as FIGS, mini-core and reference collections to identify trait specific germplasm across locations for key traits in hot spots areas and in utilization of diverse germplasm in breeding programs. The ARIs will be involved in upstream research in dissecting complex traits and mechanisms, development of tools and strategies, and capacity building. This objective will work with numerous partners globally to disseminate germplasm, and associated information and technologies to the intended users. In addition to strong collaboration among the four CGIAR centers, NARS genebanks, germplasm networks and research programs, ARIs, Millennium Seed Bank, public and private sector breeders/researchers, Global Crop Diversity Trust (GCDT), farmer's communities and NGOs involved in conservation and use of germplasm, FAO and SINGER will be involved. We will work with the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) on the issues related to genetic resources policies. More detailed description of role of partners is given in Chapter 6 on Partnerships.

5.1.5 Gender Strategy

Traits of specific interest/importance to women and men farmers and consumers have been identified through participatory varietal selection undertaken across crops in each of the centers during the last decade, but opportunities for identifying new ones as well as changes in preferences exist under Objective 2. This objective will link up with Objective 2 to gain information on traits that are important for users, particularly women (e.g. mechanically harvestable legumes, herbicide tolerant varieties to minimize drudgery, etc.). Women play a major role in on-farm conservation of germplasm, and as providers of improved household nutrition. Gender specific studies to further analyze gender preferences of crop traits will be designed in collaboration with CRP2 for contexts where information is scanty. Within the framework of this objective where the primary users of the outputs are geneticists and crop breeders, the program will aim and encourage a balanced staff structure where women researchers, technical staff and students will be trained to manage national genetic resources and genebanks. More details on Gender Strategy are given in Chapter 7.

5.1.6 Lessons learned and research questions to be addressed

- Use of germplasm in crop improvement is low (<1%) mainly due to lack of reliable information on traits of economic importance (e.g. yield, resistance to biotic and abiotic stresses, quality) on which breeders work.
- In spite of a large number of germplasm accessions conserved in various genebanks, a few gaps in collections still exist.
- Phenotyping is critical for enhancing use of germplasm. Many wild species have novel alleles to improve resistances and for important agronomic traits.
- Good progress has been made in sequencing some species and linkage maps are available to enhance efficiency of breeding.

Key research questions to be addressed are:

- Can geospatial and diversity-sampling tools/protocols such as FIGS, core, mini core, and reference sets increase the accuracy and predictive power of germplasm characterization, resulting in more efficient and effective use of the genetic resources collection by breeders?
- Can these tools/protocols increase our ability to identify gaps in the collections more accurately and suggest high-probability locations for collection activities to fill those gaps?
- How can we enhance the use of wild relatives to create novel variation and improve valuable traits of cultigens, including the use of transgenic approaches where needed?
- What new tools and technologies are needed by breeders to enhance the efficiency and effectiveness of crop improvement?

5.1.7 Outputs

5.1.7.1: Grain legumes genetic resources collected, conserved and made available to researchers globally.

Description

This output focuses on increasing germplasm diversity in genebank collections by collecting germplasm of interest, threatened germplasm from high priority areas, and under-represented germplasm in global collections. This requires analyzing gaps in our collections, prioritizing, and devising mechanisms for carrying out explorations based on eco-geographic information (geo-reference data from past missions), and historical data. Help of expert taxonomists is needed to ascertain high priority areas where the germplasm is at the risk of extinction (such as adapting the International Union for Conservation of Nature Red List approach, developed for wild species to identify germplasm at risk of extinction). Germplasm may also be acquired from existing collections held by national institutions/organizations based on the available passport data. In most grain legumes a founder effect (Ladizinsky, 1985) has resulted from domestication, and thus most of genetic diversity has been left untouched in the wild. Wild relatives growing in the centers of origin/diversity have the adaptive mechanism to withstand changing climatic conditions. Germplasm collection missions need to collect such related wild species of grain legumes, which will allow us to not only fill gaps in collections and collect germplasm that might be at the risk of extinction but also to conserve rare and useful genes for use in future breeding programs. The period for collection depends on several factors and hence could be long term. Grain legumes germplasm will be acquired from partner countries, and supplied to researchers globally on request using the Standard Material Transfer Agreement (SMTA). Newly acquired germplasm will be indexed and cleaned for diseases of quarantine importance. The CGIAR Centers have developed technologies and have access to needed agro-ecological conditions in most cases to increase/regenerate the seed of related wild species, and to make them available to the community. The participating centers in the CRP will work together to share facilities for cost-effective regeneration of unadapted germplasm, upgrading skills/training, and safety backup.

Methodology

Vast improvements in the quality of passport and characterization data has occurred particularly after the World Bank-funded Global Public Goods (GPG) projects 1 and 2, especially with landraces and wild species accessions in such a way that GIS packages such as FloraMap and DIVA-GIS can fruitfully be applied (Jones et al. 1997; Ramírez-Villegas et al. 2010). Gap analysis will be done in terms of representation of species, of populations, and of land/ ecological conditions sampled so far as well as genetic erosion prediction. Priorities for collecting will be established from the analyses for species, populations and areas to carry out joint explorations for grain legumes of interest. The CRP GRAIN LEGUMES approach would avoid multiple collecting missions in the same country. Traits specific targeted collecting missions will also be organized using the environmental information. Partners to the ITPGRFA will be contacted jointly for launching of target collecting activities and negotiations carried to collect germplasm of all legumes under the Treaty. Data bases of the genebanks will be compared and unique accessions not available in the Center's genebanks will be acquired from NARS partners and other institutions following SMTA. The GPG1 and 2 projects led to significant improvements in physical infrastructure and operation procedures for efficiently managing the collections. These areas include conservation, characterization/evaluation, multiplication/regeneration, documentation and distribution. Standard protocols are now in place for efficiently carrying out these operations as technical manuals (Upadhyaya and Gowda 2009) and the genebank knowledge base (croptgenebank.sgrp.cgiar.org). For conservation and distribution, best practices for grain legume genebank management will be developed in collaboration with partners. A two-tier system of conservation includes medium-term storage at 4°C and 25% RH for maintaining working collection for accessions of frequent use, and long-term storage at -20°C. The perennial and vegetatively propagated wild species (e.g., some *Arachis* species) and relatives will be maintained in

field genebanks. All these will enable the legume genetic resources and the associated information to be available as global public goods following SMTA for effective utilization in crop improvement research.

Key milestones

- Gaps in existing germplasm collections of at least three legumes identified (2012-14)
- Available and newly acquired genetic resources (at least 500 accessions) of grain legumes safely conserved (2014)
- Germplasm of cultivated and wild species of grain legumes collected/assembled from the geographic areas rapidly eroding and/or less represented in existing collections (2012-14)
- At least 5,000 accessions of grain legume germplasm supplied via SMTA to researchers globally on request (2014)
- At least two training courses for NARS partners on genetic resources management conducted (2013-14)

5.1.7.2: Genetic resources characterized, evaluated and documented for unique traits/genes related to nutritional value and adaptation to current and future stressful environments.

Description

The grain legume germplasm needs to be properly characterized following standard descriptors' list. The size of entire germplasm collection in the CGIAR genebanks is too large to carry out multi-location evaluation of germplasm for traits of economic importance such as yield and traits related to quality and to adaptation, which often show high genotype x environment interactions. Hence, the large size germplasm collection need to be sampled to bring the size of the collections to a manageable level (for example core collection, 10% of entire collection) for meaningful evaluation (Frankel 1984; Tohme et al. 1995; Mahalakshmi et al. 2007; Parra-Quijano et al. 2011) and for greater utilization of germplasm in crop improvement. However, in the large collections such as in the CGIAR centers, even a core collection will be unwieldy for replicated multilocation evaluation. To overcome this Upadhyaya and Ortiz (2001) proposed mini core collection (10% of the core collection). Using passport information and characterization/evaluation data, core collection (10% of the entire collection) and mini core collections (Upadhyaya et al. 2002; 2006) have been developed in some grain legumes and would need to be augmented with additional diversity from new germplasm. Reference sets (Upadhyaya et al. 2008) have also been developed in some legumes using molecular markers. Existing FIGS algorithm need to be verified for robust application across crops and new algorithm is required for the selection of best-bet subsets (Beebe et al. 1997). These germplasm subsets need to be evaluated across locations by partners for agronomic traits, stress response, quality traits to assess the genetic diversity to target sources of useful traits for identification of diverse trait-specific germplasm accessions for use by researchers in crop improvement programs. Molecular characterization of these sets using high-throughput genotyping platform as the one set up by IBP (Integrated Breeding Platform) under the coordination of the GCP is required. Approaches such as association genetics will help to associate marker/sequence-based haplotypes to specific traits (López et al. 2003). Besides, implementing analysis such as mass spectrophotometry could open the way for screening the entire collections. Tolerance to stresses such as drought and heat have been noted on limited sets of designated germplasm, and new methods for screening germplasm, such as using digital and infrared imaging can be implemented, as they have proved to be good and rapid proxy for traits of interest such as water saving traits (Zaman-Allah et al. 2011). A host of data and information on the genetic and phenotypic characteristics of legume crops will be integrated into an information bank that will be readily available to CRP partners and other interested R4D organizations globally.

Methodology

Key to the achievement of this output are: precise characterization and evaluation of the germplasm collections, documentation of evaluation data, and identification of trait-specific germplasm lines for use by the breeders for traits related to nutritional value (micronutrients, especially minerals and vitamin A) and adaptation to various biotic and abiotic stresses. In most cases, the existing and new germplasm accessions are generally characterized for morpho-agronomic traits following standard descriptors. Many of the traits of breeders' interest are polygenic and display high genotype x environment interaction that necessitates replicated multilocation evaluation to identify germplasm lines for use as parents by the breeders. Since size of most collections is too large for such evaluations, core collection (10% of the entire collection) and mini core collections (10% of core, 1% of entire collection) (Upadhyaya and Ortiz 2001) will be developed using passport information and characterization/evaluation data for grain legumes for which such sets are not available. In legumes where such sets exist, these will be augmented with additional diversity from new germplasm. Reference sets (Upadhyaya et al. 2008) will also be developed using molecular markers. Existing FIGS algorithm will be verified for robust application across crops and new algorithm developed for the selection of best-bet subsets (Beebe et al. 1997). These subsets (FIGS, core, mini-core, and reference sets) with small number of accessions will be used for replicated multilocation evaluation at appropriate locations to identify trait-specific accessions for biotic and abiotic stresses and for agronomic and nutritional traits. FIGS, core, and mini core sets will be characterized using molecular markers based on high-throughput genotyping platform such as the Integrated Breeding Platform (IBP) under the coordination of the GCP. Approaches such as association genetics will be used to associate marker/sequence-based haplotypes to specific traits (López et al. 2003). Information on molecular markers will also be used to identify genetically diverse parents among the trait-specific germplasm lines. Agronomic evaluation of the trait-specific germplasm would be undertaken to determine their agronomic desirability. This will satisfy the needs of plant breeders for trait-specific, genetically diverse and agronomically desirable parents. Such materials (trait-specific genetically diverse and agronomically desirable) with information on which breeders can rely would be made available to the scientists not only in the CGIAR centers but to the global community through user-friendly information system. For complex traits such as drought, the identification of germplasm with key traits of adaptation will be through dissection of the key mechanisms of adaptation to drought and from a clear understanding of interactions of such mechanisms with their environment and resulting G x E interactions. This would form basis for the choice of trait in the genebanks (Vadez et al. 2011a; Zaman-Allah et al. 2011; Kholova et al. 2010a, b; Vadez et al. 2011b). The value of critical traits will be tested through crop simulation modeling to predict the effect on yield of these key traits across locations and weather conditions, following recent work (Hammer 2006; Sinclair et al. 2010).

Key milestones

- Global legume phenotyping networks formed, priority traits, methods, research partners, and germplasm accessions to be characterized agreed upon (2012)
- Phenotypic data available on targeted traits in structured and representative sets of germplasm of each CRP legume species (2013-14)
- Trait-specific germplasm identified using core/mini core, reference, and FIGS sets in at least five legumes (2013-14)
- Comparative performance of neglected species (e.g. *Phaseolus coccineus*, *P. dumosus*, and *P. acutifolius*) and wild relatives of CRP grain legumes assessed in different environments for climate change-related traits (2012)
- A web-based resource made available for open access on phenotyping protocols and standard methods to evaluate stress resistance (2014)

5.1.7.3: Novel and efficient breeding methods/tools for cultivar development established and shared.

Description

Integration of biotechnological tools such as genomics and bioinformatics in breeding methods, referred to as modern breeding, has been very effective and is routinely used in developed countries, especially in the private sector, for developing superior cultivars in many crops. However, various bottlenecks still impede adoption in developing countries. Limited human resources and inadequate field infrastructure remain major challenges, although through virtual platforms aided by the information and communication technology revolution, breeders now have better access to genomic resources, advanced laboratory services, and robust analytical and data management tools (Ribaut et al. 2010). Modern breeding projects and capacity building activities considered in this proposal helps bridging the gap between developed and developing countries, improving capacity of partners from national programs and providing access to biotechnological tools and services. Along the same lines, paucity of genomic resources coupled with narrow genetic diversity, has also hampered deployment of modern breeding methods in majority of the legumes (Varshney et al. 2010; Glaszmann et al. 2010). Advent of next generation sequencing and high-throughput genotyping platforms offers the possibility to develop not only molecular markers and genetic maps but also the whole genome sequences in the legume crops (Varshney et al. 2009b). Newly developed molecular tools are useful for identification of duplicates, collection diversity assessment, and analysis of the representativeness of the gene pools maintained *ex-situ*. Genetic and physico-chemical basis of resistance to diseases, pests, and environmental stresses for individual legumes, and across legumes (comparative genomics) for targeted traits determined. Knowledge and information from model legumes such as *Medicago* and *Lotus* will be exploited to facilitate identification of desirable germplasm accessions that can be utilized in variety development. Advanced tools such as molecular markers developed in the GCP and other initiatives, and trait-specific germplasm will be used to design better legume varieties with farmer and consumer-preferred traits using the cost-effective methods (Miklas et al. 2006). Genetic and phenotypic diversity of legumes' genetic resources will be assessed to identify novel and potentially useful genes/alleles to increase yield potential, and improve resistance/tolerance to biotic and abiotic stress. This would enable researchers to introgress novel alleles from landraces and crop wild relatives into elite germplasm using conventional, doubled haploid, transgenic, and non-transgenic approaches to broaden the genetic base (nuclear and in some cases also cytoplasmic) of legume crops for increased productivity. Doubled haploids are required in some of the legumes (GN, CP, PP, and CB) to shorten the breeding cycle.

Methodology

Molecular markers and genetic maps are pre-requisites for undertaking molecular breeding. These tools are available in some crops like SB, and progress has been made recently in terms of development of molecular markers such as SSR markers and limited genetic maps in crops like CB, CP, and CW (Varshney et al. 2010). However the remaining legumes like LN, FB still do not have enough SSR markers and good genetic maps. Low level of genetic diversity associated with several legume crops, however, demands large number of molecular markers so that good genetic maps become available. Genotyping with SSR markers at large-scale is expensive as well as technically demanding. Recent advances in genomics, especially advent of low-cost high-throughput sequencing and genotyping platforms offer the possibility to develop genome sequence as well as large scale markers such as SNPs or genotyping-by sequencing (GBS), a simple highly multiplexed system/approach that includes reduced sample handling, fewer PCR and purification steps, no size fractionation and inexpensive bar-coding, can facilitate accelerated development of genetic maps in almost all the crops (Varshney et al. 2009b). Among targeted legume crops, genome sequence has become available only for SB and will be available soon for CB and PP. Genome sequence for CP and CW and transcriptome sequence for LN, FB will be generated using next generation sequencing (NGS) methods. These sequence data will be used for: (a) identification of SNPs and develop cost-

effective SNP genotyping platforms in CP, CW, PP, CB, GN, LN, and (b) developing genotyping-by-sequencing (GBS) platform in SB, CB, CP, PP. In turn, these platforms will be useful for: (a) exploring the genome wide selection approach in the breeding programs of SB, PP, CP and CB, and (b) allelomining and analyzing genome sequence variation in the germplasm collections in the genebank in at least one legume species. High-throughput and cost-effective SNP genotyping platform will be used for genotyping the mapping populations segregating for targeted traits in different legumes. These genotyping data will be used for developing the genetic maps, and together with the precise phenotyping data on the mapping populations, employing QTL analysis, trait-linked molecular markers will be identified in CB, CP, CW, LN, and FB. These trait-linked markers will be validated using different genetic background and wherever required and possible, the diagnostic markers will be converted into cost-effective marker assays such as CAPS, inexpensive cost effective assays wherein the sequence alignment for more than two genotypes with SNPs is subjected to identify the restriction sites for restriction enzymes using SNP2 CAPS assay or KASPar, the inexpensive, robust and flexible genotyping system which allows gene-specific SNP assay development, *in silico* SNP validation, marker saturation of the loci of interest, etc.. Under the IBP framework the GCP has supported the conversion of SNP markers to KASPar assays for CW, CP and PP and will initiate it for CB and SB in the coming months. Genotyping platforms like the IBP will be used for undertaking marker-assisted recurrent selection (MARS) as well as other breeding applications such as fingerprinting of parental lines or varieties, assessment of purity of hybrid seeds in pigeonpea, etc. The IBP provides access to modern breeding technologies, breeding material and related information, tools and services, including high-throughput genotyping services, in a centralized and functional manner (Delannay et al. 2011). The IBP will be used in improving efficiency of plant breeding and data management in developing countries and hence facilitate the adoption of molecular breeding approaches - from simple gene or transgene introgression to gene pyramiding and complex MARS and GW projects. In legume species such as SB, PP, CP, and CB, where genome sequences are already available, or will be available soon, Protocols for doubled haploids will be developed to shorten breeding cycles in selected legumes (CP, PP, GN, and CB).

Key milestones

- Mapping populations (RILs/AB-QTL, MAGIC lines), TILLING populations and other genetic stocks developed in CRP grain legumes for use in genetic studies and for practical use in breeding programs (2013)
- Whole genome sequence information available for at least one accession in CP and GN and strategies for genome-wide selection developed in CB, CP, GN and PP (2014)
- High throughput genotyping platforms such as SNP established for at least CB, CP, CW, PP and SB (2013)
- Integrated high-density genome map with >2000 markers developed for CP, CW, GN, PP, and CB (2013)
- Diagnostic markers linked to key traits identified in CB, CP, CW, LN, FB (2014)
- Cross-legume genomic studies of gene expression to identify genes involved in the transition from vegetative to reproductive phase completed (CB, CP) (2014)
- Better understanding of the mechanisms and genetics of resistance/tolerance to biotic and abiotic stresses (CB, CP, GN, LN) (2014)
- Genetic basis of interaction of drought and low P with BNF understood (2014)
- Key trait-linked markers validated and converted to cost-effective platforms for implementation in breeding programs of CB, CP, CW, LN, FB (2012-14)
- Protocols for development of double haploids validated in CP and PP (2013)
- Plant breeding software and IT equipment (private or public) integrated in CRP crop legumes breeding and genetics programs (2013)

5.1.7.4: Novel genes/traits accessed/mobilized/incorporated through wide hybridization/genetic engineering to broaden the genetic base of grain legumes.

Description

Legume production requires substantial progress in developing new varieties possessing the qualities for adaptation under different cropping systems and newer niches. The Intergovernmental Panel on Climate Change predicted that by 2100 the temperature will rise in the range of 1.1 to 6.4°C due to global warming, which will have serious consequences to global agricultural and food production (IPCC 2007, Lobell et al. 2008). It is well known that domestication of legumes was accompanied by bottlenecks that reduced genetic diversity (Tanksley and McCouch 1997, Mallikarjuna et al. 2011). This restricts crop improvement by limiting the range of traits available for breeding. Wild relatives of legumes are important sources to widen the genetic base (Mallikarjuna et al. 2010). The development of pre-breeding lines has long been advocated as a means to facilitate the transfer of genes from wild species and broaden their genetic base. Resistance to storage weevil (*Zabrotes subfasciatus*) has been successfully transferred into common bean, and progenies display better agronomic traits, such as early maturity, high grain yield, large-seed weight, and some with high seed mineral content (Kornegay et al. 1993; Acosta-Gallegos et al. 2007). Recent advances in the synthesis of exotic genetic libraries, such as introgression lines (ILs), near isogenic lines (NILs) and advanced backcross lines has made the use of alien genomes more precise and efficient. This set of pre-breeding activities would involve crossing between elite cultivars and known testers and wild forms of the primary gene pool on the one hand, and with wild species of the secondary gene pool on the other hand. This could be done with specific characteristics to transfer, considering that novel variation can be expected due to complementarity of alleles or epistasis. Any mutant, even if with deleterious effects, particularly those related to plant architecture, will be carefully kept as it might bring explanation on how genes work in food legumes. Recent successes in genetic engineering of legumes with efficient protocols for their genetic transformation are available for routine applications (Khatib et al. 2011; Sharma and Ortiz 2000, Sharma et al. 2005). This can be a pipeline approach for developing transgenic events of grain legumes (GN, PP, CP, CW, LN) for addressing major biotic and abiotic constraints. This is especially true for the constraints for which the durable high-level of resistance sources are not available in the existing germplasm (such as *Helicoverpa* pod borer resistance in chickpea and pigeonpea). While effective phenotyping of the developed transgenic events will be a key factor in the successful use of this technology, translating these technologies into breeding lines/varieties will be an important activity following their biosafety assessment. The Platform for Translational Research on Transgenic Crops (PTTC) facility at ICRISAT can play a lead role in validation of transgenic product concepts followed by their translation in to commercially viable products involving public and private sector partners.

Methodology

Wide hybridization and genetic engineering tools and platforms will be established for unraveling the underlying resistance mechanisms for various biotic and abiotic stresses in the primary as well as secondary and tertiary gene pool of grain legumes. In cases where the wild species represent a possible source of high-levels of such resistance, introgression of desired traits/genes from wild species into improved cultivars will be undertaken. In case of groundnut, the progenitor diploid species *A. duranensis* (A genome) and *A. ipaensis* (B genome), and other A and B genome species from section *Arachis* will be used to produce allopolyploids (Mallikarjuna et al. 2010) to access novel alleles that may have been lost during evolution. Similarly, *Phaseolus coccineus* and *P. acutifolius* will be tapped for genes to improve the common bean for climate extremes including excessive rainfall, drought and heat (Singh and Schwartz 2010; Butare et al. 2011). In many legumes (e.g., pigeonpea), secondary and tertiary gene pool species are sources of resistance to many biotic and abiotic constraints (Mallikarjuna et al. 2011b). Attempts will be made to tap these sources with the help of appropriate molecular tools. One or two backcrosses with cultivated parents will be used to

recover more of the cultivated genome using markers. Since the success of wide hybridization in food legumes has often been limited due to lack of information on crossability (lack of taxonomic knowledge) and appropriate ecologies for the parents and offspring from the crosses. Hence, when relevant, a molecular phylogeny using the plastid DNA or ITS sequencing will be established to know the closest relatives of the food legumes considered. GIS tools will be used to predict the ecology of the different species involved so that better conditions for blooming and pod setting will be obtained, and similarly for the congruity backcrossing. Breeders will be continuously involved directly or through web imagery to see the outcomes of the crossing experiments, so that novel variation or promising materials can be directly included into regular crossing programs. Mutants or exceptional segregants will be included into the collections of genetic stocks handled by the respective genebanks and/or interested institutions. If crosses are planned for harsh environments (e.g. drought or extreme temperatures), the offspring will be shared with the breeders/ physiologists in the Centers or partners in order to make better use of these rare materials.

However, in the absence desired genes/traits in different gene pools, potential alternative sources of resistance will be tapped by harnessing genetic engineering and RNAi technology platforms for developing such resistance. This involves developing a large number of transgenic events for individual crop/trait combination so as to maximize the chances of obtaining optimal phenotypes (without any yield penalty) for further characterization and validation under greenhouse, contained and confined field trials. The multidisciplinary teams will be involved in extensive phenotyping of the generated transgenic events of individual traits as a pre-breeding component. Notable amongst these will be *Helicoverpa* pod borer resistance in PP and CP, Maruca pod borer resistance in CW, pests and herbicide resistance in LN and drought tolerance in GN (Bhatnagar-Mathur et al. 2007), CP and CB. For traits involving nutritional enrichment, special emphasis will be on establishing activities on nutrient profiling and bioavailability in GN and PP. The advanced transgenic events will undergo comprehensive biosafety assessment prior to making them available for plant breeding activities on variety development. This will involve establishing translational research protocols and practices involving multiple partners, and facilities such as the Platform for Translational Research on Transgenic Crops (PTTC) at ICRISAT will play a significant role.

Key milestones

- Key traits not available in cultivated germplasm such as resistance/tolerance to pod borer/bruchid (CP, PP), leaf spots and aflatoxin (GN), sitona weevil and *Orobanche* (LN) introgressed from wild relatives (2013)
- Broaden the genetic base of legumes (GN, CP, PP, CB, LN) utilizing wild relatives from different gene pools (2013)
- Inter-specific derivatives with enhanced yield and improved yield related traits identified in CB, CP, GN, PP, and LN (2014)
- Transgenic events for biotic constraints including pod borer (CP, CW, and PP), viral diseases (GN) and fungal pathogens (GN) developed and characterized (2014)
- Transgenic events for tolerance to abiotic constraints including drought (GN and CP), developed and characterized (2013)
- Transgenic events developed for enhanced micronutrients (pro vitamin A) in GN and PP, and candidate genes/promoters for improved oil quality in groundnut (2014)
- Resistance associated genes/proteins for complex combinational traits (e.g., aflatoxin-resistance and drought tolerance) in GN identified (2014)

5.2 Strategic Objective 2: Accelerating the development of more productive and nutritious cultivars for resilient cropping systems of smallholder farmers

5.2.1 Rationale

The goal of the Strategic Objective 2 is to develop improved legume varieties with higher and stable yield and increased nutritional and commercial value by exploiting genetic and genomic resources/tools developed in Strategic Objective 1. The average farm yield of legumes is very low, and wide yield gap exists between current on-farm yield and the yield obtained at research stations and well-managed farmers' fields (Bhatia et al. 2006, Singh et al. 2001, 2009). The global average yield of CP, CB, CW, GN, LN and PP is less than 1.0 tons per ha (FAOSTAT 2009), which is not even half of their realizable yields recorded in experimental fields. The expansion of area under grain legumes in the last 14 years is at the annual growth rate of 0.37%. At this rate, the projected global demand for grain legumes (10% in the coming decade and 23% from current level by the year 2030) can only be met by an increase in average yields of grain legumes (Akibode and Maredia, 2011).

Farmers cultivate legumes as sole crops or as intercrops with cereals, oilseeds, and other staples; fit them into the short-season windows between cereal crops; or as relay crops (Amede and Kirkby, 2004). Food legumes are excellent crops in agro-pastoral areas to exploit rainfall suitable for short season crop production. Legumes are critical components in food systems, offering dietary diversity in cereal-based systems, and supplying protein, minerals and vitamins. However, with cereal production expected to double over the next 30 years (Specht et al. 1999), cereals will continue to occupy and expand in more favorable environments available to farmers while legume crops will gravitate to marginal areas characterized by poor soils, fragile ecosystems and comparatively short growing periods where the intensity and occurrence of adverse events such as drought and temperature extremes are more frequent and intense. While insect pests, diseases and extreme climatic events are seasonal, when coupled with edaphic constraints lead to low and unstable yields.

Studies show that legumes contribute more than 20 million tons (MT) of atmospheric N₂ to agriculture each year (Herridge et al. 2008) but much higher levels of N₂ fixation are possible. For example, N₂ fixation with soybeans can easily exceed 300 kg per ha per year. In Brazil, soybeans provide up to 94% of total plant N and represent an estimated saving to the economy of up to US\$6.6 billion per year (Hungria et al. 2006). In northern Tanzania, studies showed that pigeonpea provided 100% of its N requirement and left behind about 40 kg of N/ha to the systems (Adu-Gyamfi et al. 2007). Legumes can also improve the phosphorus availability in cropping systems. In low-input cropping systems farmers usually do not apply phosphorus fertilizers to their crops, making it one of the limiting macro-nutrient for crop production. Legumes, such as chickpea (Li et al. 2004) and pigeonpea (Noriharu et al. 1990), can solubilize phosphorus and make it available to companion crops.

Grain legumes are remarkably diverse in their range of adaptation (Hall, 2004). CRP3.5 will exploit the diversity of legume species, to confront the challenges of climatic, edaphic and biotic constraints, through a strategic combination of both increased productivity and resilience to bridge the yield gaps and to exploit new niches like short-season windows of the existing cropping systems. Researchers of CRP3.5 GRAIN LEGUMES will seek efficiencies through sharing facilities; joint testing of improved germplasm in new niches; screening for abiotic and biotic stresses in target environments and controlled conditions; and exploiting genomic resources across species.

5.2.2 Priority setting

The priority regions for CRP3.5 GRAIN LEGUMES are given in Chapter 3 Justification. However, we will focus research in primary countries where the expected impacts are high, and it is expected that a few secondary countries (Appendix 3) will also benefit from this research, apart from spill-over benefits to many other countries in the region and globally.

Yield of grain legume is constrained by several abiotic and biotic stresses. Appendix 6 has details of relative yield losses caused by the abiotic and biotic constraints in the target crops in the different regions. Based on the yield losses we have prioritized the key constraints that we will be addressing in Strategic Objective 2 (Table 5.2.1).

Table 5.2.1. High priority abiotic and biotic constraints for genetic enhancement of grain legumes

Trait	CB	CP	CW	FB	GN	LN	PP	SB
Abiotic constraints								
Drought	√	√	√	√	√	√	√	√
High/low temperatures	√	√		√		√		
Edaphic constraints (low P and BNF, Al toxicity)	√	√	√		√		√	√
Biotic constraints								
Diseases								
Root diseases (wilt/root rots)	√	√				√	√	
Fungal foliar diseases (Ascochyta blight/Botrytis grey mold/ Stemphylium/rust/chocolate spot/ early leaf spot /late leaf spot)	√	√		√	√	√		√
Viral foliar diseases (mosaic/sterility mosaic/rosette/bud necrosis/ yellowing/stunting)	√	√	√		√		√	√
Insect-pests								
<i>Helicoverpa/Maruca</i>		√	√				√	
Aphids/leaf hoppers/pod fly/bean fly/flower thrips/Apion	√		√				√	
Parasitic weeds			√	√				

Note: CB=common bean, CP=chickpea, CW=cowpea, FB=faba bean, GN=groundnut, LN=lentil, PP=pigeonpea, and SB=soybean

The priorities are based on yield losses. See Annexure 6 for Relative yield losses due to abiotic and biotic constraints in target legumes in different regions.

In addition to resistance/tolerance to abiotic and biotic stresses listed above, emphasis will also be on development of cultivars with suitable phenology to match the available length of crop season in the target environments. This includes development of early to extra-early maturing cultivars in CB, CP, PP, LN, GN, CW and SB. The priority traits for improvement of nutritional quality include enhancing micronutrient (iron and zinc) and protein contents in CP, CW, FB, PP, GN, and LN; and oil content and quality in GN. The end-user and market preferred traits include physical appearance of seed (size, shape and color) in all legumes, split (Dhal) making quality in CP, LN and PP and cooking quality in CB, CP, CW, FB, LN and PP. The cooking quality is an important trait for women as it can save considerable time and energy spent on cooking. Mechanization of legumes cultivation is desired for reducing cost of cultivation and reducing drudgery on farm-women. Development of cultivars suitable for mechanical harvesting will be a priority in CP and LN and herbicide tolerant cultivars in CP, GN and LN. The other priority traits include improving biological nitrogen fixation (BNF) efficiency of in CB, CP, CW, FB, GN, and SB; and phosphorus use efficiency in CB, FB, GN, LN, CW and SB.

5.2.3 Impact Pathway

Grain legumes are generally cultivated in marginal environments and are affected by several abiotic, biotic and edaphic constraints (see above). The outputs of Strategic Objective 1 (genetic resources and novel breeding tools/methods) will contribute significantly to the outputs and impacts of Strategic Objective 2 by providing useful genetic resources for important traits and novel breeding tools/methods. The outputs of SO2 will be elite breeding lines and cultivars with enhanced yield potential, greater yield stability due to improved resistance to stresses and enhanced nutritional and commercial value. These will be shared with partners both in public and private sectors who will evaluate these for local adaptation. The selected lines will be evaluated at multi-locations within the target region and the best performing lines will be released as varieties by the partners in different countries through their national systems. Farmers and end-users will be involved in participatory varietal selections, so that the selected lines would have better acceptance when released commercially. This will be the input from this objective to Strategic Objective 4 on Seed Systems. Inadequate availability of quality seed is a major bottleneck in legumes for spread of new cultivars. Availability of seed and enhanced awareness of farmers about improved cultivars and production technologies will help in enhancing adoption of improved cultivars technologies, which will not only reduce the yield gap and yield variability but also lower production costs and risks. The impacts at farm level will include changes in terms of income, asset accumulation; human capital, food consumption, nutrition and health (see Figure 5.2.1). The research findings including methodologies developed will be shared with the researchers in the national system thorough publications and presentations at various forums. These will help partners in improving efficiency of their legume improvement programs. They would be better equipped to respond to the future needs of cultivars and develop these more rapidly.

5.2.4 Key partners and their role

Strategic Objective 5.2 will work closely with CRP1.1 and CRP1.2 (dryland and humid tropics production systems) for developing and testing improved legume cultivars in different production systems. The diversity of legumes adaptation to varied ecological niches make them valuable assets for these CRPs. Collaboration with CRP7 (climate change) will identify key regions for targeting the development of resilient legume varieties for changing climatic conditions. We will work with CRP4 to extend successes with beans to other legumes with enhanced nutritional composition. We will work closely with the other CRP3s (especially maize, wheat, rice, dryland cereals, and roots, tubers and bananas) for effective and integrated cropping systems; and CRP2 for policy and impact studies. Our intention is to leverage capacity and resources from within the CGIAR, the larger national research and development programs, and advanced research institutions (ARIs) in an effort to increase the capacity of smaller, under-funded national programs. Major legume programs beyond the CGIAR are found in Brazil, Turkey, Canada, India, Mexico, Ethiopia, Australia, and the United States. Several of these countries are centers of diversity of important legumes, and can offer important insights on the exploitation of genetic diversity in crop improvement. Partnership with these programs and networks, like Dry Grain Pulse Collaborative Research Support Program (Pulse CRSP), will support in sharing the resources and expertise for developing greater national capacities and help to facilitate germplasm and information exchange. Many ARIs have expressed their interest to collaborate with CRP 3.5 GRAIN LEGUMES and negotiations for collaborative efforts are well under-way. Research will be carried out in close collaboration with national research programs, ARIs, universities, and the private sector. The ARIs will mainly be involved in upstream research, but with a shared interest in applying this to practical plant breeding, while location specific technologies will be developed in partnership with NARS. The partners for developmental activities will include NARS, and various governments and NGOs involved in developmental activities. Roles and responsibilities of partners are dealt in detail in Chapter 6 on Partnerships.

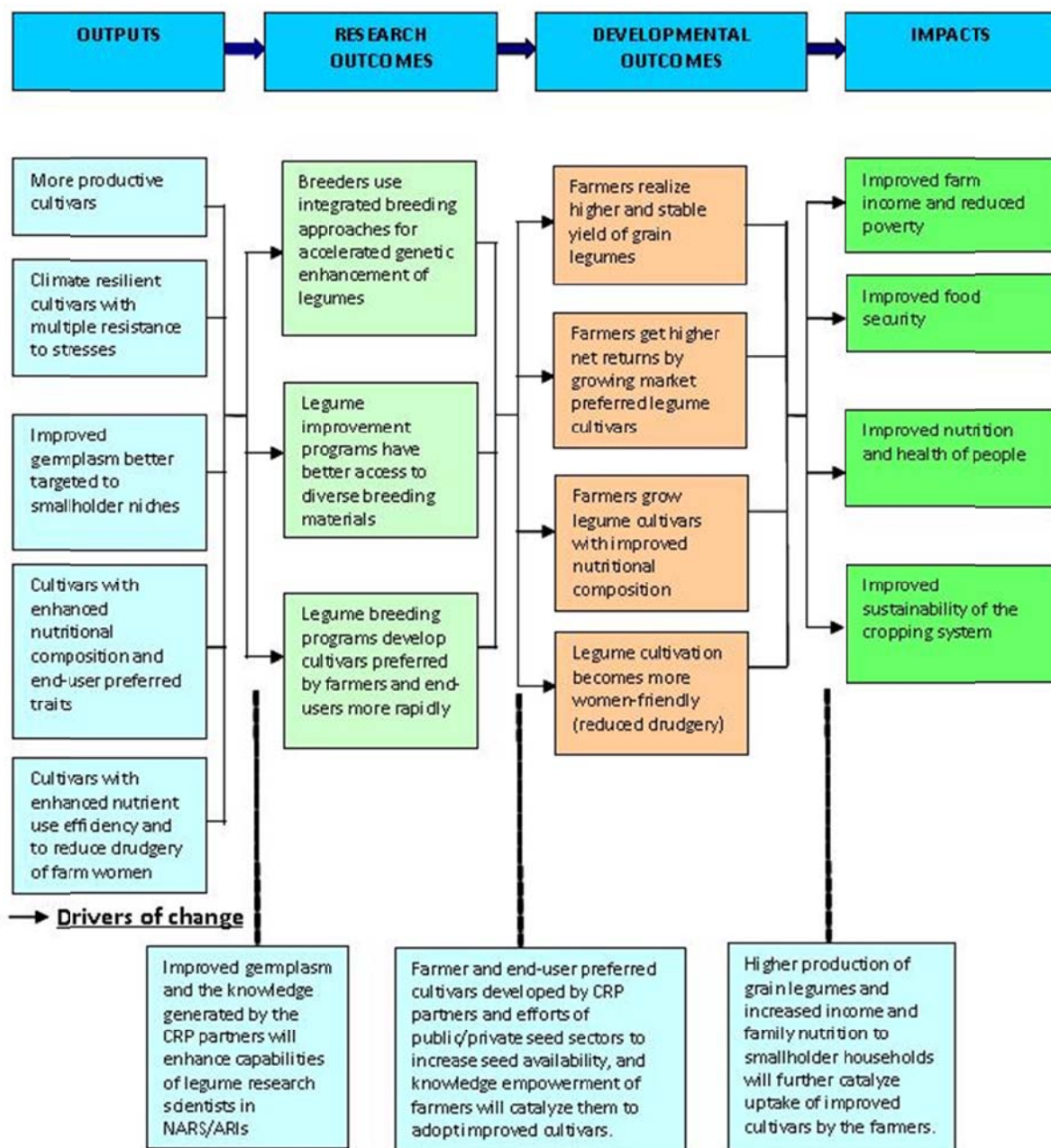


Figure 5.2.1. Impact pathway for Strategic Objective 2

5.2.5 Gender Strategy

Traits that benefit women e.g., fast cooking and micronutrient-rich grains; varieties suitable for mechanically harvest, and herbicide tolerant varieties to reduce drudgery for women (Badiger et al. 2004), will be given prominence in varietal development. Women and children (the most vulnerable groups nutritionally) will be the primary clients of nutritionally improved legumes. Women play a critical role in any nutrition education component, both for their own health, and their role as care givers and homemakers (including food preparation). The most likely role of legumes is in improving maternal health, especially during pregnancy, which in turn impacts on infant health. The IFPRI Conference on Leveraging Agriculture for Health and Nutrition (10–12 Feb 2011, New Delhi, India; <http://2020conference.ifpri.info/tag/day-2/>) identified women as key enablers in the integration of

the three sectors: Agriculture, Health and Nutrition and their active involvement in the breeding process will be vital.

Farmers' participatory varietal selection (FPVS) approach currently in use across centers will continue to actively involve both men and women farmers of different social classes to increase their influence on the breeding criteria. Plant varieties chosen by women will not be limited to yield or disease resistance, but may also relate to peaks in labor requirements during the crop cycle. Specific targeting of various women groups (from richer households, vulnerable etc.) will be emphasized during the selection of varieties where potential trade-offs between traits (i.e. micronutrients, commercial value, drudgery) exist to ensure that the program does not stray from their concerns, or is able to adjust to any changes in these concerns. Legume cultivars with such women-preferred traits would thus enable closing of gender gap in agriculture that would generate significant gains to the society. Qualitative assessment of trait preferences will be complemented with quantitative assessment of trait trade-offs for each gender group to ensure that gender targeting is achieved while maximizing welfare gains.

A participatory monitoring and evaluation system will integrate local- and gender-specific indicators for monitoring outcomes. Gender disaggregated data and analysis will provide feedback lessons to draw from for improving the mainstreaming of gender into the activities of this objective. Views, perceptions and knowledge of rural women will be fully captured and incorporated into the research process. The capacity of implementers at various to mainstream gender in the program activities will be enhanced through training and mentoring by gender experts.

Problem solving approaches of men and women researchers are often different, thus drawing on both men's and women's knowledge base can add significantly to the quality of research methodology and results. The program will aim for a balanced staff structure where the participation of women researchers and students will be encouraged. Women researchers will be attracted to legume improvement early in their career while they are undergraduate students through three to six months attachment in research stations so that they will be exposed to hands on experience on legumes.

5.2.6 Lessons learned and research questions to be addressed

The average farm yields of grain legumes are low and wide gaps exist between the yields realized at the research stations and at the farmers' fields, as grain legumes are largely grown rainfed in marginal environments with sub-optimal inputs and are prone to several biotic and abiotic stresses. The adoption of improved cultivars and technologies is low as compared to staple cereals and other high value crops. The crop cultivars available have narrow genetic base and most of the breeding programs are not using novel breeding methods that can improve precision and efficiency of breeding programs.

Key R4D questions to be addressed include:

- How much can yield and yield stability be increased given the stressful, short-season environments that grain legumes typically face?
- Can drought and low phosphorus tolerance in roots increase BNF and therefore grain yield under stress?
- Are any yield trade-offs involved in breeding for nutritional qualities (minerals, protein, oil, vitamins, reduced anti-nutritionals)?
- What breeding targets might contribute to more efficient and robust seed systems?
- How can breeding targets for climate change-proofing grain legumes be made robust despite the uncertainty and wide range of climate change scenarios and forecasts?

The research approaches to address these questions are described under methodologies section. Strategic Objective 2 will set priorities for Strategic Objective 1 to develop molecular tools, novel

breeding methods, phenotyping assays and trait specific germplasm. Objective 2 will use these products and services of Integrated Breeding Platform for increasing efficiency of breeding programs in speedy development and delivery of improved cultivars. Yield potential of the cultivars will be enhanced by improving the plant type, enhancing BNF and nutrient use efficiency, and maximizing the remobilization of photosynthates from vegetative structures to grain. The genetic variability in the breeding materials will be enhanced and novel traits introduced through interspecific gene transfers and transgenic technologies to develop cultivars with enhanced resistance/tolerance to stresses. The existing and introduced genetic variability will be exploited in developing cultivars with enhanced nutritional quality and other end-user preferred traits. Varieties will be developed which are amenable to mechanization for bringing down cost of cultivation. The participatory varietal selection approach will be used and seed systems will be strengthened (under SO4) to enhance adoption of preferred varieties by the farmers and end-users.

5.2.7 Outputs

5.2.7.1: Elite lines/cultivars with at least 25% higher yield potential than the best available cultivars developed for different production systems.

Description

Global grain legume yield data provide an impression of yield stagnation; however, an increasing trend is noted in the average production and yield of grain legumes since 1990 with stabilized or modest increased trend in per capita consumption in the developing countries in the last 14 years (Akibode and Maredia, 2011). However, the average yield of grain legumes in developing countries still remains less than 1 ton/ha. While cereal yields received a boost from nitrogen fertilizers, legumes are physiologically more complex with regard to N metabolism and its relation to photosynthesis. In the past relatively less emphasis has been given to enhance yield potential, compared to resistance breeding. We seek to improve yield from the present level of 800 kg/ha to at least 1200 kg/ha, by replacing existing local varieties with improved varieties, and adoption of improved crop management technologies. In the medium to long term, the yield potential of legumes requires substantial improvement within different cropping systems. High yield potential in legumes can be achieved either by improving biomass and its favorable partitioning to grain, or by breeding cultivars responsive to inputs (fertilizer and irrigation). Over the next decade, legume breeding programs will likely reorient their objectives to develop higher yielding cultivars with appropriate phenology and plant type for mixed crop with cereals, or fit within the short-season windows available between cereal crops. This output is set to develop and test high yielding elite lines/cultivars in partnership with NARS and through on-farm participatory research, to ensure the results fit the target production environments and meet requirements of smallholder farmers and end users.

Methodology

Interdisciplinary breeding teams, integrated across CG centers and NARS partners sharing critical facilities and learning from each other will identify and define productivity enhancing traits and ideotypes for different production environments, and adapted to varied future cropping systems. Approaches such as crop simulation modeling will be used for identification of yield enhancing traits. The combination of conventional and advanced molecular tools for parental and pedigree selection and better understanding of the genetics of agronomic traits should lead to more efficient breeding programs that make optimal use of the available resources including genetic/genomic resources. Strategic research will be carried out by Centers involved in collaboration with ARI and NARS partners on varietal improvement and advanced breeding methodologies. Multilocation evaluation across Africa, Asia, and Latin America will be accelerated, in partnership with regional networks, as a driver for germplasm enhancement, exchange and variety testing in different target environments.

Attempts have been made to define **ideotypes** of grain legumes for different growing conditions (Sedgley et al. 1990, Lather 2000). Spontaneous and induced brachytic mutants with short

internodes and compact growth habit have been used in ideotype breeding in CP and promising progenies with compact growth habit and which can be grown at high plant density have been obtained (Lather, 2000, Gaur et al. 2008). **Phenological adaptation** to the growing environment is critical when grain legumes move to new areas due to changes in climate and farming systems. The most important stage is the transition from vegetative growth into the reproductive phase or “flowering”. In the last ten years, major advances in understanding of the flowering process have been achieved in model species *Arabidopsis thaliana* and rice (Salomé et al. 2011), and in garden pea (*Pisum sativum*) (Wenden and Rameau 2009). Recent progress in *Medicago truncatula* has enabled comparative mapping across major grain legumes. CRP GRAIN LEGUMES will seek to translate the knowledge on flowering time in *Arabidopsis*, using current information available in pea and *Medicago*, to improve breeding efficiency in target legume crops. Dissecting genes triggering the shift from vegetative to reproductive development could play a key role in maximizing the **remobilization of photosynthates** from vegetative structures to grain (Rao et al. 2009; Beebe et al. 2011). During grain filling, the major factor limiting the quantity of grain produced is nitrogen (and then next probably phosphorus). Therefore, every possible increase in the N nutrition of legumes, and especially a boost in its BNF capacity will increase the pool of available N toward grain filling (Sinclair and Vadez 2002). In beans improved plant efficiency in remobilization has been associated both with yield potential and with earlier maturity (Beebe et al. 2008). Enhanced harvest index will favor yield if it is combined with adequate biomass accumulation during the vegetative phase of growth. Genes that enhance this shift to the reproductive phase should be identified and employed in breeding programs in combination with both root and shoot traits that contribute for greater biomass production and N accumulation during vegetative phase. Wild species or cultivated related species could bring additional variability in essential physiological traits. The yield of some legumes (PP, FB) will be significantly improved by focusing on **hybrid vigor** and heterosis. The nuclear-cytoplasmic male sterility system (CMS) is well established in PP (Saxena et al. 2005, Saxena and Nadarajan 2010) and is under exploration in the case of FB. This will require the use of elite breeding materials, but also the introgression of crop wild relatives to diversify the nuclear as well as the cytoplasm of the lines (A, B, R) involved in the CMS system (Bohra et al. 2011). The use of **molecular breeding** strategies developed in Strategic Objective 1 will bring precision and accelerate the breeding processes and will become an integral part of cultivar development. These strategies include Marker-Assisted Selection (MAS) which targets the selection of specific alleles for traits conditioned by a few loci; Marker-Assisted Backcrossing (MABC) which is used to transfer a limited number of loci from one genetic background to another; and Marker-assisted Recurrent Selection (MARS) that deals with the identification and selection of several genomic regions involved in the expression of complex traits within a single population. For certain crops like CB, CP, CW, GN the use of these strategies under the current Tropical Legumes I project has been initiated (Varshney et al. 2010), and we plan to include other crops in due course.

Key milestones

- Ten elite lines with at least 25% higher yield than the best available cultivars developed across target legumes and shared with NARS partners (2013-14)
- At least five hybrids/ parental lines (A-,B-, R-lines) of PP made available to partners (2013)
- Prototype of ideal plant type for various production zones conceptualized and shared with national partners in targeted legumes (2014)
- Traits for enhanced photosynthetic remobilization to grain identified for at least one grain legume (2013)

Output 2.2: Elite lines/cultivars with enhanced resistance/tolerance to key biotic and abiotic stresses and resilience to climate change developed.

5.2.7.2: Elite lines/cultivars with enhanced resistance/tolerance to key biotic and abiotic stresses and resilience to climate change developed.

Description

Breeding efforts using conventional and molecular methods have produced a few cultivars that are resistant to key biotic and abiotic stresses, thus stabilizing productivity to some extent. However, in the face of global climate variability and change, there is an urgent need to improve resistances and tolerance to multiple stress factors by pyramiding useful genes. It is forecast that some areas will be getting drier while others will become wetter (Yadav et al. 2011). The impact from increased heat and moisture stress would be significant on overall production of grain legumes (Cutforth et al. 2007). Heat and drought can occur together and have some added effect on similar processes, including those involving reproductive processes. Reproductive processes are indeed damaged when stress occurs at critical developmental stages, reducing seed set (Wahid et al. 2007; Bourgault and Smith, 2010; Upadhyaya et al. 2011; Zaman-Allah et al. 2011). In addition, heat increases the rate of development processes, shortening the crop season and, while this is desirable in environment that are severely water-limited, this can bring a yield penalty in better endowed environments with regards to water. Several traits like earliness and deep-rooting trait are being used to develop drought-tolerant varieties with potential to escape drought and extract water from deeper soil layers. Similarly, rising temperatures and changes in moisture are predicted to alter the pest spectrum and dynamics, particularly their distribution, virulence/aggressiveness of pathogens, and emergence of new pathotypes/races/ biotypes affecting these crops (Beebe et al. 2011, Vadez et al. 2011, Yadav et al. 2011). Breeding for resistance offers the most environmentally sustainable approach to pest and disease control, allowing farmers to reduce pesticide applications and increase profit margins. Given the pace with which climate change is occurring, and because it takes 10-12 years or more to achieve impacts in farmers' fields, the research agenda of this output must be geared to deliver through a well-coordinated and multidisciplinary approach for developing improved germplasm for combating these production constraints and avoid crop failures in the target regions.

As mentioned above, legumes are attractive to pest and diseases and these are major yield limiting factors. In addition, legume species are often exposed to a combination of possible disease. Therefore, modern breeding offer here an opportunity to develop improved cultivars having several beneficial genes for resistance to different diseases. In this, the output from SO1 will also be critical, first to exploit the best of available germplasm toward breeding, but also to include wild relatives of legume cultigens which often harbor higher levels of resistance to certain diseases.

Methodology

Existing lines will be improved for resistance/tolerance to key biotic and abiotic stresses. Accessions from the germplasm collections both cultivated and **cross-compatible wild relatives**, with desirable traits will be used as parents in both conventional and molecular breeding approaches. For example, within the genus Phaseolus, *P. coccineus* and *P. dumosus* are adapted to moist environments and are resistant to many pathogens of CB. At the other ecological extreme, *P. acutifolius* is adapted to hot and dry conditions of the American southwest and northern Mexico. These species may serve as physiological and genetic models of adaptation, and/or sources of genes to overcome the effects of climate change. This, along with known contrasting lines within each species, will also contribute to the understanding of critical adaptation mechanisms and traits; whether those are either constitutive or stress inducible. Since several abiotic stresses involve constraints at the level of soil (drought, soil fertility, aluminum toxicity, reduced soil organic matter due to accelerated mineralization, etc.), adapting to these stresses will involve in part fitting the right root system to the specific soil environment. This is a particular challenge, and **root biology** should play a significant

role in defining a target phenotype, in identifying the source materials for breeding programs, and in defining selection criteria (Lynch 2011). Methods that can address these dual constraints are available through collection of much more precise and dynamic data on the contribution of root systems (Zaman-Allah et al. 2011; Vadez et al. 2008). Progress has been made in identifying major QTLs associated with yield under drought stress in chickpea (Imtiaz 2010). Near-isogenic lines (NILs) possessing drought-tolerance QTLs will be analyzed physiologically to unveil mechanisms involved in tolerance and the interaction between these QTLs and facilitate their effective use in breeding. **Crop simulation** efforts will also contribute to an important step of testing the effect of specific traits or mechanisms across a large range of environments and weather conditions. Efforts are already underway in CP and CW to transfer **drought tolerant QTLs** into sensitive genotypes which are otherwise high yielding and adapted to areas of production. **Phenotyping methodologies** for these stresses will be standardized to establish and share platforms for large-scale evaluation under managed stress conditions to facilitate precise measurements of stress related traits including grain yield. Environments representative of future production conditions of heat and drought will be identified through **GIS/remote sensing** analysis in cooperation with CRP 7. This will permit identification of currently available germplasm for wider testing, in preparation for the future (20-50 years) as well as extreme climatic events that could occur even in the next few years.

Diseases, insect pests and parasitic weeds will be monitored in order to know their spatial and temporal distributions using GIS/remote sensing (Dionissios et al. 2010) for better targeting of the breeding programs to develop pest resistant/tolerant cultivars. The data will be used to develop **pest and disease distribution maps** to monitor their spread over time as food legumes are introduced into new niches. The breeding lines will be tested under hot spot areas in Africa and South Asia and also under controlled conditions for their resistance/tolerance to aggressive pest populations. Insect, parasitic weed and pathogen diversities will be studied using conventional and modern techniques to expose the breeding materials against aggressive populations. Evaluation of multiple resistance/tolerance to pests will be done through **international and regional nurseries**. **Genetic transformation** efforts will be strengthened particularly for difficult traits, for example, cowpea with Bt gene for resistance to *Maruca* pod borer, and Bt chickpea and pigeonpea for resistance to *Helicoverpa* pod borer.

Key milestones

- At least 100 breeding lines with improved resistance to key diseases and insect pests developed across all target legumes (2013)
- At least 20 breeding lines with improved drought/heat tolerance in CP, CW, CB, GN, FB and LN developed and shared with partners (2014)
- At least 15 elite lines with combined resistance to key biotic and abiotic stresses per year across legumes developed and shared with partners (2012-13)
- At least 6 breeding lines with improved water-logging tolerance developed in CW and PP and shared with partners (2013)
- About 20 breeding lines with better adaptation to problematic soils (salinity, acidity) developed/identified (CB, CP) (2014)
- Better understanding of the mechanisms and genetics of resistance/tolerance to biotic and abiotic stresses (CB, CP,GN, LN) (2014)

5.2.7.3: Improved germplasm better targeted to smallholder niches using GIS and other novel methods

Description

Legumes typically present narrower adaptation ranges than cereals and are sometimes referred to as niche crops. Targeting of materials to niches has two broad dimensions: one is biophysical, and

the other is social and includes farmer and consumer preferences. Biophysical targeting can be supported by GIS analysis of crop data across environments, to classify production regions into clusters with similar crop response. In the early days of the CGIAR centers, international nurseries were planted widely, and data from these trials permitted studies of adaptation and classification of environments. As budgetary limitations reduced systematic international testing, such broad based databases were no longer generated, and most targeting in recent years has been based on experience and empirical knowledge. Meanwhile, new genotypes with wider adaptation and specific adaptive traits have been developed. It is likely that the adaptive pattern of newer materials is different than those in past, and updating environmental classifications based on currently available germplasm would facilitate targeting. For example, CIMMYT revised its mega-environment system for wheat and maize breeding as genetic advances were registered and these have been used to assist with priority setting and targeting of germplasm (Setimela et al. 2005; Hodson and White, 2007). International centers can develop gene pools with traits of high yield potential, resilience under climate change etc. but such traits must be deployed in varieties with local adaptation, and with specific farmer and consumer preferences. Varieties are increasingly being developed by national partners, either by selection within such gene pools, or within populations created specifically for their own purposes. More dynamic and productive breeding programs will result when the strengths of both IARCs and NARS are brought to bear on breeding challenges, especially when bolstered by inputs from farmers, traders and stakeholders. This output is designed to focus on better targeting of improved germplasm through improved methods such as applications of GIS, simulation models, global dissemination of improved germplasm, selection of farmer and end-user preferred cultivars, data curation and providing easy and open access of databases to the global research and development agencies.

Methodology

Germplasm dissemination: Information based on performance of the materials at multiple locations will be centralized and used to predict adaptation of the germplasm to areas having similar **agro-ecological conditions**. Nurseries of germplasm with unique **adaptive traits** will be evaluated for yield across the range of production environments, to study the adaptive patterns of modern germplasm and the **classification of environments** based on crop response, including those that simulate future stressful environments. Accompanying physiological analysis will relate yield response to adaptive traits. Application of **predictive programs** such as Homologue (gisweb.ciat.cgiar.org/homologue/) will extend results to other environments and serve to highlight best environments for phenotypic selection. This will indicate potential adaptation even across continents where work on a given crop is limited. Predictions of climatic effects (especially heat stress) will be refined with CRP 7. Fitting germplasm to environments requires systematic and accessible databases. **Data management** for breeding programs will be streamlined in accord with efforts spearheaded by the GCP. Data will include phenotypic and genotypic data but also climatic and soil parameters, and **farmer preferred traits**. Crop ontologies will facilitate standard annotation of legume traits. Data management systems (software) will support all steps in the breeding process (inventory of seed, experimental design, preparation of field books, field planting plans, data collection, data analysis, selection of materials). Commercial (e.g., AGROBASE) and publicly developed platforms (**Integrated Breeding Platform**) will be used in combination with electronic field books. As molecular breeding becomes a regular practice, molecular-marker data will be integrated into the breeding software to more efficiently estimate the value of genotypes and potential parents in breeding populations. Data and germplasm will be made available to NARS breeding programs for the development of segregating populations tailored to local needs. Crosses will be planned and selected jointly with partners to bring together strengths of the centers and national breeders knowledgeable of local preferences. The final word in targeting germplasm lies with farmers. **Participatory variety selection** (PVS) will document farmers' needs and preferred traits in legume cultivars, and **farmer preferences** will be registered in the database. PVS complements the efforts of traditional **on-farm trials** which give limited choice of varieties that were preselected by breeders. PVS is now widely applied in many

breeding programs in Africa, CWANA and Asia and its use will continue.

Key milestones

- Database on multi-environment trials (MET) generated and made available to national partners (2013)
- Climate change effects on grain legumes assessed with CRP 7 (2013)
- New niches (both current and under climate change scenarios) for grain legumes identified using crop models and GIS spatial technologies (2013)
- Data management Centre for target grain legumes established and publicly available (2013)
- Methodological framework for the analysis of a crop yield gap developed (2014)
- Trait specific germplasm is tested over multiple sites to develop crop response clusters for at least four crops (2014)
- Suitability of new legume crops in different environments evaluated by crop simulation modelling (2014)
- At least two regional/international nursery of improved germplasm in each grain legume constituted and distributed to partners annually (2013, 2014)
- 2-3 farmer and end-user preferred varieties identified for each grain legume in each target region through PVS where women's participation is encouraged and their preferences appreciated (2013)

5.2.7.4: Elite lines/cultivars with enhanced nutritional composition and end-user preferred traits developed.

Description

Legume crops play important roles in the diets of the poor, especially of vegetarians around the world. Grain legumes, when combined with cereals, provide a nutritionally balanced amino acid composition. Regular consumption of grain legumes is now recommended by most health organizations (Leterme, 2002; USDA, 2010). In addition to their role as high-protein food crops, they are good sources of micronutrients like iron and zinc, and in some cases vitamin A. The SRF identifies addressing micronutrient deficiencies as a priority for nutritional work of the CGIAR. Iron deficiency is the most common nutritional deficiency, affecting as many as 4 billion individuals worldwide (ACC/SCN, 2004). Severe iron deficiency leads to low levels of haemoglobin (anemia). An estimated 329 million women in the Americas, Africa and south Asia are anaemic, together with 221 million preschool age children (WHO, 2008). Several success stories have demonstrated the feasibility of using plant breeding to address nutritional problems. Currently, the HarvestPlus Challenge program under CRP4 is developing crops, including CB, which carry higher levels of iron, zinc and/or beta-carotene. When biofortified CB were compared to normal CB, consuming biofortified CB improved iron status of school children in Mexico when transferrin receptor was used as an indicator of iron status (Haas et al. 2010). Soybeans have also been shown to supply bioavailable iron to legume consumers in significant quantities (Murray-Kolb et al. 2003). HarvestPlus has taken the lead in demonstrating the potential for genetic improvement of CB for iron and zinc concentration (Beebe et al. 2000). However, HarvestPlus focuses work on CB in Rwanda and the Democratic Republic of Congo (CRP 4). We would broaden the scope of this work to other countries in Africa in the case of CB, and to other legumes and countries that are not researched under CRP 4. Levels of anaemia and the potential to address micronutrient malnutrition among populations that traditionally consume legumes justify this effort. Both agronomic and quality traits such as seed characteristics (size, shape and color) influence market price and farmers' decisions of what to plant. For example, the large seed size in kabuli CP and GN fetches a price premium in the market. CRP 3.5 will focus on combining nutritional quality with farmer-, consumer- and market-preferred traits, to create gene pools that

can be employed readily for the creation of nutritionally enhanced varieties with other market preferred traits such as large seed size, and less cooking time.

Methodology

Biofortification: We will work closely with CRP 4 in identifying research gaps for grain legumes in relation to nutritional quality. Nutritional status of the population is a primary criterion, although practically all countries in South Asia, Sub-Saharan Africa and in Latin America present moderate (20-39%) to severe (>40%) levels of anemia in women and children (WHO, 2008). The lower social strata has even higher levels. The CRP 4 lays out the criteria for establishing a **breeding program for biofortified crops**:

- Can plant breeding and modern agricultural biotechnology techniques increase the nutrient density of food staples to target levels that can potentially have a measurable and significant impact on human nutritional status?
- When consumed under controlled conditions, will these extra nutrients be bioavailable and absorbed at sufficient levels to improve the nutrient status in target populations?
- Will farmers adopt the biofortified varieties?
- Will consumers purchase/eat the biofortified varieties?

Among the edible grain legumes, research on biofortification of CB is most advanced and experience in CB can orient the development of breeding activities in other crops, to respond to the four issues above. The evaluation of a core collection of CB addressed point 1 above, and was a useful tool in the identification of high iron sources (Beebe et al. 2000). Lines or accessions derived from wide inter-gene pool crosses often gave the highest levels of iron, and interspecific crosses contributed additional genetic gain. Broad based germplasm collections for CP, PP, CW, GN, LN, such as those developed under the GCP, together with related species and materials derived from wide crosses, will be evaluated for **micronutrient concentration**, following procedures of HarvestPlus (Stangoulis and Sison, 2008). **Mineral** analysis will be carried out using atomic absorption in the first stages, followed by confirmation with ICP. Carotenoid measurement of LN, CP, and PP will be adapted to the use of NIRs (in partnership with CRP 4). Issues of **bioavailability** (point 2 above) can only be resolved experimentally, and this has formed part of the HarvestPlus program, but to date results with beans are promising (Tako et al. 2009). Haas et al. (2010) found a beneficial effect of high iron CB in school children with lower levels of consumption than had been assumed necessary for a significant health outcome, suggesting that bioavailability could be higher than expected. It will be necessary to combine the high micronutrient trait together with **agronomic traits** to promote adoption by farmers (point 3). No resistance from consumers is expected to eating legumes **biofortified** with minerals since this is an invisible trait, but consumer acceptance of legumes with high **carotene cotyledons** may require acceptability studies if deployed in regions where these are not customary. In contrast to the efforts with CB which sought to create biofortified varieties with all necessary traits in the short run, high micronutrient gene pools will be created whereby the nutritional trait(s) will be combined with one or two agronomic and/or acceptability traits, to create parental material for further genetic combinations in a second cycle of crosses. We deem that this will be more efficient and simpler genetically, and may not delay the ultimate product in the long run.

Transgenics are being developed for enhanced beta-carotene contents in GN and PP at ICRISAT and the selected events will be evaluated further. **Trypsin inhibitors** will be assayed in soybean to reduce this anti-nutrient. NIRS will also be calibrated for the evaluation of protein concentration in grains of CP, CW, PP, GN and LN, and in both grain and stover of GN and CW. The relationship between nutritional traits and/or anti-nutritional factors with productivity and resistance to **diseases and/or insect pests** will also be established.

Key milestones

- Genetic variability determined and a baseline is established for relevant nutrients, anti-nutritional and/or biochemical factors in CP, CW, GN, LN, PP, FB and SB (2013)
- Information on relationships between anti-nutritional factors and resistances to insect pest and diseases, and between nutritional traits and productivity available in CB and shared with partners (2013)
- High iron CB tested in another five countries in Africa outside of Rwanda and D.R. Congo (2013)
- Stability of nutritional trait expression determined over environments (CB, CP, CW, GN, LN, PP, FB, SB) (2014)
- At least 20 breeding lines with high protein and/or micronutrient content developed/identified in CP, CW, FB, PP, GN, and LN and shared with partners (2014)
- At least 5 breeding lines with high oil content/oil quality developed/identified in GN (2014)
- At least 20 breeding lines with market-preferred seed traits, such as large seed size in CB, kabuli CP, GN and SB developed (2014)
- At least 15 breeding lines with faster-cooking quality developed in CB, CP, CW, FB, LN and PP (2014)

5.2.7.5: Elite lines/cultivars with enhanced nutrient use efficiency, high N₂ fixation potential and other traits for system efficiency developed

Description

Excessive use and inefficient management of nutrients like N and P threatens the environment and increases crop production costs, thereby reducing profitability and increasing the risk associated with crop production. Though there are several definitions of nutrient use efficiency, a widely acceptable one is based on minimizing the intensive use of fertilizers along with genotypes that are able to mobilize the limiting nutrient in greater amounts, particularly in marginal areas where farmers do not apply adequate amounts of fertilizers (Keneni and Imtiaz, 2010; Lynch 2011). Fertilizers are not affordable and/or available for farmers in developing countries. Sasakawa Global 2000 conducted well over 600,000 on-farm demonstrations in 12 SSA countries where they showed excellent response to fertilizer applications (Quinones et al. 1997). Studies have revealed that the average fertilizer application in SSA is approx. 9 kg/ha/yr compared to 86 – 142 kg/ha/yr in Latin America or South East Asia (Crawford et al. 2006, Bekunda et al. 1997). Development of nutrient efficient genotypes (FAO 1995) and BNF efficient cultivars in legumes along with effective rhizobial and mycorrhizal association and the synergistic relations have been suggested (FAO 1995; Clark et al. 1988; McKnight Foundation 2008). Nevertheless, little effort has been made to genetically improve adaptation of legume crops to nutrient deficient marginal soils despite the technical possibilities (Keneni and Imtiaz, 2010). In addition, to improve system efficiency, N₂ fixation in grain legumes by plant breeding needs to be enhanced. Similarly, legumes compete poorly with weeds leading to significant yield reduction. For example in CP yield reductions of 23–87% due to competition from weeds have been shown to occur (Yenish 2007). Furthermore, most grain legumes are susceptible to post-emergence herbicide and this is another area neglected in the past. Therefore the research agenda for this output of the CRP3.5 GRAIN LEGUMES will be geared to achieving system efficiency through provision of resilient, water- and nutrient-use efficient, herbicide tolerant and high BNF capacity legume germplasm for deployment in breeding programs.

Methodology

High N₂ fixation legumes: One approach to be followed will be breeding for **promiscuous nodulation**. Promiscuous legume genotypes fix atmospheric N with the available rhizobium in the

soil whereas non-promiscuous types require specific rhizobium to fix N. Typically soybean requires specific inoculants but lines have been bred to nodulate promiscuously (Gwata et al. 2004; Gwata et al. 2005). Promiscuity is a heritable trait and cultivars were developed by introgressing promiscuity into non-promiscuous genotypes with **superior agronomic** performance (Giller and Dashiell, 2006). Generally, cultivars bred for promiscuous nodulation with the indigenous rhizobia were thought to increase production of legumes in tropical Africa with minimum cost affordable to small-scale farmers (Zengeni and Giller 2007). Selection for enhanced nodulation in promiscuous soybeans has resulted in improved gain for this trait in SSA (Tefera 2011). This approach will be followed to develop promiscuous lines with high **BNF**. The second approach to be followed in breeding for high BNF is optimizing the numbers and effectiveness of rhizobia in the rooting zone through strain selection and inoculation techniques (Herridge and Danso 1995). The BNF potential of legumes will be enhanced through specific rhizobial strain by legume cultivar interaction. Selection of legume lines under no N fertilization condition but inoculated with effective *Bradyrhizobium* or *Rhizobium* strains will be employed. The success of BNF in Brazil has been based on this principle (Alves et al. 2003). Germplasm lines with high BNF potentials under stressful environments such as low P and drought will also be identified following approaches and methods previously used (Vadez et al. 1999; Sinclair et al. 2000). Tall and erect to semi-erect cultivars suited to mechanical harvesting will be developed in CP and LN to reduce cost of cultivation and drudgery to women. Similarly, **herbicide tolerant cultivars** will be developed to reduce yield losses from weeds, and reduce drudgery to women from manual weeding. Several herbicide-tolerant crops have been developed and commercialized from herbicide-tolerant mutants obtained through chemical mutagenesis followed by herbicide selection or direct herbicide selection of spontaneous mutations (Tan and Bowe 2009). Commercial herbicide-tolerant crops developed from herbicide-tolerant mutants include imidazolinone-tolerant maize, rice, wheat, oilseed rape, sunflower, and lentil; sulfonylurea tolerant soybean and sunflower; cyclohexanedione-tolerant maize; and triazine-tolerant oilseed rape (Duke 2005). Among the chemical mutagens, EMS was the most popular one. We will focus on developing simple and efficient herbicide tolerance screening techniques and identification of novel source of herbicide tolerance in target legumes from the germplasm and also inducing through chemical mutagenesis. These will then be used in breeding programs for introgressing herbicide tolerance in the selected popular cultivars. CRP3.5 GRAIN LEGUMES will collaborate with ARIs working on herbicide tolerance in legumes. Nutrient imbalances such as P and Zn deficiency and Fe and Al toxicity are widespread in most production areas in Asia, Latin America, and Africa. Root traits have been shown to play critical roles in P efficiency in crops (Ramaekers et al. 2010; Lynch 2011). Identification of the quantitative trait loci (QTLs) conferring superior root systems could significantly enhance genetic improvement in legumes P efficiency (Quan et al. 2010). Other traits contribute to more grain production per unit of nutrient absorbed by the plant (Rao, 2002). Studies of root morphology and architecture to determine optimal rooting patterns for efficiency in nutrient uptake and fertilizer efficiency and testing of germplasm with enhanced tolerance to drought and low P availability, to determine if such traits influence BNF positively will also be a focus of this CRP. Donor parents for tolerance to these soil problems will be identified and physiologically and genetically characterized, and molecular approaches (markers or major QTLs) used in breeding programs to develop **nutrient efficient legume cultivars**.

Key milestones

- At least 15 early- to extra-early breeding lines for short-window cropping seasons developed in CB, CP, PP, LN, GN, CW, SB and made available to partners (2012)
- At least 5 breeding lines suitable to cereal based intercropping systems developed in PP (2014)
- At least 4 breeding lines suitable for mechanical harvesting to reduce manual harvesting, especially by women, identified/developed in CP and LN (2013)
- At least 10 breeding lines with high BNF capacity in CB, CP, CW, FB, GN, and SB

developed/identified and tested under a wide range of environments (2013)

- At least 10 P efficient breeding lines developed/identified in CB, FB, GN, LN, CW and SB (2014)
- At least 5 breeding lines with improved herbicide tolerance to reduce manual weeding by women in CP, GN, LN developed/identified (2014)
- Nutrient and water-use efficient varieties (2-3 in each legume) for increasing legume productivity identified (2014)

5.3 Strategic Objective 3: Identifying and promoting crop and pest management practices through farmer participatory approaches for sustainable legume production

5.3.1 Rationale

Food production would need to increase by 70% to meet the demand of world's growing population expected to reach 9.1 billion by 2050. In developing countries, 80% of the necessary production increases would have to come from increases in yield and cropping intensity and only 20% from expansion of arable lands. The Strategic Objective 3 aims at developing crop and pest management options that allow optimization of production of legumes leading to enhanced productivity and intensification of the cropping systems and sustainability of the farming systems, in collaboration with the system level work undertaken in CRP1.1, CRP 1.2, CRP 5 and CRP 7. Grain legumes play an important role in sustainability of farming systems through nutrient inputs into the soil, and nutritious food for human beings and livestock (Graham and Vance, 2003; Serraj, 2004). Legumes possess an enormously valuable trait to fix atmospheric nitrogen (N) through biological nitrogen fixation (BNF) into plant-available N forms. They effectively make their own N and also leave significant amounts of N in the soil that benefits the subsequent crops (Serraj, 2004; Bado et al. 2006; Kumar Rao et al. 1998; Goergen et al. 2009; Lupwayi et al. 2011). Nevertheless, they are also risky crops because they attract several insect pests and diseases (due to their rich nutrient content), parasitic weeds and the process of BNF is extremely sensitive to major climatic (drought) and edaphic (P deficiency) constraints (Serraj and Sinclair, 1998; Vadez et al. 1999). In addition, the nitrogen coming from legume residue may not be released in a timely manner to the subsequent crop that it is supposed to benefit and may then be leached out. Therefore, crop management options that optimize the fitness of legume-cereals rotation to maximize the recovery of N from legume residues to the cereal are required. Practices that favor BNF tend to favor yield per se, and thus have immediate economic returns as well.

Food security requires sustainable increases in land productivity. Yet soil health is degrading fast due to faulty/inappropriate intensification of production systems. For example, total factor productivity has declined significantly in the intensive rice-wheat cropping system in the Indo-Gangetic Plains of South Asia despite increase in fertilizer use (Joshi, 1998). For most resource-poor farmers in the developing countries, fertilizer use for legume production at adequate levels is not an option, and the soil is being mined of nutrients through crop production. Estimates of soil nutrient depletion in Sub-Saharan Africa, Asia and Latin America suggest a current net removal of 20 to 70 kg ha⁻¹ of N from agricultural land each year. Replacing soil nutrients in sub-Saharan Africa alone is estimated to cost at least US\$4 billion annually (Sanchez, 2002).

The proportion of total N in legume plants sourced from BNF varies widely (0-95%) depending on crop species, availability of soil soluble N, suitable rhizobia, and suitability of soil conditions for productive symbiosis. For example, legume species and varieties varied in their nitrogen fixing abilities in lentil and pea (Abi-Ghanem et al. 2011). Studies have shown that grain legumes contribute more than 20 million tons of fixed N to agricultural crops each year (Herridge et al. 2008). However, BNF is very sensitive to abiotic stresses such as drought (Sinclair and Serraj, 1995; Serraj et al. 1999), which reduces legume yields and their potential benefit in crop rotations. Therefore, special effort is required to identify legumes and rhizobium strains that are better adapted to drought stress. In addition, legumes that are efficient in acquiring phosphorus (P) from high fixing soils are needed to increase the benefits from BNF (Li et al. 2004; Nori haru et al. 1990). Use of legume varieties that are efficient at acquiring P from less available sources would also benefit subsequent cereal crops through increased BNF. Micronutrient availability in the soil also plays an important role in improving BNF capacity and productivity of grain legumes. Drought and low P that constrain the BNF potential are a major research priority to capitalize on the benefits of BNF by grain legumes. Understanding the genetic factors underlying genotypic differences in BNF could make a major contribution to increase the overall contribution of legumes in crop production. Review of past BNF research identified several key constraints for limited adoption and /or impact on food

legume production (Bantilan and Johansen, 1995). The constraints were inadequate technology demonstration; presence of adequate native rhizobia, high soil mineral nitrogen levels, inadequate quality control of inoculum and difficulties of inoculating under tropical conditions. These constraints are still prevailing and needs to be addressed together with new emerging biophysical and other related issues.

Due to their high nutritional value, legumes are as attractive to insect pests and diseases, as they are to humans and livestock. Although breeding has overcome some of these problems, pesticides are still needed to manage many key pests such as *Helicoverpa* and *Maruca* to improve legume productivity (Sharma et al. 2010; Chen et al. 2010). At the production level, it is essential to expand pest and disease management options to include integrated pest management (IPM) approaches, especially host plant resistance, biopesticides, natural enemies and rational use of synthetic pesticides – particularly those that have wider application across legumes, and are less disruptive to the ecosystem and human health. Crop rotation and intercropping practices using grain legumes also tend to reduce the intensity of weeds, diseases and insect pests that are increasing in severity due to climate change, and changes in farming systems. Efficient integrated pest management (IPM) in climate resilient cereal-legume cropping systems will result in more stable crop production, and reduce vulnerability in areas threatened by climate change.

Our vision is to increase productivity and sustainability of smallholder agriculture in the face of climate change by increased cultivation of grain legumes in cereal based cropping systems, and crop-livestock systems. Our objective is to gain a better understanding of the genetic and environmental constraints on BNF, and insect pests and disease – plant host – environment interactions across grain legumes. Our aim is to identify cropping systems, varieties, and pest management practices to increase the productivity of farming systems involving grain legumes, where it is most likely to reduce poverty and environmental degradation. Land degradation and nutrient depletion are very severe in sub Saharan Africa, particularly in arid areas in the Sahel, and over populated areas such as the great lakes region and highlands of East Africa. We will conduct these research activities in partnership with CRP 1.1, CRP 1.2 and CRP 5, CRP 7 and with Dry Grains Pulse CRSP which has active research in the areas of BNF and IPM. In this strategic objective most of the research for development activities will be done both on-station and on farm where farmers will participate in the trials management, which will facilitate the adoption of technology and setting up future research priorities. It is recognized that both improved germplasm (varieties/hybrids) and better agronomic and resource management practices are necessary for improved crop productivity, and for enhancing the role of legumes in the production systems (see Appendix 16 for details).

5.3.2 Priority setting

The priority regions for specific legumes are described in the Chapter 3 on Justification. Priority for tackling different biotic and abiotic constraints in different crops is based on yield gap analysis as described in the below paragraph and given in Table 5.3.1.

It is common knowledge that improved legume varieties alone have limited potential to raise crop productivity, and that there is a need to combine improved varieties with other cropping systems technologies to improve yields of legume crops. Yield gap analysis, the loss in yield in different legumes due to insect pests, diseases, drought/water management, biological nitrogen fixation, weeds, etc. was estimated as a proportion of the total yield gap between realizable yield (average yield that farmers can plausibly obtain in their fields using optimum crop management) minus actual yield (average yield actually harvested by the farmers across regions (FAOStat 2009)). Proportional loss in yield due to different stresses was based on the contribution of a trait/factor to the total yield gap. Plausible closure of yield gap was based on the yields which could be realized by overcoming various yield reducing constraints over the next 10 years through R4D. The average realizable yield

gap in grain legumes has been estimated to be 65% (61% in lentil to 71 % in groundnut). Major constraints responsible for yield loss (see appendix 6 for details) are: poor soil fertility, drought and water management, diseases, pests, and weeds. Hence, substantial yield gain is possible with better soil, water, crop and pest management practices, in addition to improved cultivars.

The overall priority will be to develop integrated crop and pest management strategies that alleviate key biotic and abiotic constraints (insect, weed, and disease management, and poor soil fertility, in partnership with CRP 1.1, CRP 1.2, CRP 5 and the CRSPs) in grain legumes in the context of cereal-legume based production systems. Ultimately, smallholder farmers will be provided with a basket of options to choose from to manage their crops economically and effectively in an environment-friendly manner. This calls for participatory research processes which are consultative in nature, where researchers and farmers are actively engaged in developing and evaluating the crop and pest management technologies to select ones that work best under given circumstances. Note that unlike varieties which can be adapted to large areas or ecological regions, the integrated crop and pest management technologies could be localized, based on the prevalent biotic or abiotic constraints. This further emphasizes the need for farmer participatory research processes to be done on-farm, using farmers' own production conditions, because what works well at one site may not be applicable at another site. Through participatory research processes, and demonstration plots of technologies that work best, farmers in the communities share knowledge of the best practices, which helps to disseminate the technologies in areas where they can be applicable, termed farmer participatory research and extension (FPRE). Lessons learnt through FPRE will be synthesized and used to scale out technology to other similar environments. Sites for FPRE will be selected based on being representative of large impact zones. Approaches to scale out promising pest and crop management technology to these larger impact zones will be developed in close collaboration with CRPs 1.1 and 1.2 (SRT3).

Table 5.3.1. Yield gap and plausible closure of yield gap (PCYG) for grain legumes across priority target regions

Grain Legume	Area ¹ (m ha)	Actual yield ¹ (t/ha)	Actual production (m t)	Realizable yield ² (t/ha)	Yield gap ³ (%)	PCYG through R4D ⁴ (%)
Chickpea	12.6	0.878	11.07	2.5	64.9	33.6
Common bean	9.5	0.721	6.85	2.0	63.9	32.0
Cowpea	10.1	0.523	5.29	1.5	65.1	35.1
Faba bean	1.1	1.353	1.49	3.5	61.4	30.7
Groundnut (in shell)	20.9	1.011	21.12	3.5	71.1	38.6
Lentil	2.6	0.779	2.03	2.0	61.0	36.4
Pigeonpea	5.1	0.774	3.95	2.5	69.1	38.3
Soybean	14.3	1.225	17.52	3.5	65.0	35.9
Total	76.2		69.31			
Mean		0.908		2.63	65.2	35.1

¹ Area and actual yield (the average yield harvested by the farmers) are across regions from FAO Stat 2009

² Realizable yield is the average yield that can be obtained in most of the areas by adoption of improved cultivars and optimum crop management

³ Yield gap = [(Realizable yield – actual yield)/realizable yield] x 100

⁴ Plausible closure of yield gap (PCYG) is the gain in yield that can be realized by overcoming the stresses, optimum crop management, and adoption of high yielding cultivars over the next 10 to 15 years through R4D.

There are exciting opportunities across grain legumes for comparative studies that will contribute to identification of some common mechanisms of tolerance of BNF to major abiotic stress factors and development of some basic principles and concepts of integrated crop and pest management in legume-based cropping systems. These will include: (i) Rhizobium adaptation to poor soil and marginal environments and capitalizing on BNF to reduce use of N fertilizers; (ii) benefits of grain legumes to soil health and cropping system productivity; (iii) use of cultivars with resistance/tolerance to pathogens and insect pests in IPM; (iv) development and deployment of biological control agents and bio-pesticides, and their integration into habitat management strategies; (v) biosafety of pesticides and transgenic crops to the environment, and reduction of pesticide residues; (vi) understand the influence of legume root-microbial and endo-symbiont interactions on crop tolerance to pathogens and insect pests; (vii) farmer-participatory research and extension (FPRE); and (viii) expand legume cultivation in cereal-based cropping systems and new niches to improve sustainability of the farming systems.

5.3.3 Impact Pathways

Figure 5.3.1 presents the impact pathways for integrated crop and pest management demonstrating the available avenues through which the research outputs translate into research and development outcomes and impacts. Increasing inappropriate intensification/exploitation of agriculture and other natural resources for short-term gains is causing degradation of natural resources (soil health, and water and air quality), which ultimately impair human and animal health and their productivity. It is also causing the farmers to drift away from legumes, which are considered more risky than the cereals, although the legumes have traditionally been an essential component of the farming systems. This objective will focus on: enhancing the availability of inoculum of rhizobia and other beneficial microorganisms and natural enemies through networks, private industry and NGOs; dissemination of information on the benefits of BNF, IPM, and nutrient management and resilient productive cropping systems through web based information, training courses, farmers field schools, print and audio-visual media to promote environment-friendly pest and crop management technologies for legumes production; reduce pesticide use without causing any adverse effect on crop yields; and promoting grain legumes for increasing system productivity and sustainability.

The main indicators of impact at the farm-level will include: changes in fertilizers and pesticide use, changes in crop yields and yield stability, changes in cost of production, farm incomes, and human and animal health. These changes will progressively lead to reduced vulnerability, higher production, improved food security, increased marketed surpluses, higher incomes, and improvements in sustainability of the agro-ecosystems. Farmers may encounter many constraints in adoption of improved technologies, especially pest and nutrient management practices, which are knowledge-intensive. These will be documented to draw lessons for future research. A database on economic and environmental indicators will be developed and used to scale up benefits of BNF and crop and pest management technologies. The major clients of this initiative will be legume breeders and agronomists, NARS, policy analysts, governments, NGOs, private sector, and the farmers. The initiative will enhance the client orientation and impact of legume R&D, helping development partners, governments and local actors to translate outcomes into concrete progress toward MDGs.

5.3.4 Key partners and their role

Research will be carried out by CRP GRAIN LEGUMES partners in close collaboration with national research programs, advanced research institutes (ARIs), universities, private sector and the farmers. This objective will work closely with BMGF funded N2Africa Project and DGP-CRSP in target countries. Many CRP Grain Legumes research activities will be in partnership with CRP 1.1, CRP 1.2, CRP 5 and CRP 7. The ARIs will be mainly involved in upstream research, while all location-specific technologies will be developed and tested in partnership with the NARS and farmers, where the process of participatory research and extension will be a key element. The work on rhizobia biodiversity and genomics will be carried out in partnership with NARS and ARIs. Efficient production

and delivery systems for *Rhizobium* inoculum and other beneficial microorganisms will be done with *Rhizobium* manufacturing public and private industries, N2Africa Project and NGOs. The work on integrated crop and pest management and their components, policy advocacy and capacity building will be done in partnership with NARS institutes and NGOs (see more details in Chapter 6 on Partnerships).

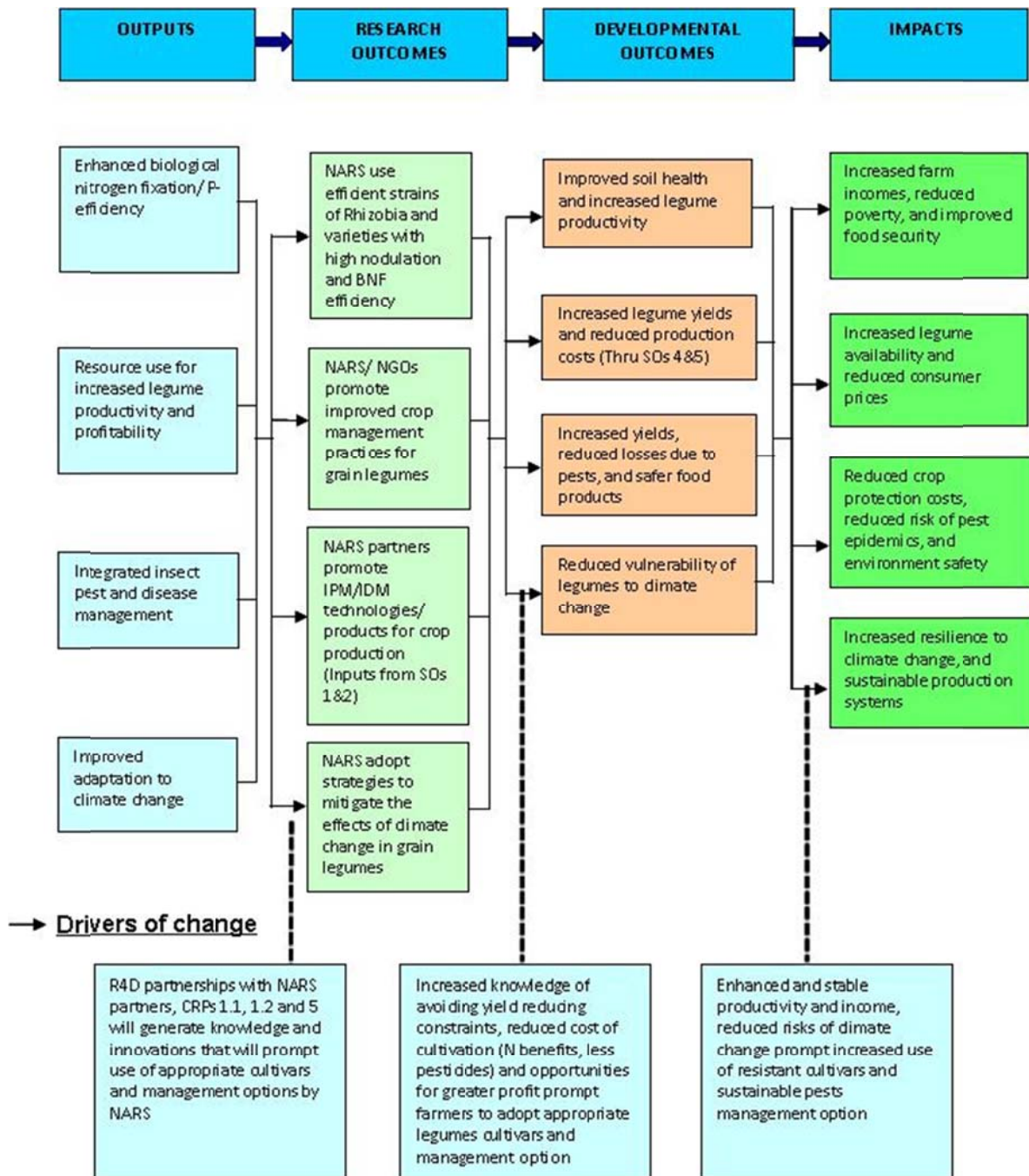


Figure 5.3.1. Impact pathway for Strategic Objective 3

5.3.5 Gender Strategy

Technologies related to Rhizobium, biocontrol, IPM, and overall system intensification have environmental and societal implications. However, weeding is an activity mainly undertaken by women and children. Gender analysis and mainstreaming will enable identification of potential equitable opportunities for women and the youth to ensure successful uptake of efficient interventions that will increase family income and enhance the livelihoods. The opportunities to build upon the advantages of women's participation in technology development and value chains of legumes with effective access to input and product markets because of their crucial role in household economies and welfare will be enhanced. This will be facilitated through identification and involvement of women extension agents, and their training, wherever needed in gender mainstreaming, and organized focused group meetings and workshops to ensure that gender mainstreaming is internalized by partners. Other participatory techniques at the community level will be used to promote appreciation and understanding of the importance of gender roles, and thus help communities develop strategies to enhance their livelihoods through increased participation of women. It is recognized that in some communities, the religious and cultural contexts require that separate male and female groups work on such issues; while in others, joint participation will be possible. Equity will be promoted at the community level, while encouraging individual, community, and group initiatives to take ownership and responsibility for implementation of activities (see also Chapter 7 on Gender Research Strategy).

5.3.6 Lessons learned and research questions to be addressed

- Grain legumes not only fix the atmospheric nitrogen, but also improve the soil structure through addition of organic matter from roots and above ground biomass.
- Resistant cultivar have been deployed effectively as a component of pest and disease management, while the levels of resistance to a few pests such as pod borers are low to moderate, and need to be managed through IPM approaches, including biopesticides and rational application of synthetic pesticides.
- Short-duration legume cultivars can be grown effectively in different cereal based cropping systems, as catch crops in the summer season, or in crop windows between crops.
- Legumes such as chickpea and lentil can be grown profitably in rice-fallows in South and South East Asia. In East African highlands, early maturing lentil and chickpea can fit double cropping system.
- Total productivity of resilient intercropping systems, mixed and relay cropping as a whole is higher than that of the sum total of component crops. Both main and component crops may require intervention for improving overall stability and productivity of the cropping systems.
- Biopesticides can be used as alternatives to synthetic insecticides, but there is a need to improve their efficacy, availability, and stability of the formulations.

Key R4D questions to be addressed are:

- In view of the interdependency of pest – host plant – environment interactions, what R4D approaches are most likely to generate robust, reliable, smallholder-affordable IPM technologies?
- How can crossover GxE interactions for BNF be moderated in order to achieve reliably higher BNF across locations?
- How can the recovery of N from legume residues by subsequent crops be maximized?
- What selectable traits and/or agronomic practices could increase P uptake, and therefore BNF (which is often P-constrained) in low-P environments typical of smallholder farms?
- What agronomic practices and genetic traits would optimize the productivity of grain

legumes in the short fallow periods available between rice-rice and rice-wheat crops?

- What are the farmers' criteria for selecting and accepting appropriate productive and resilient cropping patterns/systems for different agroecologies, socio-economic and other dimensions?
- What are the factors which contribute to the efficient delivery of various crop and pest management technologies to farmers for wide scale dissemination: 1) in geographically-dispersed regions, 2) to differing wealth groups (especially poor, single headed households), 3) of different gender categories (women and men), 4) of different production orientation (household food security versus market) and 5) with support from a variety of institutional set-ups and partnerships (looking at the complementarities of rural agricultural extension service providers).

5.3.7 Outputs

5.3.7.1 Strategies to optimize Biological Nitrogen Fixation by legumes developed and promoted

Description

Grain legumes with their hallmark trait of BNF, provide an important alternative means of maintaining or increasing soil N levels as compared to N fertilizers, which are beyond the financial reach of smallholder farmers. Grain legumes also leave considerable amounts of organic matter in the soil through leaf fall, and the root mass in the rhizosphere. Species and varieties vary in the amount of N they provide to following crops. Herridge et al. (2008) estimated that 50% of N fixed by a chickpea crop remains underground; 33% for soybean; and 30% for other grain legumes. Greater gains may be possible from crops or varieties of longer duration such as multi-purpose soybeans selected for vegetative growth, climbing beans, indeterminate cowpea, faba bean and long-duration pigeonpea. This objective will focus on the effect of drought and poor soil nutrient availability (especially P) on N fixation, develop and use protocols for effective manipulation of BNF efficiency, and understand the biodiversity of rhizobia and other beneficial microorganisms for increasing productivity of grain legumes. In addition, there is a need to develop production and delivery systems for quality products of rhizobia and other beneficial micro-organisms.

Methodology

High nodulating and nitrogen fixing strains will be isolated from various legume crops, in addition to already available strains in collaboration with other institutions and projects such as N2Africa. These strains will be further characterized for their efficiency under greenhouse conditions following standardized procedures. The efficient *Rhizobium* strains selected from the greenhouse studies will be tested further in on-station field studies under drought stress and low P availability. The most promising strains identified from the field studies (conducted in partnership with NARS) will be mass produced and supplied to NARS and private sector partners for further scaling up. The importance of inoculation with good quality *Rhizobium* will be promoted by capacity building of technicians involved in *Rhizobium* inoculum production. Also, *Rhizobium* inoculants available in the market will be monitored for their quality control. Efficient cultivars with high nitrogen fixation capacity selected under SO₂, evaluated on-station and made available to partners through international nurseries platforms. The efficient and cost effective carriers that support *Rhizobium* for longer periods will also be identified and shared with the partners. The most promising *Rhizobium* strains for different legume crops will be characterized by molecular means and further identified by 16s ribosomal DNA analysis, preserved and made available to partners (Elboutahiri et al. 2009; Bazzicalupo and Fani, 1995; Pandey et al. 2005; Alschul et al. 1990; Thompson et al. 1997; Saitou and Nei, 1987).

Methods are available to test the effect of drought on the BNF by legumes, and these have been used to select and use germplasm of soybean with a capacity to maintain high BNF potential in low soil moisture (Serraj and Sinclair, 1996; Sinclair et al. 2003, 2010; Vadez and Sinclair, 2001). These methods have recently been used to identify germplasm of groundnut with high BNF under drought

(Devi et al. 2010). Similar work needs to be carried out in other legumes in different regions. Work in common bean has also allowed the identification of germplasm with a capacity for high efficiency of BNF under low P availability (Vadez et al. 1996, 1999), and there are significant differences among legumes in how P is partitioned to the nodules under low soil P conditions, with cowpea allocating more P to the nodules than bean, and having higher N return from BNF under low P (Gomez et al. 2002). These approaches will be used to select varieties with a capacity to acquire P and maintain high levels of BNF under low soil P and/or drought conditions. The potential of cross legume comparisons will be explored to reveal the advantage of soybean and faba bean over other legumes. Technology generation and validations will be done by participating farmers.

Key Milestones

- Protocols to select grain legumes for efficient BNF in LN, FB and CW developed under drought, heat and low P conditions (2013-14)
- Efficient host genotypes and strains of *Rhizobium* and other beneficial soil/plant health micro-organisms identified and made available to public/private sector partners (2014)
- Technologies for mass production of *Rhizobium* and other beneficial micro-organisms developed and made available to public/private sector partners (2014)
- Interaction of genotype x rhizobium x environment under drought, heat and low P determined in at least two legumes (2014)
- Interaction of BNF with other microbes (*Mycorrhiza*, *Pseudomonas*, and inducers of secondary metabolites conferring resistance to pests) documented (2014).

5.3.7.2 Methods to increase legume productivity and profitability through increased resource use efficiency developed, tested and promoted

Description

The inappropriate intensification of agricultural production systems has led to serious problems of land and environmental degradation. Due to increasing pressure on land, area under traditional fallow systems has declined, resulting in significant losses of soil fertility and biodiversity. Soil productivity continues to decline, and the current farming systems have become unproductive and unsustainable. Rising concerns over possible negative environmental effects of chemical fertilizers and pesticides has necessitated the need to expand the use of alternative technologies that offer the greatest environmental and economic benefits for resource poor farmers. Integrated approaches are needed that recognize the centrality of smallholder farmers and adequately address issues of the environment and the need for integrated soil health and crop management options.

Methodology

Different cropping systems (double cropping, mixed cropping, relay cropping) that increase land productivity will be evaluated in collaboration with farmers. Double-cropping improves the capture and efficient use of annual precipitation and photosynthetically active radiation (PAR) in comparison to single cereal and legume crops (Caviglia et al. 2004). Therefore, we intend to evaluate short-duration common bean, cowpea, chickpea, pigeonpea, and soybean varieties, which can be relay cropped with early-maturing cereals and/or used in crop rotations to allow for double cropping in the same or different cropping seasons, and thereby, allowing for efficient resource use for crop production (collaborative research with CRP 1.1, CRP 1.2, CRP 5 and CRP 7, conducted at common test locations, where possible). Short-duration pigeonpea cultivars have been found to be advantageous in the cereal based intercropping systems (Pande et al. 2006). Availability and adoption of more drought- and heat-tolerant varieties of legumes, particularly pigeonpea and chickpea, are expected to extend the cultivation of legumes to rice based cropping systems in the Indo-Gangetic plains and in central India as well as irrigated dry areas like in Sudan. Partnering with CRP 5, water balance models will be used to identify cultivars of appropriate phenology to take full

advantage of soil water as well as the crop growing duration. GIS and the spatial information (from CRP 7) will be used for diversifying legume based cropping systems (joint studies with CRP 1.1 and CRP 1.2). Influence of crop varieties and root exudates to suppress the weed population will also be assessed, and legume varieties that are more efficient in suppression of parasitic and non-parasitic weeds will be identified for use in different cropping systems. Cultivar differences in improved BNF activity and P-use efficiency (kg of grain produced per kg of shoot P uptake) will be assessed by using field or controlled environment experiments involving a number of improved cultivars. Efforts will also be made to optimize water and nutrient inputs to maintain soil health and sustainability of production system. Computer programs such as *Homologue* can identify niches similar to known production areas where legumes can fit.

Key Milestones

- Legume varieties and cropping systems for crop intensification/diversification in cereal based systems/rice fallows identified and promoted (2014)
- Appropriate legume production packages developed, demonstrated, and promoted (involving at least 50% women farmers) to enhance legume productivity in different regions (2014)
- Appropriate dissemination protocols for promising varieties and other technologies identified and promoted (2014)

5.3.7.3 Tools and protocols for more effective insect pests, disease and weed management developed, tested and promoted

Description

Insect pests, diseases, and parasitic and non-parasitic weeds cause significant pre- and post-harvest losses in grain legumes and increase the vulnerability and risk of growing grain legumes for small-scale farmers. Insect pests alone cause an estimated loss of over US\$16 billion annually (Sharma et al. 2008). However, extent of losses (quantity and quality) due to insect pests, diseases and weeds are not well documented. In cowpeas, yield losses can be as high as 80% under high pest pressure (Singh et al. 1990). Synthetic insecticides, where and when available, can reduce pest damage considerably. However, insecticide use is uneconomic under subsistence farming conditions, and there is lack of access to recommended quality pesticides (Coulibaly et al. 2002). As a result, farmers resort to inappropriate and hazardous practices when applying pesticides (some of which are already banned in developed countries!), such as the non-use of protective equipment and noncompliance with standard dosage and application intervals. Moreover, the lack of cash pushes the farmers to opt for lower cost subsidized insecticides with obvious environmental and human health hazards (Sharma 2006). Some of the insects have also developed resistance to commonly used insecticides, particularly pod borers, *Helicoverpa armigera* (Sharma, 2005) and *Maruca vitrata* (Ekesi, 1999; Sharma, 1997). Therefore, there is a need for rational use of synthetic pesticides, which should be integrated with both preventive and curative measures such as host plant resistance, biopesticides, natural plant products, and biological control in a more comprehensive IPM approach. While the private sector is largely involved in research and development of synthetic pesticides, the development of pest-resistant cultivars, biopesticides, and biological control agents is a central feature of CRP3.5.

A good understanding of the pest and pathogen distribution, biology and host-pathogen interactions is essential to develop science based pest management practices (Sharma 2006). Rust can reduce soybean yields by up to 80% in Africa if not controlled, and the geographical range of this disease has expanded rapidly in the past 10 years. The pathogen is highly variable and therefore understanding the nature and distribution (Twizeyimana et al. 2010, 2011) and epidemiology is essential for the development of cultivars with durable resistance (Paul et al. 2010). Weeds are a serious problem

across grain legumes. Parasitic weeds *Striga*, *Alectra* and *Orobancha* can cause complete losses in some grain legumes. Combinations of control options are needed to effectively control weeds in grain legumes. An enabling policy environment is critical to sensitize policy makers and researchers to the importance of investments in input support systems for beneficial bio-control agents, bio-pesticides, and pest resistant cultivars for pest management. Opportunities for introduction and expansion of legume-based technologies will be influenced by the ability of the farmers to reduce the losses due to insect pests and diseases through rational use of pesticides, and improved capacity to use beneficial microorganisms for crop protection. The adoption of IPM -based technologies will not only improve environmental health, but also help in enhancing the socio-economic resilience of smallholder farmers by improving the sustainability of legume production and stability of the cropping systems.

Methodology

Conventional and advanced tools such as remote sensing and GIS will be used to quantify the distribution of, and losses due to important and emerging insect pests and pathogens across cropping systems (Christian et al. 2010). Culture independent methods such as DGGE, ELISA, and DNA barcodes will also be used to identify crop pests and their natural enemies. Pest-resistant cultivars derived through expression of toxin genes from the bacterium, *Bacillus thuringiensis* and RNAi technology will also be used as a component of pest management (via Strategic Objectives 1 and 2), as and when these become available (Meister and Tuschl 2004; Sharma, 2009)). Emerging genomic and information technologies (IT) will also be used for developing robust IPM systems (Ba et al. 2009). Application of IT in IPM will involve the use of information and communications technologies, both to collect critical information on pest populations, and to deploy practical IPM solutions through decision support systems (Agunbiade et al. 2011). Application of modern biotechnological approaches for pest management requires that these be evaluated for their biosafety to the environment (Sharma and Ortiz, 2000). Standardized protocols will be followed for evaluating the biosafety of insect-resistant transgenic plants for pest management (Sharma et al. 2008; Sharma 2009).

For biological control, our approach is 'discovery-to-deployment' pipeline. Using the example of the pod borer, *M. vitrata*, regional and international partners will team up to identify better adapted natural enemies against this pest (Srinivasan et al. 2007). At the same time, efficient system for rearing of the natural enemies will be developed for each of the promising candidates, together with innovative ways of sensitizing the farmers about the new approaches by disseminating the information through cell-phone ready animation videos. In addition to their conventional application, we will investigate the application of microbial endophytes for pest management (Vega et al. 2008) to enhance plant defenses to insect pests and pathogens. Crop and region specific IPM modules will be designed using prevention-based systems, and intervention approaches which pose the lowest environmental, human and animal health risks. To expand the use of biological control, business models for commercialization will be developed and private sector partners involved in commercial production of biocontrol agents. We will also work on enabling policy and institutional issues (e.g., awareness, regulations, etc.) for enhancing adoption of biocontrol for pest management.

Key Milestones

- New bio-control agents (microorganisms, parasitoids, metabolites) for managing diseases and insect pests discovered and promoted (2014)
- Biosafety of pesticides and transgenic crops to the environment assessed in CP, PP, and CW, and resistance management strategies developed (2014)
- Integrated management options for parasitic weeds demonstrated in SSA and WANA region (2014)
- Diagnostic kits for key viruses developed in at least two grain legumes (2014)

- Inoculation methods for endophytes in CP, CB, and PP developed and defense enhancement tested (2014)
- Information on distribution, severity, and extent of losses due to insect pests, diseases, and weeds documented and shared with NARS (2014)
- IPM technologies, including the use of biopesticides for key pests tested, validated and promoted (involving at least 50% women) in farmers' fields (2014)
- Mechanisms of bean-virus-vector interactions elucidated (2014)

5.3.7.4. Potential strategies for increasing legume production in response to climate change identified and tested.

Description

It is assumed that climate variability and change will have both positive and negative effects on legume production, and on the incidence and severity of biotic and abiotic production constraints (Sharma et al. 2010; Beebe et al. 2011). Therefore, to develop potential strategies for farmers to adapt management of legumes in response to climate change, we will endeavor to create facilities and develop methodologies to study the effect of climate change variables such as temperature, heat, drought, erratic rainfall, flooding, and elevated CO₂ on production and productivity of grain legumes, as well as on the effectiveness of IPM technologies for pest management. The on-going research on climate change has indicated that heat/drought stress, foliar and pod infesting pests, and soil borne diseases should be the focus of R4D (Vadez et al. 2011b). Climate change will also affect BNF in grain legumes. In this context, strategies that will result in development of legume varieties suitable for different cropping systems adapted to a changed environment will be of top priority. Key areas of research focus will be adaptation of grain legumes to drought and heat stress, changes in distribution and severity of insect pests and diseases, and 'introduction' of legumes into new geographical areas.. Integrated crop and pest management technologies are needed to improve sustainability of smallholder agriculture as a result of climate change.

Methodology

The relative abundance and geographical distribution (current and likely future distribution) of major insect-pests and emerging new pests/pathogens will be mapped using GIS and GPS tools (partnering with CRP 5 and CRP 7 using data sets from common test sites). In addition, insect-pest and pathogen trap nurseries will be evaluated at hot-spot locations to monitor the change in insect-pest and pathogen populations, and changes in expression of resistance to the target pests. Using historical weather and pest/disease incidence/population data, efforts will be made to predict the incidence of major pests (Trivedi et al. 2005), and form the basis for simulation modeling to develop effective weather based disease/pest forecasting and or early warning systems for effective management of diseases and insect pests.. Specifically, R4D will focus on determining the dynamics of insect-pests and soil borne diseases (wilts, root rots, and nematodes) and insect transmitted viral diseases of importance in grain legumes. Research on effect of climate change will also be conducted (collaborating with CRP 7) on survival, activity and abundance of natural enemies of crop pests, which will have a major bearing on population dynamics and severity of damage (Sharma et al. 2010). The multi-faceted interactions of biophysical factors with legumes and the biotic and abiotic stresses are threatening the durability of pest-resistant cultivars. For example, wilt-resistant chickpea varieties infected with nematodes are likely to be susceptible to these constraints. In collaboration with CRP 7, efforts will be made to understand the effects of climate change variables on expression of resistance in grain legumes against key pests, and identify varieties that are stable across environments. Similar crop simulation efforts will also be used to test the effect of climate change on certain plant traits, and eventually on yield (Sinclair et al. 2010).

Key Milestones

- Changes in relative abundance and geographical distribution of major insect pests and pathogens mapped (2014)
- Better understanding of grain legume phenotypic/physiological responses to climate change (CC) and use of crop simulation modelling to better target critical traits needed for adaptation to CC (2014)
- Better understanding of the effect of climate change variables on expression of resistance to insect pests/pathogens (2014)
- Varieties with better resilience to climate change identified (mainly for increased temperature and CO₂) (2014)
- Strategies for adaptation to the effects of climate change on production of grain legumes developed and disseminated to NARS partners (2015)

5.4 Strategic Objective 4: Develop and facilitate efficient legume seed production and delivery systems for smallholder farmers

5.4.1 Rationale

Improved crop varieties can make a difference in smallholder agriculture in developing countries. They are an economical and non-intrusive means of improving the livelihoods of poor farming households. For instance the adoption studies in several African countries showed that improved bean varieties give yield increases of 30 to 50 percent above local varieties (Kalyebara and Andima 2008) and also similar results were reported in chickpea in CWANA (Mazid, *et al.*, 2009). It takes over US\$ 1 million to develop a successful bean variety (W. Janssen, personal communication, November 28, 2006) and not rendering it accessible, (i.e., leaving it on the shelf), represents a significant waste of public resources (international and national research systems). Worse yet, this denies farmers access to better income, food security and other benefits.

Despite a long list of released legume varieties, their impact has not yet been fully realized by the resource-poor farmers in the many areas of Africa, Asia and Latin and Central America due to inefficient and inadequate seed systems (Teshale *et al.* 2006; Aw-Hassan *et al.* 2003). The seed accessibility to small scale farmers is constrained by both inadequate demand creation and limited supply. This situation is also compounded by unfavorable and inadequate policy support and regulatory frameworks, inadequate institutional and organizational arrangements, and deficiencies in production and supply infrastructure and farmers' socio-economic situation (Rubyyogo *et al.* 2007).

On the seed supply side, grain legume seed business generally does not attract large seed companies since profit margins are low. The supply of certified seeds are less than 5% in major grain legume producing countries such as Ethiopia (0.1-1.5%), Morocco (1-5%), Iran (none), Syria (2.2%) and Turkey (1-2%) (Bishaw *et al.* 2008). Even Kenya, with more than 65 seed companies including multinationals, the annual supply of certified beans is 1.9 % of seed requirement (KEPHIS, 2006). More than 95% of lentil seed in India (the leading global lentil producer) comes from the informal sector (Materne and Reddy, in Yadav *et al.* 2007). The situation with respect to other legumes in India is similar. The seed replacement rate in India varies from 14% in chickpea to 35% in soybean (www.seednet.gov.in), thus indicating that a majority of the farmers still use their own saved seed. This situation is due to several factors including: the low seed multiplication rate of legumes; the reuse of grains from previous harvest as seeds and; often demand for specific varieties adapted to more narrow agro-ecologies and consumers' needs. Currently, majority of the farmers use their own seeds or get seeds of improved varieties from local supply (from other farmers or local market). Furthermore, when seed production takes place, it is often in higher potential areas, with seed stores being concentrated in zones of higher population density or those with better infrastructure (i.e. not the remote, stress-prone areas) and seed is sold in large packs which are only affordable to the well-off farmers.

One of the effective ways of introducing and disseminating improved varieties in the local seed systems of small holders systems is through the Participatory Variety Selection (PVS). The approach has greatly contributed to wider dissemination of climbing beans in Rwanda and Uganda especially when farmers were organized into groups (Sperling and Scheidegger, 1995; Nasirumbi *et al.* 2008). Almekinders *et al.* (2007) also reported that bean genotypes identified through PVS rapidly diffused in neighboring communities especially if researchers went beyond and established linkages with other service providers who support local seed production and supply by enhancing farmers' knowledge and skills in PVS and crop management. This approach was also successfully used in BMGF-funded Tropical Legumes II project where it has been instrumental in disseminating preferred new legume varieties among participating farmers particularly women who are the majority in the farmer groups (Tropical Legumes II 2011).

Starting from 2007, under the Tropical Legume II project, several grain legume production and delivery models have been tested (see Table 5.4.1).

Table 5.4.1. Seed production and supply approaches tested in Tropical Legumes II project

Foundation/certified seed production	Decentralized seed production	Delivery approaches
<ul style="list-style-type: none"> • Direct production- NARS • Direct production- NARS seed unit with contract farmers • Private seed companies • Farmer cooperatives 	<ul style="list-style-type: none"> • District/government extension services supporting individual farmers • NGOs supporting individual farmers • Farmer Cooperatives/Unions • Community-based seed production 	<ul style="list-style-type: none"> • Small pack sales: open markets • Small pack sales: country stores • Small pack sales agro-dealers • Small pack sales: seed/grain traders • Seed exchange through local seed systems (seed fairs, women networks etc.) • Direct farmer to farmer diffusion

Though large seed companies are slowly getting interested in legumes, small and medium companies seem to find legume seed as niche market, especially introducing new varieties using small packs sold through open market and agro-input shops. Follow-ups showed that women were as likely to purchase as men. Further, sale of small packs was expanding business opportunities for seed companies including large ones. During 2009/10 crop season, in Ethiopia, the use of small seed packs ranging between 250 to 1,000 g was credited to allow 65,000 farmers, including those in remote areas, to access seed of multiple new bean varieties at affordable prices and test them with minimum risks (Tropical Legumes II 2011).

The magnitude and effectiveness of local seed market (local market, seed loans and seed fairs) has also been a surprise. For instance, in western Kenya alone, it was possible to access bean seeds of drought tolerant bean varieties to 90,000 farmers (in three seasons) by community identified decentralized seed entrepreneurs who market seed locally. A follow-up study indicated that on average one farmer can sell/exchange seed to other five farmers in one season.

As small and medium seed companies are emerging and gaining interest, they are also creating effective demand for grain legume seed (Tropical Legumes II 2011). However their capacities are still limited by the inadequate and discontinuous access to foundation seed, inadequate capital investment, and lack of appropriate marketing strategies including delivery systems targeting remote and small scale farmers (Rubyogo et al. 2011). It was established that a public and private partnership would be the best approach to increase the availability of foundation seed need for subsequent seed classes.

Several policy, regulatory, institutional, technical and socio-economic constraints are also affecting the legume seed industry (Bishaw et al. in Kharkwal 2008). Grain legumes are mainly grown by subsistence farmers, predominantly women, in developing countries across Africa and Asia who grow more than one legume crop with limited use of improved technologies and without reliable output market. This situation confines these crops to be considered by policy makers as orphan crops thus attracting less interest and government support. For instance, inadequate consideration of grain legume breeding patterns has led to enactment of seed policies across various countries that impose maize seed certification conditions on grain legumes, though their breeding systems are different. This renders the legume seed certification ineffective in many countries. This situation led actors in the seeds arena to support an informal bean seed system that is not recognized in the official seed system because it falls short on the criteria for certified seed, though it produces acceptable quality seeds (Rubyogo et al. 2009; FAO, 2006).

While cross-border seed trade is a reality for maize in Africa (MacRobert, 2009), it is still not practical for grain legumes despite the fact that some bean, pigeonpea and groundnut varieties are released in more than one country, and ideally this should make seed trade across countries easier under the Regional Economic Communities Technical agreement on the harmonization of seed regulation

across regions (e.g., SADC, ASARECA, COMESA, CORAF, AARINENA). These opportunities to move volumes of seeds of grain legumes across borders remain untapped due to limited knowledge by the seed traders on the cross border seed trade requirements and procedures (FANRPAN, 2011).

Given the diversity of grain legume crops, complexity of production environments and farming systems and more localized grain preferences which result in limited seed markets, developing one model of seed delivery system for grain legumes to serve the smallholder farmers (such as the hybrid maize seed systems) is impractical. Therefore, the challenge is to get seed of the improved and preferred varieties (immediately after their release) in the hands of the farming community in a sustainable manner (at the right time, and in a quantity affordable to small scale farmers), permitting both decentralized-farm based (local) seed producers and large seed producers to access seeds of improved varieties of their choice.

Based on lessons learned and identified constraints, CRP GRAIN LEGUMES will focus on the integrated seed systems aiming at supporting both decentralized seed enterprises and emerging small and medium seed companies. The decentralized seed enterprise will be supported to produce and supply acceptable quality seeds of preferred varieties identified through the PVS processes. These entrepreneurs will be members of farmer groups who will manage the PVS sites. This will encourage women entrepreneurs (majority in the farmer groups) to undertake seed production as business. Small and medium companies will be supported to produce certified seeds and encourage sell seed using affordable packs. This will be developed in partnership with various grain legumes value chain actors such as NGOs, community based organizations (CBOs), farmer organizations (FOs), emerging private sector actors (e.g. beans and pigeonpea in Africa and hybrid varieties and seeds of pigeonpea in India are holding promise) and also with government seed policy makers, national seed services and regional bodies to appreciate and support the complexity of grain legumes seed systems.

Using this approach, bean Program in Ethiopia have been noteworthy and the achievements were remarkable (Assefa et al. 2006, Rubyogo et al. 2010). It was interesting to observe that about 65% of Ethiopian farmers that were reached within three years of innovative seed delivery, had never had access to new bean planting materials before (Katungi and Gebeyehu, 2011). Note that while the Ethiopian program was catalyzed by 'outside funding'—it is now completely owned by the bean value chain actors (Rubyogo et al. 2010). The proposed legume seed systems will depend on a combination of factors that range from the development of preferred and well-adapted varieties to the creation of effective multi-partnership seed systems that reach the majority of farmers.

5.4.2 Priority setting

Strategic Objective 4 on Seed Systems is complementary to Strategic Objective 2 on Crop Improvement and thus the priority regions and the legumes within each region for this Strategic Objective will be similar for those for Strategic Objective 2 (described in 5.2). The priority countries within each region will also be the same as given Appendix 3.

The major focus of this Strategic Objective is to enhance seed availability of farmer-preferred cultivars to smallholder farmers at the local level. Both formal (public/private seed sectors) and informal (individual farmers and farmers' groups) seed systems will be targeted for their greater involvement in seed production and distribution of the targeted grain legumes.

5.4.3 Impact pathways

The adoption of cultivars developed under Strategic Objective 2 will be enhanced by developing efficient seed production and delivery systems. Developing sustainable legume-seed systems involves conducting research to solve bottlenecks and seeking solutions to create impacts across legumes. Legume seed systems will link scientific and development objectives through translation of technical information and technological outputs generated through scientific interventions into information and practices which are accessible to development partners (national and local

governments, NGOs and CBOs, private sector operators and farmers). Interactive and consultative meetings and workshops will be used as tools to strengthen linkages and to share skills and knowledge between scientists and development partners during the planning, implementation and reviews. This involves embarking on integrated seed systems (formal and informal) engaging numerous market and non-market actors in a coordinated division of labor in a set of activities spanning legume production, seed multiplication, marketing, and promotion/information (as described in section 5.4.3 and Figure 5.4.1).

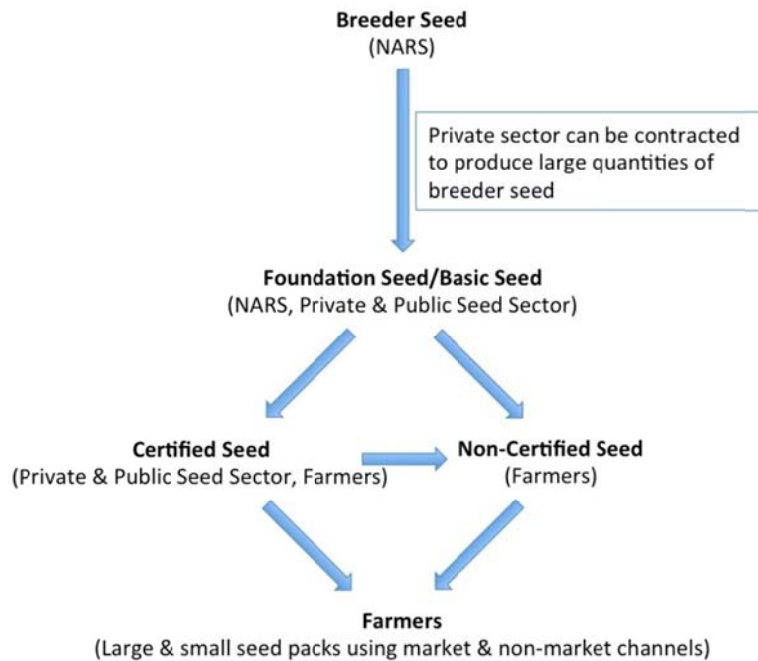


Figure 5.4.1. Integrated grain legume seed system

Grain Legumes seed systems will mainstream the use of appropriate seed production and supply channels aiming at wider uptake and reducing time lag between release, acceptance and adoption. Development and adoption of integrated seed systems (informal and formal) will fast track and speed up the use of promising and proven systems carried out by national and regional efforts across Africa, Asia and LAC. Well-tested seed system models, such as decentralized seed production systems and innovative marketing of certified and labeled seeds using the small seed pack (250 g to 10 kg) approach will be enhanced. As a result of created seed demand of improved legume varieties through this CRP, the demand of breeder/foundation/certified seeds will increase. Strengthening the capacity of NARS to produce adequate amounts of breeder/foundation seeds and supporting the development of alternative means of producing these classes of seed would bring efficiency in seed production chain. This effort will be linked to the BMGF supported TL-II project achievements and other efforts (such as AGRA/PASS) in addressing the bottlenecks of seed supply.

Once the varieties are accepted, the grain legumes seed systems will also contribute to the increase of grain legumes productivity through improved natural resource management and catalyzing the use of complementary and improved farming management practices. This will be done with users along the supply and demand chain through the promotion of Innovation Platforms (IPs) across legumes owned by local actors (Rubyogo et al. 2010). This participatory approach will improve technology uptake and provide opportunities to farmers to interact with other actors (members of IPs) along the legume value chain such as suppliers of other complementary inputs/services (fertilizers extension services, traders etc.). The increased seed access of preferred varieties coupled

with the use of improved crop management practices will lead to increased productivity. This will lead to improved nutrition and food and income security at household level and increased national and regional economic outputs.

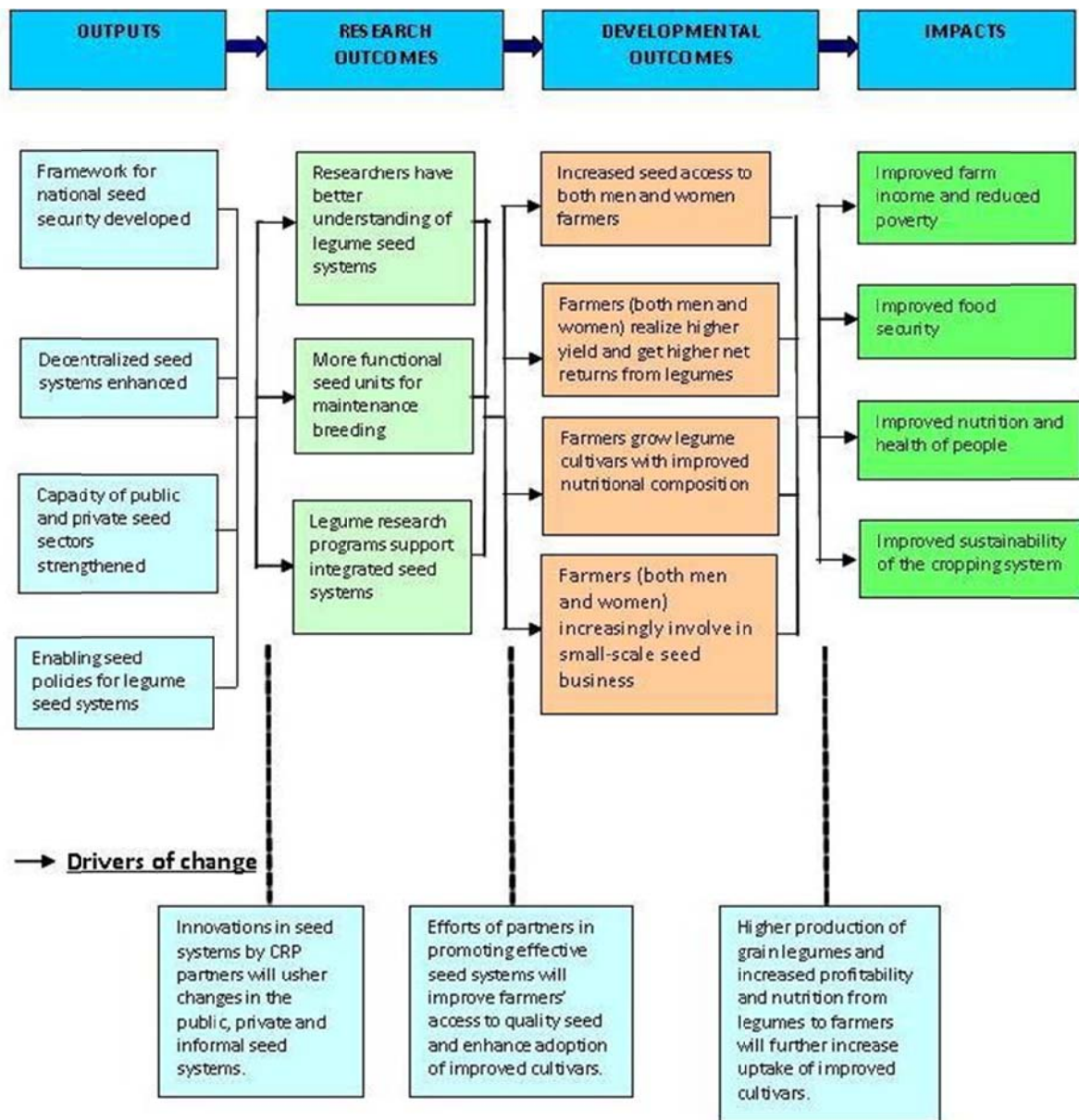


Figure 5.4.2. Impact pathway for Strategic Objective 4

5.4.4 Key Partners and their role

The seed systems research for development will be carried out along the value chain by catalyzing partnerships for impact. These include national policy makers and national/regional seed services, public/private seed sector, civil society (NGOs and producers organizations), farmers and other stakeholders such as grain traders and exporters. National seed services and agricultural policy bodies will create conducive environment for multi-seed seed trade (including cross-border trade). The CGIAR and other ARI partners will facilitate development of innovative seed system approaches, including efficient and productive seed multiplication techniques (Rubyogo et al. 2010). These

institutes and the NARS partners will provide training in seed production and business skills. The production of nucleus/breeder/foundation seed of improved varieties will be mainly through NARS partners. The public seed sector (e.g. NSC, SFCI and State Seed Corporations in India; ESE, TOSCI, KEPHIS, National seed services of Mozambique, etc.) and the private seed sector (e.g. Krishidhan Seeds Ltd, Nimbkar Seeds Pvt Ltd in India; Kenya seeds, Leldet seeds Ltd, NASECO Seeds, Victoria seeds in Kenya; Zenobia seeds, Tansed International, Krishna seeds, Miombo Estate in Tanzania, etc.) will be involved in foundation and certified seed production. The public and private formal seed sectors are the key for foundation seed production (Tripp, 2006; Tropical Legumes 2011) that is the major bottleneck in grain legumes seed systems. The private grain trade sector has to be engaged to stimulate grain market that will drive seed production through grain market, and market chain development for a range of products of grain legumes. The farmers' groups will also be involved in production of certified seeds. The informal seed system (production of uncertified seed; truthfully labeled seed) will be promoted through individual farmers and farmers' groups. Agriculture Departments and Extension Agencies (e.g. Myanma Agriculture Service; State Agriculture Departments in India), NGOs (e.g. CARE, World Vision, CRS, Africare, Techno serve, IKURU, CLUSA), community-based organizations, farmers' cooperatives, private entrepreneurs will help further to multiply, market and diffuse seed in decentralized zones of actions – where the target communities reside. They will also be major players in knowledge empowerment of farmers. More on role of partners is given in Chapter 6.

5.4.5. Gender strategy

Varietal characteristics especially associated with women include early maturity (food security, especially during the hunger gap), fast cooking (to save firewood, labor and water) and market – preferred traits (seed color, size etc.). In several regions women take lead roles as seed multipliers, seed and grain sellers. To a certain extent, income from the sale of grain legumes is still controlled (or at least accessed) by women (PABRA, 2008). Therefore, grain legumes are wonderful 'pro-gender crops'. In terms of seed storage options, women are in the forefront of adaptive research – and they often make the hard decision of what to use for seed, and what to use as food to feed their children. This may be important especially for decentralized seed enterprises, since gender-linked goals should be both to maximize positive benefits as well as to lessen the negative consequences of commercialization, which often comes with a shift in control of the finance, from women over to men. Thus understanding gender relations at household and community levels, followed by gender equity and sensitization trainings for both men and women, and exploration of alternative income generating activities are vital. Seed production and delivery approaches and tools that capture priorities from both male and female participants as well as giving them equal opportunities for participation, will be emphasized. Joint gender analysis with CRP2 will help in identifying the specific nature of support (and where it will be need) for women as equal participants in these initiatives. However deliberate support will be extended to potential women to undertake decentralized seed production/supply enterprises of improved varieties in hard- to- reach areas where farmer- to- farmer seed exchange and market grain/seed acquisition are still the most prevalent seed supply channels and being carried out by women (Bishaw and van Gastel, 2008).

A gender considerate skills and knowledge enhancement in areas of seed systems will facilitate an equitable participation of men and women. Considering that a certain number of farmers have limited literacy, information systems and communication strategies will be established to enable equitable access information about varieties and seed quality to both illiterate and literate. These strategies include decentralized demonstration/field days, study tours, variety posters and integration of traditional information systems

5.4.6. Lessons learned and research questions to be addressed

Surveys have clearly shown that non-availability of quality seed is a major constraint for adoption of improved legume varieties. Many farmers and extension service providers are not aware of new

varieties, their potential advantages such as agronomic and utilization characteristics or where to access them (IFPRI, 2010; Tripp, 2006). Information and awareness creation is essential to serve the poor (particularly illiterate women) farmers in remote areas, policy makers and extension service providers, and supply chain actors for sustainable grain legume seed system development. Efforts to engage policy makers in Ethiopia yielded a better government support toward grain legume crops (beans and chickpea) production and marketing (Personal Communication: Setegn Gebeheyu, Coordinator, Bean Program, EIAR, Ethiopia). This led to increased productivity, better returns to supply chain actors including farmers (CSA, 2010). Many seed production and delivery models have been tested in the BMGF-funded TL II project (see Table 5.4.1), and some have been found effective. Among these, the decentralized seed system model and sale of small seed packs have been found effective in many areas.

Considering these lessons learned, this objective attempts to address the following R4D questions:

- How can farmer-participatory varietal selection (PVS) achieve sufficient scale and effectiveness through decentralized seed production systems?
- How can the formal and informal seed sectors be connected and harmonized to ensure sustainably-effective seed systems?
- What strategies and business models would motivate small and medium seed companies to enter the legume seed business?
- How can initial successes with small seed packs be up- and out-scaled across grain legume species?
- How can we engage regional and national policymakers to strengthen supportive seed policies?

5.4.7. Outputs

To establish efficient seed systems in small holding systems requires research which entails solve bottlenecks in seed production, accessibility, information systems and related policies. This involves a wide range of issues such as institutional arrangement to produce various seed grades, linking decentralized seed production of locally preferred varieties identified through Participatory Variety Selection (PVS), advocacy for policies that stimulate private-public partnership, implementation of harmonized regulatory frameworks to create wider national and regional seed markets targeting multiple country released varieties; strengthening of capacity for seed production and marketing for maintenance of seed quality (with adequate equipment and facilities) and for human resource development to provide effective leadership in enterprise development and management.

5.4.7.1: Decentralized seed systems enhanced through systematic diagnosis and implementation of appropriate models

Description

In the developing countries, particularly for grain legumes, the formal seed sector is still young or highly subsidized and evolving at different stages of development. In some countries, it is almost non-existent. The informal seed sector is and will remain the dominant player in legumes. In recent past, development partners and researchers have realized the importance and significance of quality seed in agriculture and several projects have been implemented or are in progress in developing countries to improve seed availability of improved farmer-preferred varieties to farmers. The first step in resolving access to quality seed would be a thorough understanding and critical assessment of the status of existing seed sector (both formal and informal), their bottlenecks and comparative advantages and complementarity. Several on-going and concluded projects will provide lessons to build up a new framework which will enhance a speedy use of improved and preferred varieties through sustainable seed availability and accessibility (quality, quantity and timeliness).

In addition, other innovative models across decentralized legumes seed production enterprises

owned by farmers (individual or groups particularly women) will be established in impact zones including in remote isolated/stress prone areas with poor infrastructure, via organizations which are potentially sustainable and which can be scaled up. These include (1) private entrepreneurs (small, medium and large scale) and (2) NGOs with seed expertise that can facilitate scaling up by local producers. These enterprises are: participatory—to mobilize and involve small farmers in target environments; decentralized—to multiply locally adapted and farmer preferred varieties; business oriented—to link seed production to demand from communities; cost effective—to minimize transaction costs, thus reducing seed prices; using relevant quality—to adopt seed quality appropriate to farmer requirements; employing appropriate technology—to use low-cost mobile cleaner/treater to improve seed quality; sustainable—to empower farmers particularly to take leadership in decentralized seed business (Bishaw and van Gastel, 2008).

Methodology

Assessing existing seed production and supply models and deepening their understanding will be carried out through a systematic analysis such as the cost-benefit analysis (financial and social), institutional viability, the type of farmers reached and their numbers/gender and wealth, the quality of seed supplied by each model and risks associated. The evaluation will also include the type of germplasm and speed with which the varieties move will be evaluated. The complementary and comparative advantages of the informal and formal will also be assessed. Promising model or combination of different models will be mainstreamed for wider uptake and utilization of released varieties. A range of seed producers will be supported to access these parent material to produce certified and quality declared seed (QDS)/farmer accepted quality seed (Rubyogo *et al.* 2009b).

Based on critical need assessment, the emerging seed entrepreneurs particularly women operating in hard-to-reach areas will get support for improving their capacity. These farmer seed enterprises will be established through a multi-stakeholder process involving different institutions and will be provided with key facilities (e.g. mobile cleaners, storage facilities), trained in technical aspects and business management, and linked to formal sector institutions (e.g. for source seed etc.). Innovative seed marketing approaches such as affordable small packs (especially to women) will be tested and mainstreamed where appropriate. Under the TL-II project, the small pack approach has reached several thousands of farmers. The monitoring shows that women are just as likely as men to purchase small seed packs (Rubyogo *et al.* 2009a; Tropical Legumes 2011). From the private sector point of view, the small packs are opening up novel and sustainable business opportunities (Rubyogo *et al.* 2011). Thousands of farmers particularly women were actually buying certified seed. These seed production and supply units will be monitored and evaluated for their profitability and sustainability. Factors contributing to their success or/and failure will be investigated.

Key Milestones

- Cost and benefits of major seed production/delivery models determined (across legumes crops), documented and findings widely shared to GL community, seed policy makers (national and regional/continental) (2012)
- Implication and effects of gender relations toward grain legumes seed systems at household and community levels better understood (2012)
- At least 2 entrepreneurs per participating country produce and sell acceptable quality seed of at least one grain legume (2013)
- At least 4 NGOs/farmer groups/farmer unions in each participating country facilitate the scaling up of seed production with at least 20 decentralized seed producers (50% being women) per each grain legume crop (2014)
- Diversified decentralized partners produce at least 500 Tons per participating country per season per each grain legume crop (2014)

5.4.7.2: Capacity of public and private sector in legume seed systems strengthened

Description

One of the major bottlenecks in the grain legume seed sector is related to inadequate knowledge and capacities along the seed value chain. In most countries, the number of scientists working on grain legumes is low and in some cases with inadequate training. In addition, government seed policies and regulations are biased towards major cereals. All these have resulted in insufficient legume seed production and poor market networks. Several public-private/civil society organizations partnership models for seed sector development have emerged in recent years (Tripp and Rohrbach, 2001). Partnerships are forged between public organizations (NARS and National Seed Agencies) and private operators (small, medium and large) in areas of seed production, supply and information flow to adequately respond to seed supply chain actors' demand.

The project will focus on capacity enhancement of partners involved in seed systems for both degree and non-degree courses. This will ensure that there are better linkages between participatory variety selection (PVS) trials (identification of end user preferred varieties), release process, immediate seed production and dissemination of selected grain legumes varieties. CRP GRAIN LEGUMES will reinforce interactions to enable partners and participating communities to build skills, knowledge and experiences through community of practice. Capacity building will be a continuous process through technical backstopping and capacity building of training of trainers in key areas that could have impact on end users. Part of the initiative will include the continuous assessment of internal constraints or emerging bottlenecks that will require urgent solutions for the development/promotion of improved varieties of grain legumes technologies.

Methodology

Skills and knowledge of implementers and supply chain actors through training will be in partnership with development partners and private sector. Efforts will be made to enhance linkages and interactions with seed producers and seed market as well as improving farmers marketing skills. Multi-media information channels for both literate and illiterate farmers will be used to support and promote improved varieties and complementary technologies. CRP 3.5 GRAIN LEGUMES will support research degree courses in fields related to seed systems bottlenecks and project outputs. Efforts will be made to sensitize and educate seed supply chain actors in the value of integrated seed systems (formal and decentralized) including national and regional seed services. Resource manuals will be developed or adapted including translation in local languages to avail the information in a user friendly package for wider use among the clients.

Support will be provided to maintain seed quality and increase the availability of foundation seed. Training of trainers on seed production and business management will be conducted for seed producers for each partner country. Training in seed production and business management will be conducted in partnership with continental and regional seed bodies including Regional Economic Communities (RECs) and Africa Seed Trade Association (AFSTA). Seed production and innovative training manuals, variety information (brochures, leaflets and posters) and mass awareness creation instruments (demonstration, radio and TV messages) will be developed and disseminated to targeted audiences. Students pursuing degrees in seed system related topics will be supported and guided by scientists in CRP 3.5 GRAIN LEGUMES.

Key Milestones

- Capacity at NARS research stations to meet the demand of Nucleus/Breeder/Basic seed of legumes strengthened to produce at least 20 tons of foundation seed per season for each grain legume in each participating country (2013)
- Knowledge and skills of seed producers (informal and formal) on seed production, post-harvest handling, marketing and seed rules/regulation enhanced (at least 20 seed producers per country) across legume crops (2013)
- At least one radio/ TV/ video program across legumes in each participating country presented to promote improved grain legumes varieties and agronomic practices (2013)
- 5000 copies of resource manuals developed and disseminated to users in each participating country per crop (2013)
- Public/Private seed producers are facilitated to produce at least 20 tons of foundation seeds per season for each grain legume in each participating country (2014)

5.4.7.3: Enabling seed policies for legume seed systems based on thorough analysis of current arrangements

Description

Traditionally, the private seed companies avoid marketing seeds of self-pollinated crops like grain legumes due to several reasons including limited profitability and unreliable seed market. The supply mainly remains through informal seed system. However, there is a limited support and integration of the informal seed sector in the seed policy establishment, leading to limited availability of quality seed of improved varieties to farmers. This situation has led many development actors (projects/donors) to support an informal seed system that is not recognized as assured source of seed, though it produces acceptable quality seeds (Rubyogo et al. 2009b). CRP 3.5 GRAIN LEGUMES facilitate the certification, institutional and policy systems to allow seed certification from different models. Rationalizing and harmonizing of policy and regulatory frameworks pertaining to variety release mechanism, IPR, seed certification scheme and phytosanitary measures would facilitate cross border movement of seed. This will introduce competition and create opportunities for private sector (domestic and foreign seed companies) to enter the regional seed market in favourable, commercial and hard to reach areas. Efforts should be made to build on already existing initiatives in sub-Saharan Africa (ECA, SADC, COMESA and CORAF) and CWANA (ECO) regions and international bodies such as seed trade associations across the three continents. This will provide more choices for farmers by accelerating varietal release and access to seeds. In addition, infrastructure and policy must be improved to strengthen the capacity of the public and emerging private sectors including farmer-based seed production and marketing units to enter into seed business which enhances the seed availability, access and use of seed of new legume varieties at the farm level.

Methodology

The legume seed supply chain actors including the national seed agencies (certification agencies and seed policy makers) will be facilitated to carry out situation analysis of existing seed policies and their effects on equitable accessibility of improved legume varieties to farmers (women and the poor). The results will be widely shared with users. This will guide better informed decisions by national governments and contribute to the establishment of efficient seed systems. Seed actors' awareness will be enhanced in the areas of national and regional seed policies (regional variety release, phytosanitary issues, etc.) and facilitate cross-border movement of safe seed within the regions. The CRP will facilitate the establishment of national and regional databases (variety catalogues and seed sector actors) and other activities for information and knowledge dissemination on new seed policies and regulations, and newly released and commercialized varieties. Streamlined variety release procedures supported by a thorough review of variety maintenance and adequate

breeder-seed production will ensure subsequent seed multiplication and reduction of the time lag between the variety release and the use.

Key Milestones

- A policy analysis (national and regional) with regard to legumes carried out in each participating country or region (2012)
- At least two policy briefs developed on a) the value of certification and b) seed quality/risks associated by various modes of seed production and supply (2013)
- Policy makers and seed supply actors sensitized in each of the participating country (2014)
- National and regional cross legume seed policies supporting the integrated grain legumes seed systems enacted in five countries (2014)

5.4.7.4: Framework for national seed security for vulnerable regions and households (poor and women) developed

Description

Grain legumes are increasingly being grown by subsistence farmers in higher stress and marginal areas which are located in fragile ecosystems. Many regional and national partner countries are experiencing disasters of various degrees (man-made and/or natural) on a relatively regular basis. For instance, intensive use of land (season after season) is leading to build up of diseases and pests. Since the formal seed sector tends to perform poorly in those areas, the majority of farmers in these agro-ecosystems acquire seeds through local seed supply systems (farmer to farmer) which are women operated (David and Sperling 1999). It is important to mobilize, organize and support the farmers themselves for producing and marketing quality seed within their communities and beyond. For instance local seed systems using seed loan and seed fairs approaches organized by local NGOs in remote parts of western Kenya under BMGF funded TLII project has accelerated the access of drought tolerant beans in the many part of western Kenya (Tropical Legumes 2011). Research on alternative seed delivery in remote and disaster prone areas can build on these local self-help initiatives, local institutions and on the knowledge, skills and experience of farming communities, particularly women.

Methodology

At the local level, activities will be carried out to access stress tolerant and locally preferred varieties obtained through PVS to women farmers who will be playing a major role in the variety selection. Partnerships will be enhanced with development partners (government, donors, private sector and civil society) to devise strategies aiming at designing technically sound and efficient seed systems to supply quality seeds to vulnerable regions and households (particularly women and poor). These strategies include judicious and self-targeted use of public support and marketing of affordable seed packs in the proximity of farmers (Rubyogo *et al.* 2011).

Four areas will be emphasized:

- To support the decentralized seed systems (market and non-market access) to accelerate the access of stress tolerant varieties in the vicinity and to fit in the agro-ecology niches
- To engage partners operating in stress areas and supporting vulnerable communities e.g. judicious and self-targeted seed support operations
- A policy sensitization workshop will be carried to educate agricultural policy makers on how to increase the grain legumes productivities in stress areas; and
- Devise cost-effective and less public-sector dependent partnerships with private- public-civil society organizations to supply seeds of improved varieties to vulnerable farmers, e.g., small packs.

Key Milestones

- At least two cost effective seed systems models to accelerate the access of improved varieties in vulnerable environments across legume crops identified and tested (2013)
- 500 tons of seeds supplied through different seed system models per each vulnerable impact zone (2014)
- 500,000 vulnerable farmer households (65% being women) accessed quality seeds of improved varieties of their choice (across legumes) in selected participating countries (2014)
- One cost benefit analysis of different seed systems across legumes to access quality seeds of improved varieties to vulnerable farmers (2014)

5.5 Strategic Objective 5: Enhance grain legumes value chain benefits captured by the poor, especially women

5.5.1. Rationale

Value chain analysis is a mainstream methodology for understanding market-oriented development and how to improve its processes in favor of the poor, especially women. In recent years, leading voices in international development have been urging increased attention to market-oriented development to achieve poverty escape (the goal of SLO1). Among these voices are the following:

- World Bank (World Development Report 2008)
- NEPAD's Comprehensive Africa Agriculture Development Program (CAADP) (built on a vision of "Dynamic agricultural markets within and between countries and regions in Africa")
- The Forum for Agricultural Research in Africa (FARA, with its high-level Specific Objective of "Broad-based agricultural productivity, competitiveness and markets sustainably improved in Africa", carried out through value-chain approaches in the sub-Saharan Africa Challenge Program)
- USAID's Feed the Future initiative, with its major investment area 'Expanding Markets and Trade'
- The Bill and Melinda Gates Foundation (through a top-level investment focus on "Access and Market Systems" (www.gatesfoundation.org/agriculturaldevelopment/Documents/agricultural-development-strategy-overview.pdf))
- The Alliance for a Green Revolution in Africa (AGRA)'s Market Access Program (www.agra-alliance.org/section/work/markets1)
- The sub regional R4D body CORAF's Mission Statement indicates a vision of 'Sustainable improvements to the competitiveness, productivity and markets of the agricultural system in West and Central Africa'
- The World Food Program's "Purchase for Progress" initiative to include smallholders in value chains to source its food aid (www.wfp.org/purchase-progress).
- USA's Dry Grain Pulses Collaborative Research Support Program (Dry Grain Pulses CRSP - www.pulsecrsp.msu.edu) that declares one of its four top-level Technical Themes as "Strengthening Pulse Value Chains" in concert with a market-oriented development strategy

The CGIAR's SRF likewise flags the opportunity inherent in harnessing markets, indicating that the "depth and distribution of rural poverty often leads to arguments that agricultural growth based on commercializing smallholder production is essential..."

Value chain analysis has long been standard operating procedure in large-scale commodity industries. Surprisingly, value chain analysis has rarely been applied to staple crops of the poor in the developing world, and to grain legumes in particular. Occasional references are found, e.g. a recent conference on Transforming African Economies for Sustained Growth, Poverty Reduction (IFPRI 2011) concluded that "Without broad-based agricultural growth, including in pulses and alternative cash crops, poverty reduction in Malawi will be difficult."

Women's participation in and benefits received from value chains have been particularly neglected. A notable exception is Dry Grain Pulse CRSP (see above) (Bernsten et al. 2009; Mazur et al. 2009). Illustrating the potency of this approach to deliver particular benefits to women, their value chain research has identified cowpea flour as a critical bottleneck in the sustainability of women's small-scale enterprise in the postharvest preparation and sale of products such as moin-moin in Nigeria (Lowenberg-DeBoer and Ibro 2008). The Dry Pulse CRSP will be an important partner in CRP 3.5 GRAIN LEGUMES. A number of countries and institutions are increasing their efforts identifying promising agricultural value chains for investment, as in Kenya (Value Chain Finance Center 2009), Nigeria (UNIDO, 2010) and Malawi (USAID Feed the Future).

Major inefficiencies exist in smallholder-scale grain legume value chains, posing opportunities for CRP 3.5 impact. Net value gained by smallholders is diminished by the relatively high prices that they must pay for essential inputs such as fertilizer and improved seed; and/or (more often) much value is foregone through low yields when farmers cannot access or afford enough of those inputs. Smallholders are especially disadvantaged because they have limited access to markets and often sell immediately after harvest, when prices are lowest. Smallholders usually sell their produce in a relatively poor condition with high content of shriveled, discolored and (in the case of groundnut) even mycotoxin-affected grains due to poor post-harvest handling and especially storage conditions. Processing losses are high due to inefficient (or no) machinery. Farmers have little access to information on prices and supply and demand conditions. They sell to middlemen who pay them the lowest possible price. Women tend to be marginalized from the higher-income generating processes of the value chain.

Success cases of post-harvest value addition in grain legumes illustrate the potential (see Our Track Record section). By formulating grain legume improvement more deliberately in a value chain context, this Objective will expand and increase such impacts across crops, regions and at more intervention points along these value chains. Trade-driven value chain examples include the export of pigeonpea and chickpea from East Africa to India (Jones et al. 2002; Simtowe et al. 2010), haricot bean export from Ethiopia (Ferris and Kaganzi 2008), and regional West African cowpea trade (Langyintuo 2003). Considerable effort is being made to improve the domestic cowpea value chain in Nigeria, including the development of new commercial food enterprises (Lowenberg-DeBoer and Ibro, 2008).

Value chain understanding also contributes importantly to the development of new and innovative partnerships to increase impact. Many key actors along the value chain are not the traditional partners of the CGIAR, such as entities involved in the manufacture and transport of inputs, collective action of women, postharvest processors and wholesalers, retailers and others that influence value chains. SRF states that "...the linear view of the innovation process has been replaced with an innovation system view of the world, where a much more diversified and complex universe of public and private actors come into play... significantly expanding the demands that national and international institutions need to confront...." (SRF, para. 33) This Objective will identify and highlight the roles and dynamics of these actors and thus will provide valuable insight to sister Objectives to help them form more effective partnerships for impact.

Sister CRPs 1 and 2 also intend to engage in value chain analysis at farming systems and macro-economic levels, but not focused on grain legume crops. CRP Grain Legumes' value chain analysis will focus on selected, specific grain legume crop/production systems of high strategic importance (see Priority Setting section below). It will generate concrete knowledge on how to improve the functioning of these value chains through specific R4D interventions in particular places and crop market channels. By so doing it will provide crucial ground-level information to complement and reinforce the broader conceptual and methodological approaches of its sister CRPs. Conversely, Grain Legumes will benefit from and apply the knowledge and methodologies on value chains that are generated by those sister CRPs. For example, the CGIAR's focus on poor smallholder families would require that the value not only of commercial markets but also of on-farm and home use of grain legume products be included in the value chain perspective. A detailed analysis of possible trade-offs implied by the emphasis on value chains, and location specificity of IPGs in value chains is in Appendix 15.

5.5.2 Priority setting

Based on high volume and value of production (Chapter 3), scope of regional and inter-regional trade, importance to women, and special attributes that provide unique and important opportunities for R4D learning (elaborated below), CRP GRAIN LEGUMES will place priority on the following five crop/system/market domains for value chain analysis:

- *Cowpea in WCA* – Important lessons on trade-off between grain vs. haulm value enhancement and markets with focus on the poorest subsistence-oriented farmers/women in risky dryland agro-pastoral economies
- *Soybean in WCA (Nigeria, Ghana) and ESA (Malawi, Mozambique, Zambia)* – Important lessons on harnessing a high-potential ‘new crop’ with strong global demand and excellent nutritional quality to drive emergent market-oriented development with strong involvement of women in postharvest value addition
- *Bean in ESA* – Most important grain legume for local production and consumption in this region; high importance in local economy and diets and for exports
- *Groundnut in SSEA* compare/contrasted with WCA and ESA – Valuable opportunity for South-South learning through value-added opportunities for a crop of high importance in both regions; groundnut is of special importance to women in WCA and ESA
- *Chickpea in SSEA* compare/contrasted with CWANA and Ethiopia – Valuable opportunity bridging CGIAR Centers for inter-regional learning based on a crop of high importance in three regions with particularly interesting trade dynamics (both import and export)

5.5.3. Impact pathways

Knowledge about value chains gained in this Objective will impact CRP 3.5 itself by:

- Improving R4D planning and priority-setting
- Identifying new/underestimated impactful R4D opportunities along the chain
- Catalyzing R4D on such new opportunities as they are identified
- Highlighting needs/opportunities for new partnerships along the value chain to overcome obstacles and exploit opportunities

The creation of these impacts requires close collaboration between actors in relevant positions along the value chain. Well-functioning seed systems (Objective 4) producing and distributing seeds of high quality and in regular quantities are critical in making crop value chains successful. CRP GRAIN LEGUMES will work closely with partners to understand how the relevant crop commodity value chains function, where the obstacles lie, and to test the feasibility and tradeoffs of potential interventions. Value chain partners will be asked to pilot-test them within their domains. They are likely to be willing to do so because of the benefit streams that will flow if the innovation is truly successful. The research outputs from this objective will better inform breeders regarding market preferred traits and enhance the uptake of the varieties developed under Strategic Objective 2. Further, the platform / dialogue that is created under Strategic Objective 6 will enhance the flow of information among stakeholders and strengthen capacity across all stakeholders.

The pathway for these impacts on CRP GRAIN LEGUMES will be through the CRP’s own management processes that are directly responsible for oversight and adjustment of the R4D agenda over time.

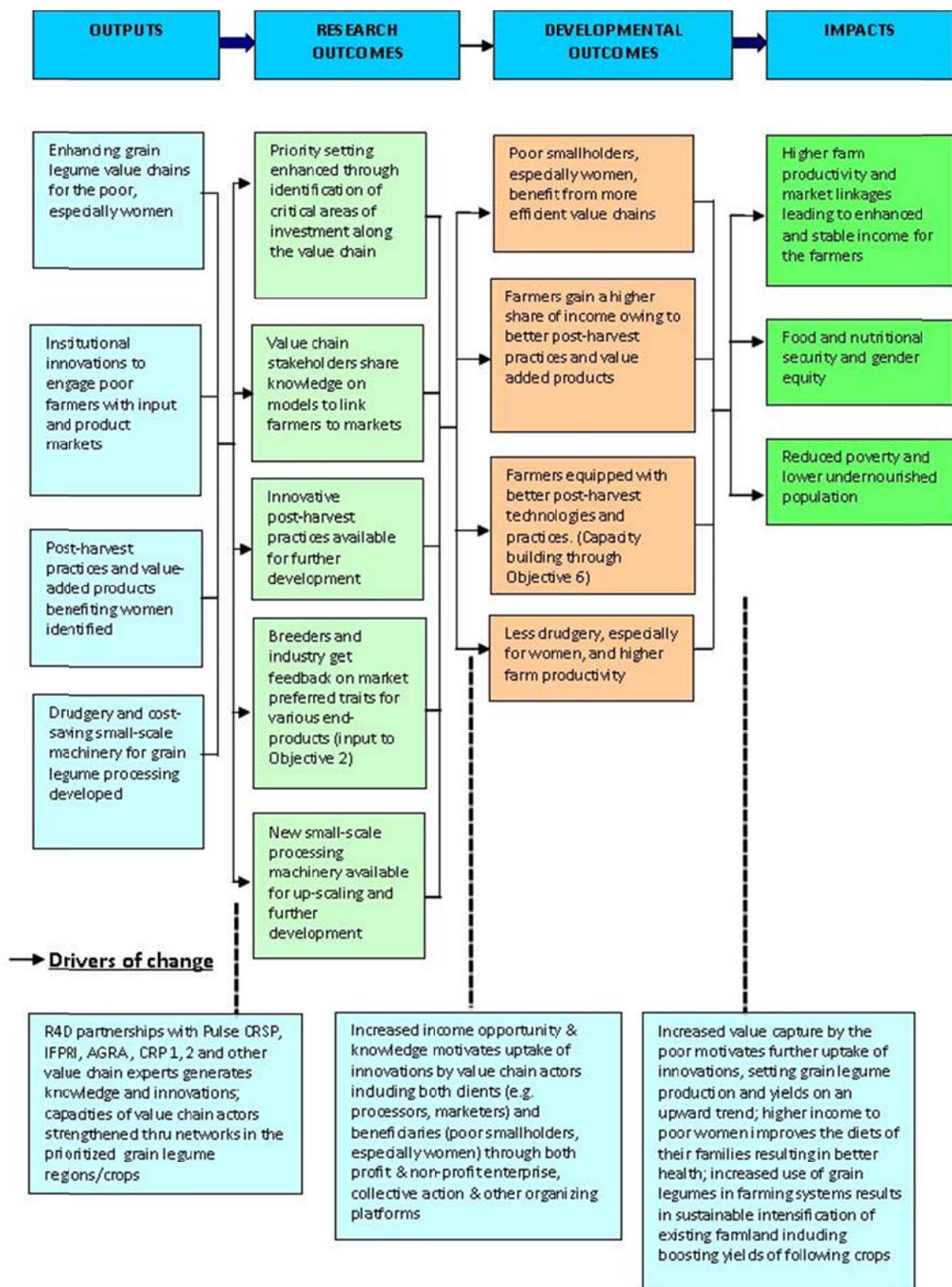


Figure 5.5.1. Impact pathway for Strategic Objective 5

5.5.4. Key Partners and their role

Strategic Objective 5 will work closely with value chain agencies and enablers in the course of mapping and discussing the implications of its R4D findings. They include partners such as government food technology and food policy agencies, legume trader associations, major legume product manufacturers, supermarket chains, health-oriented NGOs, community-based organizations

such as women's self-help groups and cooperatives, and others as relevant to the chain under study. The processing methods for perishable fresh products will be developed in partnership with NARS, NGOs and local processing industries. Innovations in dry seed processing appropriate to the poor will involve partnerships with grain processors and exporters, the international grain legumes trading association, farmer cooperatives and NARS. High value animal feeds will be developed in partnership with CRP3.7 – especially in relation to the fish and dairy sectors, the fodder trade, NGOs, CRP 1.1 and CRP 1.2, and CRP2. Small-scale mechanization of crop production and processing will be done in partnership with input suppliers including equipment manufacturers, NGOs, CBOs, and NARS. We will provide the necessary policy information to governments that will foster value addition (see details in Chapter 6 on Partnerships).

5.5.5. Gender Strategy

Women will play a central role as value chain actors and suppliers of services needed to support the legume chain. Adapting the value chains for legume crops can have significant gender effects, and this needs to be carefully considered in the design of any interventions to add value. Who will benefit most from new products and processing? Regional and ethnic domains also differ significantly for gender roles. While men tend to dominate cereal production in many societies, women are more likely to take a major role in the growing of legumes, especially in Africa. Women carry out weeding and harvesting, so interventions to make these activities less arduous can particularly benefit them. While men tend to dominate the marketing of dry grains, women are more likely to dominate the marketing of perishable and value-added products. Women are also more involved with small-scale processing, food preparation for home use or local sale, so the introduction of simple processing technologies can directly benefit them and the households if carefully introduced. It is expected that the increased and focused participation of women in the value chain could increase their involvement in higher level economic activities like marketing, managing end-product enterprises and decision making.

Innovations to increase the profitability of crops that were formerly of little economic value or for home use can improve the incomes of women, but this can also pose new challenges. Women groups and associations of women groups will continue to be targeted for building their capacity to organize produce and market collectively to different markets. Product development and identification of agro-enterprises is to be done by gender to ensure that products that are more accessible to women are developed with them in a participatory process. Past experiences have shown that men often take over such enterprises after they become profitable. Social organization helps to protect women's interests. GRAIN LEGUMES will forge partnerships with gender interest groups to advocate to changes that favor women interests while ensuring that interventions not create community conflicts (see also Chapter 7 on Gender Research Strategy).

5.5.6 Lessons learned and research questions to be addressed

- Reputation, communication and trust are important elements of successful linkages between farmers and industry both in formal (written agreement) and informal contracts (verbal).
- Innovation is possible when all stakeholders in the value chain are fully aware of the benefits of new technology/product in a clear and transparent manner, i.e., not couched in scientific jargon.
- Value addition to produce starting with simple innovations like processing can reduce post-harvest losses at the farm level and can go a long way to improve farm productivity.
- Studies such as that of Ph Action (Global Postharvest Forum) suggest a systems approach to address post-harvest losses that should include analysis of post-harvest systems and the impact of these systems on food security, food quality, and value-addition as a contribution to rural livelihoods. Thus there is a need to document, integrate, implement and assess the best post-harvest technologies and practices to benefit the grain legume farmers especially

women.

- Very few processors are involved in processing activities targeted to the consumer-ready market. Besides lack of secondary and advanced processing, the current technologies and capacities of primary processing at the farm-level needs to be upgraded.
- Very little efforts have been made to understand and develop effective technologies that can reduce drudgery of women involved in pulse production activities as compared to other crops. Effective mechanization has been successfully adopted in the small-scale maize milling sector. The adoptability of the hammer mill for maize milling was supported by clear benefits for women, as it reduced drudgery and increased time available for other productive activities. Similar interventions, at various stages of pulse production that reduce drudgery for women, offering more time to pursue productive activities.

Key R4D questions include:

- What adjustments to conventional value chain analysis are required to delineate the roles of and benefits received by the poor, especially women?
- What are the current monetary and other values associated with the major products from grain legumes, i.e. grain, prepared foods eaten at home or sold, fresh pods, fresh leaves, haulms, and nitrogen fertilizer saved?
- What are the monetary and other values associated with current and prospective innovations in the chain?
- Which high-profit processes in grain legume value chains are appropriate for increased smallholder involvement, and through what institutional (formal or informal) mechanisms?
- How can value chain findings contribute to CRP 3.5 priority setting processes?

5.5.7 Outputs

5.5.7.1 Enhancing grain legume value chains for the poor, especially women

Description

To develop the value chain perspective, a much better understanding of smallholder grain legume value chain core processes and dynamics is required. To achieve this, value chain models will be formulated that help researchers understand where and how much value is gained along the chain, by whom, and dependent on what actions, infrastructure, capacities, partnerships, and other key determinants, along the chain of processes from input supply through production and culminating in postharvest handling and marketing. Such understanding will reveal opportunities for increased impact from R4D innovations.

In areas of high poverty there are many constraints that CRP GRAIN LEGUMES partners will help overcome through a better understanding of value chains and innovations that unleash their potential. Value chains vary across crops and regions and the processes involved in bringing the different actors in the value chain on a common platform. However, value chains do not necessarily benefit the poor because they often lack the power to negotiate favorable terms and conditions for themselves. Vested interests can skew the benefits accruing to different participants in the chain. Also, the economic efficiency of different value chains will vary and the costs/ margins at every stage of the chain may not commensurate with value addition. Women involved in agriculture play an important role particularly in simple value addition activities like winnowing, grading etc. but are not compensated adequately. Their role needs to be institutionalized so they can reap the benefits of value addition and become equal partners in the value chain cycle. Women's participation is also constrained by the lack of machinery that leads to drudgery and loss of valuable time. There is thus a need to introduce small-scale equipment (to be identified under 5.5.4) that promotes women's participation in value chains in a timely manner. Despite a plethora of value added products not all may be economical due to lack of sufficient demand or supply side bottlenecks and hence need to

be prioritized before being introduced even on a pilot basis. Poor farmers and women also lack skills to effectively participate in value chains and hence reap the benefits of value addition. Capacity building related to participation in value chains thus becomes pertinent if the poor have to benefit from existing or emerging chains.

Methodology

Participatory market chain analysis will be used to map the value chains for the priority crops/region/market domains listed earlier. Market mapping involves four components:

- Core processes of the chain (e.g. input supplies, production stages, postharvest and marketing stages specific to those crops);
- Enabling environment (infrastructure and policies, institutions and processes that shape the market environment and regulate the chain);
- Value chain actors (identifying the chain actors, what they do, when and how, where and how the poor participate and benefit, the flows of products in the chain, their volumes, values, and value addition at each step, the relationships, linkages, feedback loops and other dynamics among chain processes, information and knowledge flows along the chain); and
- Service providers (the business development or extension services that support the value chains' operations and required for the chain's effective functioning (i.e. input supplies e.g. seeds, fertilizers, aflatoxin control technologies), market information (e.g. prices, trends, buyers, suppliers), financial services (e.g. credit, savings or insurance), transport services (e.g. for grain purchasing), and quality assurance - monitoring and accreditation).

Analysis of legume value chains will be done in 8 steps. First, qualitative and quantitative methods will be used to prioritize value chains to be analyzed. Once value chains have been selected, the next step will be to map them. This involves mapping the core processes, the main actors involved in the processes, the flows of products, knowledge and information, volume products, number of actors and jobs, geographical flow of the product and services, values at different levels of the chain, relationship and linkages between actors, business services that support value chain actors. The third step is to map governance, i.e. coordination, regulation and control using qualitative tools. In the fourth step, relationships, linkages and trust between actors in the value chain must be assessed. Then options for upgrading, knowledge, skills, technology and support services are analyzed in step 5. This is followed by analysis of transaction costs targeting actors along the value chain using quantitative tools in step 6. Data will be collected on costs and revenues in each node of the value chains to assess the returns in each segment and/or the entire chain. Equity implications in the distribution of income and employment will be finally examined in steps 7 and 8. This is to ensure that the poor and particularly women benefit from the interventions as well (M4P, 2008). The relative value addition from different R4D options will be compared using structured criteria comparisons following Value Chain Finance Centre (2009) methodology. Sophisticated modeling methods will be explored in partnership with CRPs 1 and 2.

In order to ensure proper choice of counterfactuals and proper attribution of value chain interventions, pilot experiments will utilize a random selection of participants and non-participants for the core processes/dynamics under study.

Key Milestones

- Initial value chain core processes, actors (gender-differentiated) and dynamics for the priority crop x regions identified (2013)
- Value chain investment opportunities identified that maximize benefits for the poor, especially women (2013)
- Business skills of at least 20 entrepreneurs (both men and women) enhanced in value addition, product development and marketing.

- At least 2 new or existing legume products within each selected market that are most likely to benefit women and improve health and incomes prioritized (2013)
- Technologies and capacity building measures needed for expansion of these opportunities for value addition identified feedback to other outputs provided (2014)
- Policy evidence to inform policymakers and development planners provided (2014)

5.5.7.2 Institutional innovations to engage poor farmers with input and product markets identified and piloted

Description

Farmers require inputs in smaller quantities that are uneconomical to buy individually. Group ordering through collective action in purchasing inputs will generate economics of scale, reducing the cost of inputs. Models that link farmers to input suppliers, and are appropriate to the region, will be pilot tested or existing models already operating in the region will be assessed. Likewise, farmers are constrained by capital. Linking farmers to financial institutions is essential for the success of value chain development. Numerous models have been tested and could be assessed.

Owing to small-scale production, poor farmers are unable to sell in the markets or sell at unremunerative prices. The bargaining power of smallholders will be limited if they are unorganized, have few assets and scarce alternative income opportunities (Key and Runsten, 1999; Patrick, 2003).

To increase their bargaining capacity and empower them, several innovation models of linking farmers to markets/end-users have been tried. For example, contract farming, bulk marketing, collective and cooperative marketing, direct marketing, linking to major international supermarket outlets such as Tesco, Heritage, Reliance, Spencer's and others. While these models have succeeded in some crops in some regions they have been unsuccessful in several instances. The contract farming models have worked well for perishable commodities like vegetables, fruits, and niche products. They have also been successful for dry seed crops like maize, wheat, etc. particularly involving industrial users or export markets.

For example, brined and pickled cowpea is a high value exportable product, but to develop this an integrated value chain model is required which will start from research, farms to markets by involving various stakeholders – researchers, farmers, aggregators, processors, exporters, skilled workers and bankers. Such value chain innovations can become local economic drivers. We have seen successful models in the pickling industry (gherkins, vegetables, onions and cowpeas) for example. Access to market intelligence would be strengthened by forming farmers associations. Warning and Key (2000) found that Senegalese smallholders who participated in a peanut contract farming program received higher income from their participation and that the program structure allows the participation of poor smallholders.

Aligning dry grain legumes to commodity exchanges is one promising value chain innovation. India and Ethiopia have experienced evolution of commodity exchanges that are ensuring price discovery and produce marketing options to smallholders. A well-adapted process with strong private sector involvement exists today. Similar innovations can be adapted to dry grain legumes from other regions particularly SSA. Partnership models involving commodity exchanges, local Government and private sector partners (traders and exporters) can assure smallholder farmer place to store the grains and plan products based on market trends.

Methodology

Success stories of various models linking farmers to spot, future and financial markets will be identified from secondary sources and adapted to legume crops and regions as appropriate. For example, contract farming models with pre-determined price, quality based pricing, models with intermediaries, formal and informal contractual agreements etc. will be considered. In India, a **self-help group (SHG)** is a village-based group usually composed of between 10-20 local women with

common objective of improving income and livelihoods for their families with collective action is presently functioning effectively in several Indian villages, especially with micro finance activities. This model can be replicated and tested for collective purchase of inputs and sale of outputs. The pilot tested models will be assessed for economic viability and financial feasibility using budgeting methods and benefit cost analysis (Hubert Schmitz, 2005).

Key Milestones

- Region/crop attuned models developed and pilot-tested for organizing women to sell grain legumes into commercial markets, significantly raising legume-sourced incomes (2012)
- Collective purchasing mechanisms devised and pilot-tested that significantly reduces costs of fertilizer and other grain legume inputs for smallholders, especially women (2013)
- Business models developed with commercial and rural banks and micro-finance institutions (2014)

5.5.7.3. Post-harvest technologies/practices and value-added products benefiting women identified and promoted

Description

Thriving urban, industrial and export markets exist for a wide array of grain legume-derived specialty foods such as peanut butter, fresh and cooked beans for breakfast and for salads, and a range of fermented and other soy products.

Grain legume haulm (vegetative tissue), mainly of groundnut, cowpea and chickpea added to cereal stover substantially increases the feeding quality of the resultant fodder; increased nitrogen supply to rumen microbes improves the digestion of stover, increasing weight gain in livestock (Grings et al. 2012). Income from haulm is often as much as that from the grain crop (Erskine et al. 1990). The marketplace rewards higher haulm quality of the improved groundnut variety ICV 9114 with a 25% price premium in Anantapur, India (Thannamal, 2011). In a study of 850 genetically-diverse groundnut advanced breeding lines, Nigam and Blummel (2010) found significant genetic variation and high heritability for fodder quality traits (crude protein, in vitro digestibility and in vitro metabolizable energy content). They found no negative correlations between fodder and grain yield and quality traits, indicating that haulm and grain can be improved simultaneously without tradeoffs. Postharvest enrichment of fodders with soybean and groundnut presscake (the residue following oil extraction) also improve feeding quality.

Pulses are key protein foods for the poor and substitute for costly animal proteins (Chapter 3). Postharvest losses during traditional harvest, drying and storage are high due to pod shattering in the field, poor drying systems, insect infestation that normally starts in the field and proceeds into storage, and storage losses to insects and mold. Smallholder incomes, particularly for women, can be significantly enhanced by improving post-harvest and processing technologies (Lowenberg-DeBoer and Ibro, 2008; Yanguba, 2009).

Fresh leaves, pod or green seeds of many legumes can also be used as a vegetable, in addition to the mature seeds. The processing and marketing of such perishable food products involves different actors than that for mature seeds. Women usually dominate the fresh food processing and marketing of fresh foods such as legume leaves. Because of the perishable nature of these products, transportation, hygiene and handling, and quality assurance issues can also be different from those for dry seed products. This work will be done in conjunction with universities, NARS, NGOs, and local processing industries. Legumes are also primarily grown for their dry seed, and as a relatively durable product it is more easily traded over long distances than fresh legume products. Larger trading and processing industries can be involved in handling legumes as bulk commodities for international trading, but there are also opportunities for small-scale value adding for local sale.

In addition opportunities exist for exploiting the nutritional and functional properties of legumes using appropriate food processing technologies to develop and commercialize various food products at the industrial scale. This work will be done in conjunction with grain processors and exporters, NARS with postharvest and gender expertise, and NGOs interested in small-scale machinery innovation. Legume haulms can provide high quality animal feed and legume seed can be an important source of protein and other nutrients for feed rations. Oilcake from groundnut and soybean are major sources of animal feed and used extensively in feed mixes. This work will be done in conjunction with CRP3.7 – especially in relation to fish and dairy sectors, the fodder trade, NGOs, CRP 1.1 and CRP 1.2, and CRP 2.

Methodology

Post-harvest interventions for each of the legumes shall be identified after detailing each step of the post-harvest operations. Understanding the characteristics and post-harvest behavior of each legume is key to identifying the appropriate protocols for harvesting, transportation, drying, storage and primary processing. Maturity and harvesting of food legumes is key factor in post-harvest management of legumes. Factors that directly influence grain quality such as moisture content of the grain, temperature, presence of micro flora (fungi, bacteria, etc.) in the grain, insect damage, physical state of the grain, and amount of oxygen-carbon dioxide ratio in the storage environment shall form the basis to arrive at strategies to reduce post-harvest losses for each legume. Use of PICS (Purdue Improved Cowpea Storage) bags to improve storability of legume seeds and grain will be explored. Socio economic factors, such as availability of labor, gender roles, access to credit, and access to markets shall be evaluated in order to develop appropriate post-harvest intervention models for each legume.

Profiling of varieties of each legume, for specific application traits, leading to diverse uses of legumes in food and feed applications shall form an important basis for breeding of legumes. In addition to nutritional properties, which are of utmost importance in order to provide nutritional security, the functional properties play an important role during preparation, processing, and storage thereby altering the sensory characteristics of food. Functional properties (foaming, emulsification, texture, gelation, water and oil absorption capacity, and viscosity, etc.) shall be evaluated in order to identify varieties of legumes for various industrial applications. In addition the possibility of the utilizing by-products of the legume milling industry based on their nutritional and functional profiling will also be investigated. Recent studies have shown that hydrothermal pre-treatment method improves functional properties of pigeonpea flour and decreases cooking time of de-hulled splits (dhal) without affecting nutritional composition of pigeonpea (Tiwari et al. 2008). Similar approaches shall be looked into in order to identify appropriate processing techniques that can lead to enhanced utilization of legumes at both household as well as industrial level. Product development activities shall focus on improving traditional processes and products with enhanced nutritional profile and sensory attributes as well as explore new innovative processes such as enzymatic pre-treatments, extrusion and extraction to develop value-added products based on legumes.

Key Milestones

- Post-harvest processing technologies benefitting women documented and prioritized based on social gains (2013)
- At least 2 post-harvest and processing technologies and associated practices, particularly suitable for farm level use or small-scale household operations documented, and strategies developed to identify new markets and scale-up the most suitable technologies (2013)
- Structure, conduct and performance of major animal feed markets for legumes assessed (2013)
- Appropriate strategies to manage aflatoxin contamination, assessed and the relative benefits to smallholders for supplying to these markets determined (2013)
- Post-harvest technologies for reducing losses due to pest and diseases in key legumes

identified/adapted/developed and scaling up assessed (2014)

5.5.7.4. Drudgery and cost-saving small-scale machinery for grain legume processing identified or developed

Description

Efforts to reduce human drudgery in handling and processing of legumes at all stages of legume production are critical. Implementation of small-scale mechanization at the farm level shall result in saving valuable time for the farm households. Small-scale mechanization allows timely operations and hence aims to increase the profitability of growing a crop by reducing production costs, but also to allow the development of new legume products and markets.

The problem of pod shattering in legume crops is severe. Laborious, time-consuming hand-picking must be carried out on certain varieties of edible legumes that mature unevenly. Such areas of legume production need to explore small-scale mechanization. Weeds are another major problem for smallholders; mechanical control is frequently impractical, but hoe-weeding is arduous. Herbicides are a possible alternative, but it is important to apply herbicides, particularly residual herbicides, at the correct rate (linked to outputs in SO 2 and SO 3 on herbicide tolerance). Animal-drawn herbicide applicators for small-scale farmers should therefore not only be robust, simple and cheap, but also ground-wheel monitored (Fowler, 2000).

Women are heavily involved in weeding, threshing, cleaning and grading of grain legumes and these operations are mostly done manually. Suitable mechanization of such operations will relieve women of drudgery and free up their time to carry out other vital activities. However, before undertaking mechanization it is also important to assess the actual benefits that would be obtained, particularly that it does not result in reduction of employment opportunities to women.

Methodology

Simple tools such as tillage equipment, hoes and weeders will be explored for each legume crop. A simple animal-drawn cutter bar is available in the market for use in the harvesting of soybean and common beans. Field level shellers or decorticators will be evaluated so that shelling operations can happen at the farm, thus reducing the drudgery of carrying bulk produce to storage. Simultaneously work will be initiated closely with local machine manufacturers in order to develop cost effective tools and equipment. Appropriate capacity building programs will be undertaken along with the machine manufacturers in order to impart necessary training to develop skills for handling these equipment and thus reducing drudgery. Mechanisms will be explored in order to secure finance for procuring these tools by the farmers.

Key Milestones

- Labour demand in smallholder legume production assessed and the potential of increased mechanization to improve profitability documented (2012)
- Weed control methods in legumes, by smallholders identified and their relative impacts on women assessed (2012)
- Options for smallholder threshing or harvesting to improve legume profitability assessed, with particular reference to uses across legume species (2013)

5.6. Strategic Objective 6: Partnerships, capacities, and knowledge sharing to enhance grain legume R4D impacts

5.6.1. Rationale

Partnerships are central to the work of all research institutions, especially for legume research, since the communities of legume researchers tend to be relatively small and in need of cooperation and interactions.

Capacity strengthening interventions have evolved along with the broadening of the scope from mere research to research for development. There is a shift from a relatively narrow focus on training for food production through extension systems to the current more systemic approaches that focus on rural innovation systems through multi-stakeholder platforms.

This evolution towards research for development, aptly exemplified by refocusing of the CGIAR on the four SLOs, raises many issues around the need to effectively reach the multiple end-users. Reflections on the lack of impact led social scientists to seriously question the pipeline approach used to resolve the “farmer’s problems” with scientifically proven technologies. Several participatory approaches have been developed and researched to convert the technology transfer pipeline into a learning cycle where next and end users of research processes learn together, support partnerships and stakeholder engagement and therefore, increase the chances of research being put into use. The participatory learning mode, where responsibilities are shared and all actors contribute, makes for a system that is less dependent on one individual or institution, and potentially more sustainable.

The involvement of a wide range of actors required the creation of a shared context (Snowden, 2002) where advances in information and communication technologies (ICTs) that make technologies truly participatory can contribute to the way we communicate, share knowledge and solve problems together. These interventions strengthen both individual and organizational capacity.

5.6.2. Key partners and their role

Operational partnerships are part and parcel of the CGIAR mandate. The CGIAR Strategy and Results Framework states that partnerships at all levels are increasingly recognized as strategic approaches to pool complementary assets such as intellectual property, genetic resources and research tools that facilitate the exploitation of economies of scale and scope, ease and improve technology transfer through arrangements with private input distributors, promote better integrated value chains, and foster mechanisms to express consumer and farmer demands for technology and product traits (CGIAR, 2011).

Traditionally these partners were NARES, Advanced Research Institutes, and Universities but it is now being realized that while such partnerships are evolving, they must bring in new partners, especially in the private sector, as well as NGOs and CBOs. The drivers are multiple, including the need to connect to upstream partners with advanced research institutes, the hope to reduce costs, or to deploy new technologies (Spielmann et al. 2007). Therefore, in making such evolving partnerships functional, agile, bureaucracy-light, and mutually satisfying, it tends to include participatory learning principles and methods.

As Horton et al. (2009) argues, “in the context of international agricultural research for development, partnership is defined as a sustained multi-organizational relationship with mutually agreed objectives and an exchange or sharing of resources or knowledge for the purpose of generating research outputs (new knowledge or technology) or fostering innovation (use of new ideas or technology) for practical ends”. This definition implies that partnerships involve different types and multiple actors and can cover informal and formal arrangements, shared responsibilities and decision making. It also stresses the fact that partnerships can cover a range of objectives, from the pure delivery of a research product to the creation of a shared context for innovation and joint

learning.

More recent approaches consider partnerships in the context of Complex Adaptive Systems (CAS) where, beyond the delivery of research products and development of tools and methods, the partnership evolves in terms of knowledge, attitudes and skills (KAS).

A partnership model with an explicitly dynamic dimension is the Learning Alliance, which relies on an iterative learning process jointly undertaken among multiple stakeholders with a common interest or goal. Typically, stakeholders might include research organizations, development and cooperation agencies, universities, policy makers and private businesses. The learning alliance approach is made up of four interrelated learning strategies:

- Capacity strengthening.
- Targeted action research that responds to specific knowledge gaps identified with partner agencies.
- Connectivity and knowledge management.
- Evidence-based decision-making in partner organizations, public sector entities, cooperation agencies and private sector firms.

Specific roles of CRP GRAIN LEGUMES partners are illustrated in Chapter 6 on Partnerships and Networks.

5.6.3 Impact pathways

In the area of partnering, capacity strengthening, and information sharing, some outputs are discrete such as training of personnel through fellowships or the establishment of technical information platforms. Other outputs are more process focused, where the concept of an impact pathway is rather different than in the delivery of a tangible product such as seed. The challenge here is to create systems, often informal, of continuing education and mutual learning among all participants (including scientists from the international center). An impact pathway often takes the form of implementation of a process.

Experience shows that these systems can find implementation on a regional basis with external funding, while low cost systems can draw partners together on a national level. In the former case an international center is normally the entity to convene the network, while the Sub-Regional Organizations (SROs) such as those in Africa are increasingly taking this role. Such networks function well within certain institutional, disciplinary, or commodity boundaries. In the experience of the sub-Saharan Africa Challenge Program, the challenge has been to identify a mid-level entity that can coordinate across disciplines of agricultural production, agro-industry, and marketing.

The impact pathway to implement such higher order networks remains a challenge to be resolved, although, there are tools such as Outcome Mapping or Participatory Impact Pathway Analysis (Douthwaite et al. 2007) that allow a systematic ex-ante, qualitative, and participatory planning of project goals in connection with the required evolution of partnerships to achieve those goals. Such stakeholder analysis that include social network analysis approaches are relevant as the partner's degree of influence towards next- and end-users has to be known and taken into consideration as a potential multiplier effect and factor for impact.

Monitoring and Evaluation (M&E) is a systematic learning and capacity strengthening process that involves all relevant stakeholders (FIDA, 2001), and is a central issue of these learning systems. M&E is an action-oriented management tool and an organizational process for generating knowledge to improve decisions on policies, programs and organizations (Horton & Macay, 2003).

In any case, the impact pathway for successful partnering requires a conscious and planned institutionalization of spaces – physical and/or virtual – for the periodic interchange of ideas and information. This is often within an action research mode, and with common goals of innovation,

where plans and progress are reviewed, revised and short terms plans are developed. In the formation of such systems or communities, conscious effort must be exercised for the inclusion of women, and to avoid that these become (quite literally) the proverbial “old boys’ club”. Once established and consolidated, it will be difficult to alter the gender balance - such that this needs to be addressed from the outset.

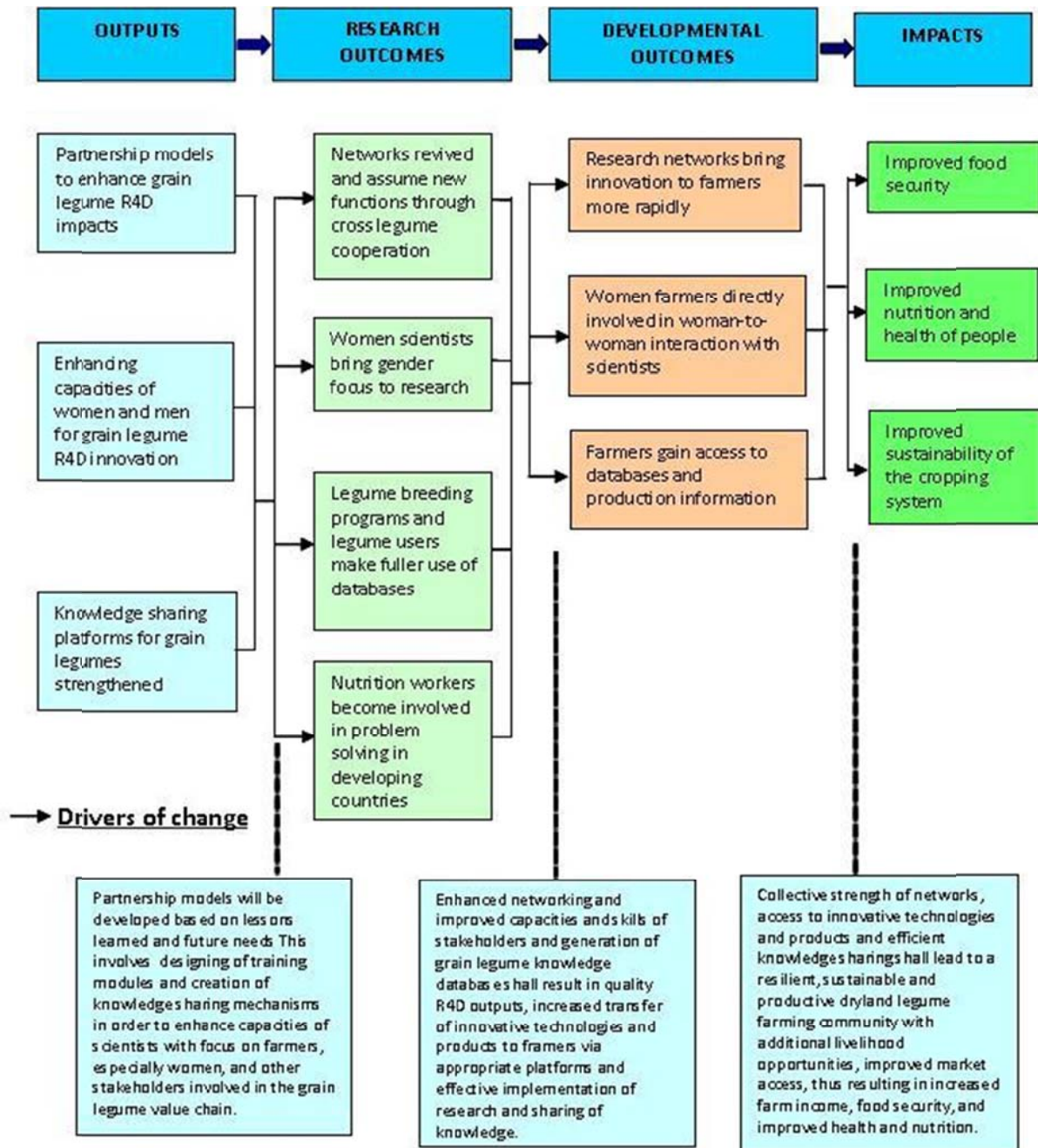


Figure 5.6.1. Impact pathway for Strategic Objective 6

5.6.4. Capacity strengthening

Capacity is both individual and institutional, and efforts have been and continue to be directed toward fortifying these capacities. Institutional capacity strengthening takes the form of facilitating investments in ICT infrastructure, training in the use of online content or facilitating changes in organizational priorities and culture. Individual capacity building is often posed in the context of higher degree training. All centers have given active support to degree training through fund raising and through support of thesis research, in collaboration with universities in-country and abroad. Other prominent actors include the US Collaborative Research Support Programs (CRSP) and AGRA/PASS. Experience with degree training in Europe, North America, and Australia shows that many trainees do not return to their country and institution of origin. This has led to a tendency to train scientists in local or regional universities. CGIAR centers should play an even more active role with universities in Africa, Asia and Latin America, to enhance the capacity of local and regional universities in specialized areas of agriculture, through sandwich programs, whereby thesis research is carried out in collaboration of a center with a university.

An even more significant contribution of the international centers to individual capacity is in the continuing accompaniment of partners in the field of service. While often referred to as mentoring, this is in fact a co-learning experience.

Other capacity building being done by the four CGIAR centers working on food legumes are through headquarter-based and in-country tailored trainings in different areas of legume improvement (biotechnology, breeding methods, IPM, biometrics, etc.) to improve the skill of young researchers in many partner countries. Another scheme called long-term training permits young scientists to be attached to CGIAR scientists during the cropping season to gain experiences in crop improvement and agronomic management to employ in their respective countries. The impact of short-term training in promoting better research for development has not been well documented. An impact study of such projects would be warranted. Additionally, in-service training can be achieved with the support of e-learning materials. Several initiatives including GCP have generated some that are relevant to CRP 3.5 GRAIN LEGUMES.

A third type of capacity is that of the community, which is less structured and often less tangible but that bolsters both the individual and the institutional capacity. Communities of practice have the advantage of enjoying low overhead and transaction costs, while facilitating communication, cooperation, and the exchange of information, germplasm or other tangible goods. Communities of practice may have some supporting “infrastructure” such as a webpage, but by and large are maintained by goodwill, trust, and mutual interest. The regional networks that several IARCs have facilitated, while initiating as formal externally funded projects, have often evolved into communities of practice maintained by long association.

5.6.5. Gender strategy

Legumes are women’s crops. A corollary of this statement is that women should play a prominent role and be full-fledged partners in the efforts of planning, partnering, capacity building, and information sharing. While gender balance in center staffing is a CGIAR policy, it plays a substantive role when science must be articulated to women farmers, and when women farmers must have complete freedom to articulate their own needs and perspectives to scientists. The Consortium Level Gender and Diversity Strategy states that “research quality increases when women are better represented on the staff of research institutions....” In this regard, there is a special urgency in incorporating more women into the CRP staffing.

In the case of farmer involvement in processes, to the extent that these are long-term learning experiences and not one-off surveys or demonstration plots, the issue of gender takes on a dimension of time and process facilitation. Beyond eliciting an accurate response on a questionnaire or communicating a technical result, participation of women in ongoing group dynamics will require

additional sensitivity to assure equitable opportunity. The CRP will be attentive to the development of a 'Gender and Diversity Network' under the leadership of the Consortium Board, and considers that the CRP GRAIN LEGUMES should play an active role.

5.6.6 Lessons learned and research questions to be addressed

In the recent past, there has been a paradigm shift in partnerships to include not only public and private sector, but also NGOs, CSOs, Farmers Organizations and farmers, especially women and other disadvantaged groups. Learning in this area is reflected in the emergence of numerous studies on the subject of partnership studies (Snowden, 2002; Horton et al. 2009). Relevant examples of partnership are the Tropical Legumes I and II projects among three international centers (ICRISAT, CIAT and IITA), the respective partners in ARIs and national programs, and the PABRA common bean network in eastern, southern and western Africa. The experience of PABRA shows that broad-based partnerships involving researchers, extensionists, seeds persons, regulatory agents, and users of technology can vastly expand the reach of research outputs, and the consultations facilitated by an IARC but convened by national partners have the potential to consolidate in an innovation platform. Partner capacities vary considerably, and hence strategies for capacity building should be tailored to the needs of the specific partner groups. Capacity strengthening can also be at various levels—from farmers training in PVS to advanced and sophisticated research techniques for scientists. For example, training of field technicians has been especially effective in implementing simple skills for drought studies. Technicians often remain in their positions in the long-term, while scientists move into administrative positions, and honing their skills can create more sustainable research programs. Technician training should receive more attention in the future. There is greater recognition of the role of women—as receiver and provider of capacity strengthening skills. Recent developments in ICT have changed the way people acquire and share information and technologies. Several innovation platforms for data and knowledge sharing are becoming available globally and there is need to establish public repositories for legume research and uses.

Key R4D questions that SO 6 will address are:

- How can the cross-crop, cross-center alliance of CRP 3.5 best be configured to add value to all partners' efforts?
- How can that alliance become a true innovation platform and not just another transaction cost?
- How can we work with partners to establish clear protocols for enhancing women's participation in partnerships and capacity building?
- How can we enhance the use of existing ICT (mobile phone, radio, TV, internet, etc.) to further exchange and sharing of information and knowledge among rural communities?
- How can nutritionists, health-care professionals and food scientists be engaged with CRP 3.5 agriculturalists to enhance mutual learning on nutritional issues of grain legumes?

5.6.7. Outputs

5.6.7.1. Partnership models to enhance grain legume R4D impacts identified and implemented:

Description

In CRP 3.5GRAIN LEGUMES, agricultural research for development (AR4D) will be predicated on the notion of establishing innovation platforms, both physical and virtual, through which different actors communicate, cooperate and interact to set priorities, develop concepts and promote agricultural productivity and profitability (Hall et al. 2004). This effort requires building a common vision and purpose and developing realistic goals and transparency about resources and responsibility sharing to build trust and commitment. Work with innovation systems and multi-stakeholder partnerships shows that effective communication among the diverse actors is critical to success. For example, in Africa, the Pan-African Bean Research Alliance (PABRA) follows this model to coordinate the

collaboration among 28 national programs regionally. Similarly, in the Nile Valley and Sub-Saharan African countries (Egypt, Sudan, Ethiopia, and Eritrea) there is an established platform of national and regional traveling workshops where researchers and other stakeholders are involved in a learning platform; and recently identified benchmark sites addressing different farming systems in the four countries. Partnerships can grow spontaneously out of information exchange when common interests emerge (Output 3 below). In the context of international agricultural research, the intent is to leverage the capacity housed in many of the larger and more advanced national systems: ICAR in India, EMBRAPA in Brazil, EIAR in Ethiopia, and the General Directorate of Agricultural Research of Turkey in West Asia. IARCs are in a position to be a communication facilitator between NARES, major or minor, or between the public and private sectors.

Methodology

An inventory of global partnerships and developing learning modules among core IARCs and partners will reveal the state of the art in networking and partnering, clarifying the most important motivators for membership and organizational expectations. Partnership development processes will be planned and executed to build on existing partnerships and obtain the tools, social processes and skills needed to develop and sustain it. These must include the institutionalization of periodic revision of progress, reflection, and planning (normally once a year) as part of a participatory M&E process that generates ownership, consolidates a common vision, and maintains trust. Under the BMGF funded TL-II project, a trial mode of interacting with IARCs will be tested, whereby cross legume meetings will be a venue for coordinating with several centers within the country/region. These meetings draw together not only NARIs and IARCs, but actors all along the value chain who are interested in technology innovation, including seedsmen and farmers' associations. Partnering with farmers usually means partnering with women, but this relationship will be far more productive with gender balance on the researcher side. For example, in Central America, this coordination function has been carried out during the regional agronomy meetings of the PCCMCA (Programa Cooperativo Centroamericano de Mejoramiento de Cultivos y Animales), attended by all national programs of the region. Such meetings will be promoted on a national level and will coordinate all legume research in the country. This will be a natural process for the national researchers since many national programs are organized in this fashion where attending to several international centers in a single meeting will be far more efficient for the national coordinators. In CWANA, national and regional coordination meetings are organized by NARIs and/or ICARDA and research programs are reviewed before the season starts and this experience will continue in the future. The Cereals and Legumes Asia Network (CLAN) helps facilitate national and regional legumes R&D activities, and is coordinated by ICRISAT, ICARDA and AVRDC. In India, both ICRISAT and ICARDA participate in the annual All India Coordinated Research Program meetings. In future, synergies will be further enhanced and duplication of R4D efforts reduced. Meetings of this nature include researchers, representatives of regulatory agencies, extensionists, CG Centers regional/country representatives, formal and informal seed producers and other input suppliers, NGO's and occasionally farmers, and serve as a seedbed for an incipient innovation platform. As a result of such meetings, memoranda of understanding between suppliers and users of technology have often resulted. Another case in point is the Hybrid Parents Research Consortium (HPRC) of ICRISAT that was formed with the basic objective of increasing the scope of accessibility to better hybrids by the smallholder farmer through effective public-private partnerships. In this partnership, the recognition of the private sector as a valuable research for development partner led to the formation of a consortium comprising of private sector companies for more than one crop (pigeonpea, sorghum and pearl millet). A significant aspect of this initiative was that the products and information generated from consortia grants remain in the domain of international public good that are freely available to the public sector organizations around the world (Kavitha et al. 2009)

Key Milestones

- The Central American bean network re-established (2012)
- The Cereals and Legumes Asia Network (CLAN) reinvigorated (2012)
- Cross crop legume meetings established in at least four countries in Africa and South Asia (2012)
- The food legumes networks in the Nile valley and sub-Saharan Africa re-established (2013)
- Effective multi-institutional and multidisciplinary teams work with farmers and other stakeholders to deliver integrated legume research results in at least five countries (2013)
- Private sector engaged to assume a major role in the production of seed of hybrid pigeonpea (2013)

5.6.7.2. Enhancing capacities of women and men for grain legume R4D innovation

Description

Many national program scientists have received or are receiving higher degrees, especially in plant breeding, biotechnology and crop protection. Other disciplines are not receiving equivalent attention. While both men and women will continue to be trained, bringing this line of work to bear on women requires actively recruiting women for training in degree programs. In Africa, many women study agricultural sciences, while in Latin America women in science tend to gravitate toward associated sciences such as nutrition or biotechnology. While gender balance in research will be sought, it will be especially important to engage women in the social sciences, to better communicate with women clients, thereby enhancing attention to women's needs and the delivery of outputs that are targeted to women.

Methodology

A gender census will be carried out to document the gender balance at all levels of research, and to identify critical gaps in the participation of women (as a part of GRAIN LEGUMES gender strategy). This will be updated periodically to facilitate the monitoring and evaluation, and reporting to the Consortium Board. Faculties of social sciences (rural sociology, economics, etc.) and food technology will be canvassed to identify fellowship opportunities for women, especially for African women due to the preponderant role that women play in legume production. Consultations with institutional partners (NARES and SROs) will investigate the interest of directors in strengthening social science and food technology with the purpose of creating additional positions for women in these fields. Women currently involved in legume science will be encouraged to participate in the AWARD program to broaden their horizons and leadership capacities.

On the technical side, a consortium of IARCs, ARIs and NARES organizations working under GRAIN LEGUMES will offer focused short-term courses in real time with extended online mentoring and advice. In addition, it is anticipated that this CRP will play a lead role in helping to change the culture of information documentation, sharing and usage among the GRAIN LEGUMES partners. This will not only involve physical improvements such as the building of advanced online data and information services, but, more importantly, the strengthening of the information capacities of stakeholders at the production end of the value chain. In many cases, this will require greater efforts to build the 'softer' human skills of networking, learning and using information to innovate. Cultural change is needed for people and organizations to work comfortably in virtual alliances and networks, freely share information and make use of it in new ways. This will be initiated by GCP through its communities of practice that will be established for most of TLI and TLII crops (CB, CP, CW, GN and SB) and will be reinforced under CRP 3.5 GRAIN LEGUMES. For other crops such as FB, LN and PP, networks will be established.

Such partnership-based experiments would feature blended use of new online tools and approaches

and also more traditional information channels such as community radio. The practice of creating and validating learning materials such as re-usable granules (Re-usable Learning Objects- RLOs) will be tested. Strong partnerships with ICT players from the private sector, NGOs and ARIs will also be needed to achieve this goal. For example, the Dry Grains Pulse CRSP is experimenting with these technologies for dissemination of IPM techniques in West Africa. Actions to achieve this output include:

- Training CRP and NARES partners to build and maintain online networks;
- Reinforcing and complementing online repositories of re-usable, adaptable learning materials; and
- Strengthening the skills for successful gender-sensitive, interdisciplinary, inter-institutional and multiple-stakeholder problem solving.

Key Milestones

- IT infrastructure strengthened in national programs to connect breeders, IPM groups and agronomists to the Integrated Breeding Platform (2012)
- At least 20 refereed journal articles co-published between national legume researchers and IARC scientists per year, thereby reflecting joint research and co-learning (2012, 2013)
- Institutional capacity in partnering and M&E strengthened as evidenced by regular attendance of researchers, seed sector, NGOs and farmer groups in yearly inter-institutional meetings in CRP3.5 target countries (2013)
- At least 20 students (at least 50% women) completed their (MSc/PhD) theses research in areas related to CRP 3.5 GRAIN LEGUMES (2014)

5.6.7.3. Knowledge sharing platforms for grain legumes crops strengthened

Description

Knowledge sharing is an area where learning by doing and collective reflection and innovation are at the core (Hall, 2006). The purpose of a knowledge-sharing platform is to facilitate the connections between multi-stakeholders innovation and “make it possible for staff to act as the managers of their knowledge” (Wenger, 2004). It is frequently observed that in the absence of a proper knowledge sharing mechanism, large quantities of fragmented data and information with the potential to support the mission lie untapped. Hence, it is important to mobilize this information in formal, but easily accessible ways.

This knowledge sharing platform will enhance awareness of stakeholders including researchers in ARIs and end users (consumers and farmers) thus enhancing grain legume R4D impacts in terms of opening up of new research areas, leading to health and nutritional benefits. Diet-related chronic diseases are reaching epidemic proportions in the developed world, and increasingly in some urban areas of the developing countries (Burslem, 2004; Tanumihardjo et al. 2007). Studies show that legumes can contribute to lower risk of diabetes due to low glycemic index (Foster-Powell et al. 2002); of certain types of cancer (Thompson et al. 2008); and of cardio-vascular disease (Kabagambe et al. 2005). The SRF states that “over the coming decades, the focus of under-nutrition will shift to the urban poor and a very different problem of calorie-rich but nutrient poor diets that contribute to chronic cardiovascular and other diseases could emerge”. The USDA now recommends increased consumption of legumes as an important part of a diet-based strategy to combat chronic obesity and chronic diseases as a high priority. Although, the CRP 4 recognizes importance of chronic diseases, it does not foresee any immediate action in this area.

The SRF notes that efforts in “nutrition, infection and chronic disease” require “separate institutional arrangements with these health research communities”. Our intervention would not involve research that would duplicate efforts in CRP 4, but will be focused on sharing current information

about legume consumption with various stakeholders, such as policy makers and those involved in consumer education, to raise consciousness about the dietary role of legumes. On the other hand, we seek to leverage efforts of colleagues in ARIs who are currently exploring the effects of legume consumption on health, and encouraging them to consider further research on legume crops for which there has been little or no study, and that do not yet form a part of their research agenda. Several of these colleagues have already expressed interest in future collaborations.

In addition to this, the data generated by various partners in GRAIN LEGUMES are one of the most important resources for research, and later will become a part of knowledge bank for legumes research and decision-making. CRP GRAIN LEGUMES partners will conduct a series of field, farm and laboratory experiments, that in turn will produce a large amount of data of various types including phenotypic, genotypic, genome sequences, socio-economic, climatic, agronomic, on farm trial, and GIS, among others. Hence, a state of the art, focused and strong data acquisition, storage, archiving, curating and management system will be required in collaboration with IBP.

At this stage, crop ontologies or trait dictionaries will be necessary to establish uniform data formats. Work on ontology for at least four crops (bean, chickpea, cowpea, groundnut) has already been completed under the auspices of TL-I project of the Generation Challenge Program and needs to be developed for other crops. To the extent possible, comparable data systems will be employed to facilitate the communication of information on multiple crops. The soybean community has already completed this step, thereby offering opportunities to develop linkages under GRAIN LEGUMES.

Often, it is observed that the collaborators are hesitant about data submission, as many experimenters are not comfortable with online submission tools. Also, most of these data repositories do not offer much to users, apart from archiving data, where the added value of participating in data compilation is not obvious. Hence, there will be enhanced emphasis in terms of online biometrical analysis, easier and user-friendly web interfaces with additional outputs, reports and summaries to collaborators and stakeholders. This will be achieved by adding reporting modules, maintaining enhanced interaction between stakeholders, keeping a strong component of training and capacity building of IARCs and NARES collaborators in use of data management system. Collaborators will also be trained in the publication of curated data to other appropriate public databases (like NCBI) with a link to central database with the necessary metadata. The Generation Challenge Program is promoting databases within crop-based communities of practice to give access to genotypic and phenotypic data. These efforts will provide the 'infrastructure' that will give the partnership and networking platforms the necessary content needed to function as described in Output 1. Such novel arrangements should also help to establish linkages with ongoing initiatives such as AG Commons that have strong GIS components.

This platform will also be complemented by several ongoing initiatives in agricultural information management such as the CIARD (Coherence of Information for Agriculture Research and Development), Agropedia and aWhere, a Bill & Melinda Gates Foundation's broad-based model to offer input to and access to a geo-referenced database using a private sector initiative that would link users at all levels including farmers. New media tools innovations involving web-to-mobile telephone information exchanges have been tested extensively in India and Kenya. Lessons learned from these efforts should prove helpful in assisting other partners to design systems that make use of this emerging technology, and contribute to novel, evolving impact pathways. We anticipate that such efforts will also help to identify research overlaps and avoid duplication. The problems associated with making best use of these materials include inadequate capabilities, lack of training, lack of metadata to assist in organizing information and inadequate channels for supporting multi-directional information flows will also be taken care of.

Methodology

Legume datasets and grey literature on legume research, uses and nutritional data will be

inventoried, curated and digitized. Under the CRP GRAIN LEGUMES, the generation of this knowledge sharing mechanism will be implemented by establishing open repositories of information and data and their re-use across the networks by using web 2.0. Additionally, information about approaches, methods and policies that work in different places, cultural contexts, and times (as well as those that do not), and the reasons for success or failure will also be shared through multiple virtual networks.

Plant breeders and data managers in IARCs and NARES will be trained in the use of this knowledge sharing platform and information repositories. Models and action-support tools will be investigated to effect scaling-out and scaling-up using innovative web interfaces and possibly mobile telephones. Blends of online (web)-offline (desktop/mobile/voice telephony, community radio) prototypes will be investigated and their effectiveness tested in developing locally relevant advisory services. To strengthen linkages between stakeholders, platforms will provide space for communication and informal information sharing and offer learning and training to improve communication and information sharing within the network under Web 2.0.

We will cooperate with the Bill & Melinda Gates Foundation initiative to deploy the aWhere model, including a seamless system for data input to aWhere.

In addition to this, a data management platform will also identify suitable statistical analysis to be used with data submitted, and will offer the user a choice of basic analysis tools via software application as services (SaaS) for analysis and visualization of data with downloadable results and reports. On request, the system may also generate an Analysis tracking ID (AID) that can facilitate further summarization, checking and more detailed analysis or status of desired analysis from concerned biometricians that in-turn will further enhance the overall system efficiency.

Finally, on a more mundane level, IARCs are in the position to inform partners in their traditional regions of operation about the availability of improved germplasm from other Centers. In each of the regions, besides the major legumes in each region that will receive attention in this CRP, other legumes are important locally. For example, cowpeas are the primary legume on the north coast of South America, and common beans are important in the foothills of the Himalayas. IARCs can be channels of information about legumes for smaller niches outside of the main cropping systems where research will be focused, with no added research investment outside of the costs of seed shipment.

Key Milestones

- A workshop to acquaint legume researchers with results of research on chronic diseases, and to introduce nutritionists to research opportunities in legumes in the developing world held (2012)
- Legume information, genomic-phenomic databases established for four legumes under the GCP (2013)
- Online biometric analysis module developed and tested (2013)
- Links to the soybean community strengthened through integration of databases (2013)
- Legume data incorporated into TL-II initiative using aWhere and farmers' access to aWhere tested in at least two countries in Africa and one country in Asia (2013)

6. Partnerships and Networks

As elaborated in the earlier chapters, partnerships are critical to CRP GRAIN LEGUMES, as one of the roles of Centers is to facilitate the R4D activities among a wide array of partners. CRP GRAIN LEGUMES will generate IPGs (international public goods) that will be customized to meet local needs and conditions by the partners. To connect global intent to local action, CRP 3.5 will harness a few of the well-established regional networks. Regional networks are highly effective for accelerating impact and strengthening capacities. However, the focus of these networks in the past has largely been limited to exchange germplasm and technologies. CRP 3.5 GRAIN LEGUMES will work with the regional networks to widen their scope and impact along the legumes value chain. (Also see additional write-up on partnerships with Farmers Organizations, NGOs, and sub-regional organizations and networks in Appendix 13).

6.1 Role of Networks

We give below the available network resources on grain legumes in the regions (fuller expositions on each are given in Appendix 7):

Sub-Saharan Africa

- PABRA (Pan-Africa Bean Research Alliance) is a consortium of sub-regional bean networks: ECABREN (Eastern and Central Africa), SABRN (Southern Africa) and WECABREN (West and Central Africa). PRONAF (ProjetNiebe pour l’Afrique) on cowpea in West Africa.
- NGICA (Network for the Genetic Improvement of Cowpea for Africa) an informal, but progressive international network applying modern ICT and biotechnology.

Amongst these, PABRA is quite large, with 350 direct and indirect partners from NARS, IARCs, donors, NGOs, sub-regional organizations (ASARECA, SADC-FANR, and CORAF), community-based organizations, seed producers, traders and the commercial private sector. We plan to initiate discussions with PABRA to possibly expand it to other legumes and make the network pan-legumes across Sub-Saharan Africa.

Latin America and the Caribbean

- PROFRIJOL (bean network - funding expired but minimal activities continue)
- AgroSalud (regional bio-fortification project including bean)
- PCCMA (Central America regional network including bean)

CRP GRAIN LEGUMES will work with all the three networks, based on the need and nature of R4D projects.

Central and West Asia and North Africa

- WANA Regional Seed Network
- Nile Valley Regional Food Legume Network includes three sub-networks: on wilt and root rot diseases (Ethiopia coordinating), integrated control of aphids and viruses (Egypt coordinating), and socio-economic studies (Egypt coordinating).
- Mahgreb Food Legumes Network (currently dormant)

CRP GRAIN LEGUMES will possibly work with all networks, depending on expertise needed. However, efforts will be made to bring together like-minded networks for effectiveness, over the long-term.

South and Southeast Asia

- AICRPs (All India Coordinated Research Programs) guide and coordinate research (agronomy, crop improvement, crop protection, soil and nutrient management, and post-

harvest technologies) on chickpea, lentil, pigeonpea, and groundnut in India.

- Cereals and Legumes Asia Network (CLAN) is endorsed by the regional organization APAARI and co-facilitated by ICARDA, ICRISAT and AVRDC.

CRP GRAIN LEGUMES will work closely with CLAN, as it has a well-established and working framework. In India, we will need to establish close alliance with AICRPs.

These networks are all regionally-based, which (desirably) places them close to the socio-economic and biophysical context in which adoption and impact occurs. Additional value will be gained by extending that learning across regions/crops through CRP 3.5 R4D activities. These networks will also act as the 'eyes and ears' of CRP 3.5 GRAIN LEGUMES will feed back regional knowledge on grain legume issues, trends, priorities, and expectations.

Among the key functions that networks will perform under CRP 3.5 are:

- Sharing evidence, best practices, innovative ideas and problem-solving expertise across crops and regions
- Sharing facilities and services among those best equipped to carry out different tasks
- Coordinating and fostering inter-disciplinary and cross-crop project collaboration
- Mentoring and training of young scientists and providing them opportunities for professional development
- Creating scientific consensus of opinion to informed policy-making

Unfortunately, a number of networks have become dormant or are at low-level of activity in the past decade due to lack of resources. Several have made adjustments, and continue to contribute to the extent possible, functioning at a very basic level without special support. Opportunistic physical meetings are enabled by single-event and often problem-focused support, and/or as side meetings at other events, rather than through long-term core network support.

CRP 3.5 GRAIN LEGUMES will attempt to support the historical trend, because that strategy has worked well in the past, and exploit the new opportunities that the trend provides.

6.2 Role of Partners other than the Centers

Ethiopian Institute of Agricultural Research (EIAR), Ethiopia

EIAR is responsible for the running of federal agriculture research centers. Currently, the EIAR comprise 55 research centers and sites located across various agro-ecological zones. Some of the research centers and sites have one or more sub-centers and testing sites. As an apex body, EIAR provides strong leadership in coordinating research, by taking a leading role in influencing agricultural policy development.

- Ethiopia has the second largest (second to only Nigeria) number of staff for agricultural research and development in the SSA region.
- The country has registered significant successes with value chain approach for legumes (mainly chickpea, common bean and lentil). Productivity and production have increased and export earnings have gone up significantly.
- Large network of research stations to conduct both on station and on-farm trials and disseminate improved technologies.
- It is a secondary center of some of the legumes and would provide unique germplasm for crop improvement

The Brazilian Agricultural Research Corporation (EMBRAPA), Brazil

EMBRAPA serves Brazilian society through the 38 Research Centers, 3 Service Centers and 13 Central Divisions distributed in different states of Brazil. EMBRAPA coordinates the National Agricultural

Research System, which includes most public and private entities involved in agricultural research in the country. EMBRAPA has an extensive network of research stations throughout Brazil, with a center dedicated to research on rice and beans. In general Brazil has long experience in the management of tropical soils that can be of use to several crops of the CRP, and possibly broader.

- Soybean, bean and groundnut are EMBRAPA's priority grain legumes can strengthen CRP 3.5.
- Strong human resource base can help the region in capacity building in Grain Legume research
- Established bio- control facilities can be a model for CG as well as NARS partners
- EMBRAPA could take the lead in exploiting the potential of transgenic beans for developing countries.
- EMBRAPA has the potential to carry out studies on heat tolerance.

The Generation Challenge Programme (GCP)

GCP mission is to use genetic diversity and advanced plant science to improve crops by adding value to breeding for drought-prone and harsh environments. This is achieved through a network of more than 200 partners drawn from CGIAR Centers, academia, regional and national research programs, and capacity enhancement to assist developing world researchers to tap into a broader and richer pool of plant genetic diversity.

- Assist in the establishment of strategic research platforms
- Facilitate capacity building in addressing new breeding tools
- Trait specific germplasm to be utilized by NARS
- Good opportunity to utilize the well-established network of with NARS and CG centres

General Directorate of Agricultural Research (GDAR), Turkey

GDAR is the apex body to administer agricultural research in Turkey. Under the administration of GDAR, there are 7 Central, 9 Regional, 32 subject-specific and 12 Soil and Water Research Institutes are in operation throughout the country.

- GDAR has good research base on crop as well as natural resources (soil & water).
- Knowledge on biodiversity with ample experience on various crops and livestock and bio-safety.
- Has a center of excellence in drought research with good facilities which could be shared for CRP 3.5 research.
- Can be a resource centre with capabilities to organize two-way collaboration between NARS and CG centres.

Indian Council of Agricultural Research (ICAR), India

The Indian Council of Agricultural Research (ICAR) is one of large NARS system among the developing countries. ICAR has 97 ICAR institutes and 47 agricultural universities across the country, with a well-established network on research institutions, supported by several State Agriculture Universities (SAUs).

- ICAR has a large human resource base to assist other NARS partners in building their capacities.
- It has extensive collaboration with several CGIAR centres, which can assist in two way interaction. Both ICARDA and ICRISAT participate in ICAR collaborative research programs on Grain Legumes.
- The National network on a number of crops and other disciplines can be utilized for CRP

research effectively and can be models for other countries.

- Well established upstream advanced research labs and downstream research and extension networks that can strengthen other CRP partners.
- Has capacity for leadership in farm machinery, mechanization, post-harvest technologies, and development of novel legume products.

The Dry Grain Pulses Collaborative Research Support Program (Pulse CRSP), USA

Pulse CRSP supports many of research efforts of the NARS' bean and cowpea programs in SSA and LAC. Pulses CRSP has sought to strengthen ties and collaborations with the CGIAR on grain legumes research and to coordinate future research activities. The CRSP has greatly contributed to the training of scientists within the NARS in sub-Saharan Africa and Latin America.

- Identify new genetic sources of resistance **to abiotic and edaphic stress factors** (including more effective root systems) and breed improved varieties
- Develop, implement and manage a **comprehensive integrated bio-control program** for insect pests on cowpea
- Improve BNF and grain yields of grain legumes through the development and promotion of the use of **superior seed inoculants**
- Develop and validate sustainable community-based seed multiplication and dissemination systems for grain legumes
- Enhance the nutritional value and health-promoting qualities of grain legumes and strengthen grain legume value chains that directly benefit women and children

6.3 CRP 3.5 GRAIN LEGUMES as a platform for innovation and learning

CRP 3.5 GRAIN LEGUMES sees these networks collectively as an international **innovation platform** (Hall and Yoganand 2004) for grain legumes. This platform will be the base from which targeted **innovation partnerships** are launched. Innovation partnerships will focus on specific problems/opportunities. All partners are responsible carry out the entire R4D cycle, from idea generation to fundraising, project execution, and monitoring and evaluation. CRP 3.5 will coordinate and advocate these innovation partnerships to investors and other stakeholders, and provide other core services such as catalytic and advisory support, quality monitoring, and public awareness services, all aimed at maintaining high credibility and visibility. Table 6.1 depicts in brief some of the main partnerships that will be essential to innovations in different core processes of the legumes R4D continuum.

The core partners in CRP GRAIN LEGUMES (ICRISAT, CIAT, ICARDA, IITA, GCP, ICAR, EIAR, EMBRAPA, GDAR, and Pulses CRSP) believe that a wide range of partners across the five regions are important to implement the R4D activities envisaged. These include both the traditional partners and many new partners, as we plan to initiate research in areas that were not on Centers' R4D agenda previously. These partners include the Advanced Research Institutes (ARI) in both developed and developing countries; several national agricultural research systems (NARS) institutes, including universities, non-governmental organizations (NGOs), farmers organizations, private sector, and other CGIAR centers. Table 6.1 provides details of activities that the partners are expected to contribute to CRP GRAIN LEGUMES R4D efforts. Complete list of global partners is given in Appendix 8. Likely commitments and investments from the partners are indicated in Appendix 14.

Stakeholder support

Innovation partnership proposals will be marketed to coalitions of traditional and new development investors – those who hold stakes in grain legume R4D, but have been largely overlooked in the past. For example, wholesalers and processors hold stakes in grain harvests that are more consistent in volume and quality; seed companies hold stakes in more profitable and efficient seed systems; and

retailers hold stakes in the improved quality and diversity of final products. The poor, and especially women are stakeholders of prime interest to CRP 3.5, and the road to success must be in finding win-win innovations, both for the commercial stakeholders and the smallholder farmers. R4D avenues will be pursued that increase the value of their stakes so that all are motivated to adopt them.

Realistically, new windows of support from stakeholders will be modest in the beginning. Support will be through both cash and in-kind support to projects (expertise, facilities, testing services, etc.) Beyond support, the active involvement of value chain stakeholders will increase the relevance of R4D and accelerate its impact, including the traditional development investor support, which is especially crucial for activities that benefit the poor and women in particular. But including these stakeholders represents a significant new way of doing business. Initially, even modest support will demonstrate commitment to the CRP 3.5 partnership by stakeholders. Overtime, as returns-on-investment become tangible, we expect that the quantity of this new support will grow.

CRP 3.5 will work closely with other regional grain legumes initiatives such as Tropical Legumes I and II, AGRA/PASS, N2Africa, SIMLESA, etc. to harness synergies in the countries and regions, especially in Sub-Saharan Africa (see Appendix 17 for details on linkages with other initiatives).

CRP GRAIN LEGUMES will proactively market innovation partnerships by having a dialogue with stakeholders about the mutual benefits that all can obtain through legumes R4D, taking their ideas and suggestions onboard to increase the relevance and effectiveness of project design. A number of recent institutional innovations in this direction bear testimony to the viability of this approach, e.g. the Hybrid Parents Research Consortium (involving IARCs and seed companies) and the Agri-Business Incubation platform fostering agri-entrepreneurship catalyzed by ICRISAT in India (and moving to Sub-Saharan Africa).

ICT for efficient networking

Addressing the decline in general network support for essential core functions such as coordination and communication, CRP GRAIN LEGUMES will capitalize on ever-richer ICT capabilities such as virtual meeting technology, web-enabled community-of-practice and professional networking applications, tele- and video-conferencing, online sharing of rich interactive databases, geospatial applications, and genetic maps. Bandwidth and user sophistication are steadily increasing across the developing world, and such tools are continuously emerging and improving at ever-lower cost. They enable both broad sharing of information/expertise at regional and global levels as well as focused problem-solving teamwork (e.g. virtual team formation for proposal development and execution). Targeted event funding will also be sought to ensure periodic physical meetings that are required to sustain mutual trust, understanding and coherence.

Table 1. Roles of partners in CRP 3.5 GRAIN LEGUMES (organized by Strategic Objective and Output)

Output	NARS in ESA, WCA, SSEA, CWANA, LA&C	ARIs	Private Sector	NGOs, Farmers Organizations	CGIAR Centers
Strategic Objective 1:Conserving and characterizing genetic resources and developing novel breeding methods/tools for improving efficiency of crop improvement					
Output 1.1 Grain legumes genetic resources collected, conserved and made available to researchers globally	Carry out explorations based on eco-geographic information, and historical data from high priority areas; and acquiring/exchange germplasm collections based on the available passport data.	Develop best practices for grain legume gene bank management (GIS, FIGS); analysis of data historical records for establishing priorities and germplasm collection/acquisition.	Use selected germplasm in developing high yielding, broad based cultivars	Assist in germplasm collection and sharing indigenous knowledge	Identify gaps in existing collections; collection, conservation and distribution of genetic resources Sharing facilities for cost-effective regeneration of unadapted germplasm; upgrading skills/training, and safety backup.
Output 1.2 Genetic resources characterized, evaluated and documented for unique traits/genes....	Evaluate germplasm sets (core, mini core, reference, TILLING population and FIGS subsets) for key traits in hot spot areas and select useful lines.	Develop new tools, methods and approaches to identify trait specific germplasm, mechanisms and component traits; assist in capacity building	Use new tools/techniques, and selected germplasm for developing high yielding cultivars with wide adaptation	On farm testing and adoption of selected germplasm and high yielding broad based cultivars	Development of germplasm sub sets, precise characterization and evaluation of the germplasm collections, documentation, and knowledge sharing
Output 1.3 Novel and efficient breeding methods/tools for cultivar development established and shared	Use new germplasm lines and modern methods in breeding programs to enhance efficiency and delivery of products and associated training activities	Technological support for developing new tools and training in development and use of modern technologies	Provide/co-develop cost-effective and high-throughput genomics technologies for the legume R4D community; utilizing new tools and technologies for product development	Promoting and enhancing adoption of new cultivars	Identification/development and use of new genetic and genomic resources, , molecular markers ,and modern breeding methodologies to broaden the genetic base for improvement of legumes and capacity building of partners
Output 1.4 Novel genes/traits accessed/mobilized/ incorporated through wide hybridization /genetic engineering	Participate in assessing research gaps on grain legume production, nutrition and safety; develop and deploy transgenic legumes for specific traits	Provide tools and technologies for use in wide hybridization and genetic engineering research on grain legumes	Participation in product development and deployment of transgenic crop varieties	Create awareness about the improved technologies and varieties, and promote their adoption among stakeholders	Develop, evaluate and share improved legume crop improvement technologies to address various crop production constraints and capacity building of partners

Output	NARS in ESA, WCA, SSEA, CWANA, LA&C	ARIs	Private Sector	NGOs, Farmers Organizations	CGIAR Centers
Strategic Objective 2: Accelerating the development of more productive and nutritious cultivars for resilient cropping systems of small-holder farmers					
Output 2.1 Elite lines/cultivars with at least 25% higher yield potential than the best available cultivars developed for different production systems.	Co-develop, evaluate and disseminate high yielding legume varieties and hybrids in various production systems	Capacity building (including graduate students) in use of modern breeding methodologies	Development and commercialization of superior cultivars and hybrids	Promotion of superior varieties and hybrids (e.g. pigeonpea)	Development of improved legume varieties with a broad genetic base for different production systems; capacity building for partners
Output 2.2 Elite lines/cultivars with enhanced resistance/tolerance to key biotic and abiotic stresses and resilience to climate change developed	Development, evaluation and selection of improved climate resilient varieties under key biotic and abiotic stresses	Assistance in developing and capacity building of high-throughput phenotyping and genotyping platforms	Commercialization of the proven technologies and superior resilient varieties with yield stabilizing traits	Promotion and adoption of climate resilient varieties	Development of improved germplasm with a broad genetic base, and sharing testing sites for the key biotic and abiotic stresses for developing climate resilient varieties
Output 2.3 Improved methods for targeting improved germplasm to small holder niches	Generate information on farmer and market- preferred traits, climatic variables, and biotic and abiotic stresses	Assistance in developing GIS tools and simulation models	Up and out-scaling farmer and market preferred varieties.	Selection of farmer-preferred varieties through participatory approaches (PVS)	Development and implementation of GIS and modeling tools and sharing with partners
Output 2.4 Elite lines/cultivars with enhanced nutritional composition and end-user preferred traits developed.	Evaluation and development of biofortified and high value market-preferred elite lines and cultivars	Generate information on nutritional quality, effect on chronic diseases, and anti-nutritional and toxic factors.	Commercialize nutritious and farmer preferred varieties suitable for niche markets	Creating awareness about nutritional value of legumes and disseminating knowledge to target communities	Genetic improvement of legume varieties with specific nutritional and other consumer preferred traits.
Output 2.5 Elite lines/cultivars with enhanced nutrient use efficiency, high nodulation N2 fixation potential...	Evaluate, select and adopt elite lines/ varieties with high nutrient use and BNF efficiency in target environments	Assistance in developing high-throughput phenotyping platforms for breeding purpose	Development and commercialization of nutrient-use and BNF- efficient varieties	Promoting nutrient-use efficient varieties in areas with poor soils	Production of high nitrogen fixing, nutrient-use efficient and herbicide tolerant germplasm
Strategic Objective 3: Identifying and promoting crop and pest management practices for sustainable legume production					
Output 3.1 Strategies to optimize Biological Nitrogen Fixation by legumes developed and promoted	Develop data base on local rhizobia and other beneficial organisms, and participate in BNF research in legumes	Development and characterization of more efficient strains of rhizobia and other beneficial microorganisms and technologies	Large scale multiplication of selected rhizobial strains and beneficial microorganisms and their commercialization	Promotion and utilization of effective <i>Rhizobium</i> inoculums to increase grain legume production	Rhizobial collections, evaluation, and promotion in different cropping systems

Output	NARS in ESA, WCA, SSEA, CWANA, LA&C	ARIs	Private Sector	NGOs, Farmers Organizations	CGIAR Centers
Output 3.2 Methods to increase legume productivity and profitability through increased resource use efficiency...	Identify constraints and opportunities for the intensification of legume cropping systems, and promotion of suitable technologies	Identification of components for enhancing resource use efficiency and their management (e.g. components related to P use efficiency, micro dosing, etc.)	Promotion and commercialization of suitable crop management technologies	Facilitate promotion and implementation of efficient cropping systems and providing the feed back	Evaluation and integration of potential legume based cropping systems and associated capacity building
Output 3.3 Tools and protocols for more effective pest & disease management developed, tested and promoted	Identify and prioritize various constraints for developing integrated crop management (ICM) practices for legume crop intensification	Development of new IPM/IDM technologies/modules	Commercialization of products and services to enhance crop protection and crop production	Encourage and promote best bet technologies	Develop, evaluate and share best bet ICM technologies
Output 3.4 Potential strategies for farmers to adapt management of legumes in response to climate change...	Evaluation and dissemination of improved climate resilient varieties and management strategies	Develop crop simulation models/protocols to facilitate climate change research	Commercialize and promote climate resilient varieties and proven technologies	Promoting the proven technologies and adoption of climate resilient varieties	Develop and evaluate efficient genetic and management strategies to overcome climatic variability/change
Strategic Objective 4: Farmers have better access to seed through more efficient seed production and delivery systems					
Output 4.1 Decentralized seed systems enhanced through systematic diagnosis and implementation of appropriate models	Identify efficient formal and informal seed systems for preferred legume crops and varieties suitable for the region	Sharing relevant models and assist in developing innovative seed delivery models	Feasibility studies on strategic investments in seed systems and feedback Promote seed business incubation systems	Facilitate seed business incubation systems Implementation and feedback	Development and sharing seeds of high yielding varieties for strengthening the village seed systems.
Output 4.2 Capacity of public and private sector in legume seed systems strengthened	Participation in capacity building of legume seed production, processing and marketing to strengthen seed systems	Share success stories of efficient models for effective implementation	Establishing better infrastructure and developing newer markets for strengthening the seed systems	Linking farmers with technology facilitators for developing efficient seed systems	Assisting in capacity building of NARS/NGO's and private sectors
Output 4.3 Enabling seed policies for legume seed systems, based on thorough analysis of current arrangements	Prioritize and document various gaps in the existing seed systems and coerce policy makers in implementing the new policy	Assist in developing efficient strategies to improve existing seed policies	Adopt new policies and provide feedback	Assist in creating awareness and adoption of the new seed policies and provide feedback	Assistance in development and advocacy of policies for improving existing seed systems
Output 4.4 Framework for national seed security for vulnerable regions developed	Identify and document vulnerable zones besides facilitating the implementation of risk mitigation strategies	Sharing the successful models, and lessons	Assured seed supply in vulnerable zones	Link knowledge providers and farmers and encourage adoption of efficient strategies.	Evolving appropriate strategies and solutions for risk mitigation for vulnerable regions/groups

Output	NARS in ESA, WCA, SSEA, CWANA, LA&C	ARIs	Private Sector	NGOs, Farmers Organizations	CGIAR Centers
Strategic Objective 5: Improving grain legumes value-chains, strengthening market linkages and promoting postharvest technologies for enhanced livelihood outcomes of smallholder farmers					
Output 5.1 Enhancing grain legume value chains for the poor, especially women	Value chain interventions benefiting small holders and women for local legumes and allied products identified and developed.	Assist with methodologies, technologies, and gender perspectives.	Identification and development of key legume allied products for capturing markets and mainstreaming through forward and backward linkages through inclusive approaches	Enhance the value chain through effective implementation at community level	Assist in identifying, and developing high value grain legume products, innovations, and capacity building of partners
Output 5.2 Institutional innovations to engage poor farmers with input and product markets	Evaluate, advocate and adopt sustainable policies to promote grain legume products, and benefit stakeholders	Assist with policy formulation, and capacity building	Promote value chain based agribusiness ventures	Promotion and adoption of inclusive market oriented systems	Develop appropriate innovations and practices for sustainable institutional systems
Output 5.3 Post-harvest technologies/practices and value-added products benefiting women...	Assess available technologies, develop prototypes and promote value-added products	Development of post-harvest and value-addition technologies and document changes in nutritional and safety parameters	Adopt post-harvest technologies and promote food business ventures	Create awareness on improved post-harvest technologies for legumes and value-added products and implement the value-chain	Identifying of pro-women post-harvest and value addition technologies and processes, and providing capacity building of partners
Output 5.4 Drudgery/cost-saving small scale machinery for grain legume processing identified or developed	Evaluate pre- and post-harvest technologies suitable for small scale farm mechanization of grain legumes pre- and post-harvest.	Provide assistance and support for appropriate technologies and help maximizing user outreach	Commercialize appropriate technologies for small scale mechanization	Creating awareness and skill development in the use of improved farm machinery	Evaluate and assess available technologies and models for small-scale mechanization and reducing drudgery
Strategic Objective 6: Partnerships, capacities, and knowledge sharing to enhance grain legume R4D impacts					
Output 6.1 Partnership models to enhance grain legume R4D impacts identified and implemented	Develop partnership opportunities to enhance grain legume R4D, and up scaling of grain legumes and allied product adoption by small holders.	Provide platform for carrying out research and development with the identified partners	Participate in development, commercialization and scale up of developed technologies.	Linking various partners to farmers and other stakeholders as well as creating awareness among farmers	Provide mentoring for development of different partnership models that improve grain legumes adoption by leveraging knowledge base of other CG centers and partners.
Output 6.2 Enhancing capacities of women and men for grain legume R4D innovation	Impart training in skills required to deliver the innovations identified as part of the grain legume R4D initiatives	Capacity building of stakeholders and beneficiaries on R4D innovations	Business orientation of R4D innovations by providing internship opportunities and support for capacity building	Create awareness as well as link the farmers to technology providers, trainers and the private sector	Assess the needs of capacity building among various stakeholders and carry out impact assessment of the capacity building programs

Output	NARS in ESA, WCA, SSEA, CWANA, LA&C	ARIs	Private Sector	NGOs, Farmers Organizations	CGIAR Centers
Output 6.3 Knowledge sharing platforms for grain legumes crops strengthened	Identify technologies, and partners, and domains for developing various knowledge sharing platforms for implementation	Develop and provide crop and other domain-specific knowledge/information	Technology platforms to disseminate knowledge of the identified technologies	Create awareness among farmers about various knowledge sharing platforms available, and facilitate implementation of appropriate knowledge sharing technologies	Anchor various knowledge sharing platforms, validate information, content and promote technologies across geographies

7. Gender Research Strategy

Gender issues in legume production systems

In the legume production systems, men, women and the youth have different and unequal access to production inputs and technologies. Similarly, ownership of resources for production and marketing of legumes and decision making on the production systems are also different with gender groups. However, the division of labor is distinct, but not rigid and depends on the specific socio-economic context. Various reports (Kumar, 1985; FAO, 2007a,b) have indicated that although rural women are the main producers of the world's staple crops—rice, wheat, and maize—which provide up to 90% of the food consumed in the rural area, their contribution to growing secondary crops such as legumes and vegetables is even greater.

In parts of Africa where legumes are purely subsistent and semi-subsistence crops, women are more visible in the production roles, marketing of perishable products like leaves as vegetables, and seed and small scale processing (e.g. groundnuts for home and local sale), while men tend to dominate in the marketing of grain up in the value chain (Bationo et al. 2011). Men also dominate in the legume value chains (integrating production and marketing) in the few highly commercialized production contexts like the common bean in the central rift valley of Ethiopia and low lands of northern Tanzania. In Asia, women integrate the production, processing, and marketing activities of chickpea, groundnut and pigeonpea. The gender division of labor in Asia appears to be changing in response to changing economic opportunities in urban areas. One reason is that when men leave agricultural communities in search of employment opportunities; women assume many tasks that were earlier done by men. Women are also increasingly getting involved in soybean processing and product development, including, akara (fried fritter), dan dawa, moin-moin (soybread), soy-cake, soy-milk, and soy-cheese, implying that women are also the direct beneficiaries of economic gains from soya bean value chain enhancement (FAO, 2007b).

Most of the men and women involved in legume production and marketing come from asset-poor farming households, but women face more extreme challenges in accessing farm inputs: land, seeds, fertilizers, pesticides, farming knowledge, post-harvest techniques, and market organization. This is because men tend to take most of the household decisions that affect women's access to land for production, income from marketed surplus and occasionally household labor (Kumar, 1985). Past experiences have shown that men often take over women enterprises after they become profitable. There are also examples of women being given poor lands to cultivate crops. Once the lands become fertile (say after growing legumes for a few years), the men take them over for growing high value crops. Limited access to credits is disproportionately high among women because they lack control over land that is usually demanded as collateral. Gender differences in technology choice have also been reported in participatory legume variety studies (e.g. Kolli and Bantilan, 1997).

Past and on-going efforts to address gender issues in legume improvement interventions

The critical importance of women in legume production and the fact that their access to necessary resources and appropriate technologies is often constrained by gender barriers is now a recognized fact across participating CGIAR centers. This recognition has stimulated the centers to incorporate gender issues in legume research and development, and efforts to overcome the gender barriers have been growing since then. For example, CIAT has for many years hosted the Participatory Research and Gender Analysis (PRGA) Program, and its work on beans over the last decade has had a strong focus on empowering rural women to manage their natural resources and access to markets. In technology development across centers, both men and women's concerns are continually being integrated in breeding criteria through participatory plant breeding (PPB) and participatory variety selection (PVS). This has enabled breeders to not only develop well adapted and acceptable varieties, but also achieve the desired varieties faster. For example, Sperling et al. (1993) observed that the

participation of women in bean variety development led to a faster identification and adoption of improved bean varieties suited to small production niches in Rwanda. Other gender related efforts have been focused on gender characterization and improvement of policy, community development projects and capacity building among partners. Building capacity included but not limited to, training and change of research approach to multi-disciplinarity to engage other players such as gender experts in research. Feldstein (1998) has given a more detailed inventory of gender related research across specific centers. Use of gender analysis tools has also been growing across centers, but with some variations in intensity and frequency.

A strategy to address gender issues in CRP 3.5 GRAIN LEGUMES

CRP 3.5 GRAIN LEGUMES recognizes that women have accumulated a wealth of legume specific knowledge and expertise that should be tapped into legume research and development, to enhance the efficiency and performance of the CRP. Lessons learnt from previous legume interventions and elsewhere also indicate that positive and negative gender-specific impacts are possible, and if not monitored and timely addressed, could undermine the ultimate goal of improving socio-economic welfare of the poor. A few examples from the past bean and groundnut evaluation research elaborate on this. Adoption of fast cooking bean varieties in Tanzania has reduced the workload on women in terms of time spent in search of firewood, cooking, and foraging for wild vegetables during the dry seasons (David and Sperling, 1999), and general consumption of annual firewood reduced by about 10% (Nkonya et al, 1998). On the other hand, the negative impacts were observed in the form of increased workload on women from adoption of soil improvement technologies, such as planting and incorporating green manure alongside varieties. In other communities, new high yielding varieties attracted more men in production, with diverse consequences that varied from antagonistic and competitive to complementary situations, depending on the context. ICRISAT's study also shows that increase in groundnut production resulting from new varieties and technologies led to increases in household incomes, but a greater workload for women in shelling the increased production (Feldstien, 1998). These and other examples indicate that overall gender-specific effects could be negative or positive especially on women, depending on which outcome is stronger. These examples clearly point to the importance of incorporating gender research and analysis, and other gender-related issues at all levels of planning and interventions that will steer efforts towards achieving reduced gender disparities and increased gender-equitable impacts.

The following outlines the proposed strategies for mainstreaming gender in CRP 3.5 interventions to ensure gender equitable benefits. The proposed strategy builds on ideas from the on-going initiatives across centers while proposing new aspects that will strengthen the ongoing efforts.

Baseline studies to support gender specific targeting

Baselines have been established in many on-going bilateral projects, such as BMGF funded Tropical Legumes II Project CRP 3.5 will conduct joint socio-economic studies (as and when needed) with other CRPs, (especially CRP 1.1, 1.2 & 2) during the first phase (2012-2014) to analyze specific contributions of men and women to socio-economic processes of legume cultivation and processing, differential access to and control over resources, and the rewards they gain from these contributions in the target production contexts. Such gender analysis will generate a deeper understanding of the gender issues, and strategic gender interests for change in the division of labor, access and control of resources, constraints, and opportunities for their full participation in the production pathways as well as post-harvest value addition processes upstream. The results will inform the development of strategies to address gender inequalities in access to and control over resources and services.

Active participation of men and women farmers in technology development process

Multi-stakeholder participatory action research will continue to be an important component of technology development through which men and women stakeholders along the legume value chains will be systematically consulted to identify their own priorities, varietal preferences, success stories, lessons learned, tools and mechanisms. The methods and tools, for actively involving men and women farmers in participatory plant breeding and variety selection to incorporate user preferences in the breeding criteria have evolved overtime, and are relatively well developed. Data is always gender disaggregated, which has enabled the gender specific analysis of preferences and incorporation of that analysis in the future breeding strategies. This practice will be encouraged to continue. In addition to this approach, specific targeting of women to involve them in the selection of varieties that suit both their food security and nutrition and market needs will be emphasized and given priority in breeding for improved nutrition. These efforts will be complemented with a body of in-depth gender-related research strategically designed to clearly document whether key technologies developed are (or are not) benefitting women to the degree expected, so as to constantly inform the nature of technology development in CRP 3.5 Grain Legumes.

Capacity building among implementers

It has been observed that while awareness of the role and importance of gender in agriculture has improved greatly, the actual incorporation of gender into agriculture research has been uneven across centers (Poats, 1991). One of the major handicaps to integration of gender into research and development activities is the lack of necessary capacity and skills. Lessons from past efforts show that training of researchers in gender issues result in substantial impacts on gender analysis among the researchers that were trained (Feldstein, 1998). Such efforts in training will need to be scaled up and out to realize even higher achievements.

Training of staff in IARCs, NARS and private sector partners in the basics of gender analysis and mainstreaming will continue to be supported and expanded to cover a wider scope of participants, both within and across institutions. Equal opportunities will be provided to women and young research staff to improve their knowledge, tools and skills in gender mainstreaming. Women and young adult farmers and traders will be mobilized and supported to actively participate in organized training meetings on gender mainstreaming.

Training will also focus on the existing staff and stakeholders and implemented through various arrangements that include workshops to encourage interactions among the participants, knowledge sharing platform and mentoring. Shared positions for experts in gender issues to mentor staff in gender analysis and audit progress will be promoted and supported across centers at sub regional levels (i.e. ESA, WCA, SSEA, CWANA, and LAC).

Lessons from past work in individual centers also suggest that capacity gaps at institutional level still exist even in areas where training was conducted, implying that training alone is not enough. For example, a study conducted by PABRA in 2008 to evaluate the benefits of their capacity building program among PABRA partners between 1995 and 2004 indicated that skills were gained at individual levels and were being used to enhance gender analysis in the respective organizations. The same study also found out that the staff turnover was high after training as new skills enhanced the competitiveness of those individuals in a wider job market, resulting in loss of capacity of that organization. These lessons led to recommendations that in order to build and maintain capacity for gender in these organizations, there is need to focus on institutionalization of gender capacity building. A gender mainstreaming policy and guideline for organizations are some of the tools that were suggested by partners as motivators for the institutionalization of capacity building for gender analysis and mainstreaming. Box 7.1 exhibits an example of a policy to articulate and implement the gender efforts in PABRA work under its ongoing Phase (2009 – 2013).

It is therefore, proposed that a gender mainstreaming policy be developed together with partners in

NARS and private sector in consultation with gender experts while borrowing from the capacity building policies already in use in some of the centers. Such a policy would promote ‘accountability’ for gender mainstreaming. CRP 3.5 will also work with gender experts to develop tools to guide implementers on ‘how to mainstream gender in the legume R4D thematic priorities’. For gender equality and advocacy at a wider community, CRP 3.5 will partner with relevant gender interest groups to support advocacy for establishment of formal gender equality where this does not exist and help bridge any gap between the formal situation and the actual enjoyment of equal rights and well-being.

Gender mainstreaming policy developed by and for PABRA research and development interventions

- All PABRA sub-projects should integrate gender in a strategic manner
- Gender has to be included as a criterion for the approval and funding of PABRA activities and PABRA related projects
- The network Steering Committees and other governance bodies of PABRA should have more than 30% representation of qualified women
- That country partners and staff are accountable in relation to gender mainstreaming, and requires them to report on certain aspects, reward those that perform significantly, and institute sharing mechanisms that promote gender
- The performance implementation framework has to show gendered outcomes, outputs and indicators and that these are reflected in the M&E framework beyond counting of numbers of men and women reached.
- Sufficient finances and other resources are directed to facilitate gender targeting and mainstreaming including capacity building.

Source: PABRA, 2009

Gender-explicit monitoring and evaluation

Monitoring should focus not only on equality of treatment for men and women, but also to ensure that the intervention outcomes provide benefits for both men and women in an equal way. To ensure this, all data from intervention activities, and M&E processes should be disaggregated by gender and analyzed to feedback lessons for better mainstreaming of gender into the CRP 3.5 programming and implementation process as well as inform policy.

It is also proposed that the participatory M&E system in each center be guided by a performance measurement framework that integrates local and gender specific indicators for monitoring project outcomes. This will ensure that these are measured both with technical indicators as well as local men and women generated indicators. Outcomes and outputs will be monitored for the extent to which they have affected both men and women. CRP 3.5 GRAIN LEGUMES will work jointly with other relevant CRPs while consulting with gender experts in adapting the performance measurement framework to identify and integrate gender specific monitorable indicators relevant for legume research and development interventions.

Annual reviews by stakeholders and gender specific audits will be periodically organized to review the progress toward gender mainstreaming and evaluate gender specific social impact on well-being.

8. Innovations

CRP 3.5 GRAIN LEGUMES constitutes a major innovation in partnership. It will overcome institutional and disciplinary barriers, and enhance cross-institution, cross-region and cross-crop learning. It will streamline the CGIAR and partner interface with grain legume clients in each region. It also presents an opportunity to share facilities and operations and gain a critical mass of scientists and research competencies described in Chapter 3 (see Why a CGIAR Research Program on Grain Legumes?). Ultimately, these improvements will accelerate progress against important and difficult challenges such as seed system bottlenecks, diseases, insect pests, drought, low soil fertility, changes in cropping systems and climate variability and change.

Exploiting Comparative Genomic Analysis: This CRP has the novel characteristic of bringing together multiple species within a common botanical family, but with even more contrasting evolutionary histories among these species. This represents a unique opportunity to understand how genomes that could be quite similar (e.g., cowpea and common bean are close relatives) have adapted to contrasting environments. Physiological research will reveal patterns of adaptation that can offer models across crops. Genomic cross-crop learning will have a particularly strategic role to play: following the principle of gene synteny, it can reveal the genetic and functional control of traits in one crop that can provide valuable lessons for application in another grain legume species. Furthermore, the integration of genomic knowledge management systems with conventional breeding systems across crops will create a more efficient, powerful platform for progress in technology deliveries. Successful implementation of molecular markers in breeding programs requires not only integrated data systems but also the tools necessary to rapidly and easily monitor marker-trait linkages in the breeding process (Varshney et al. 2005). For example, the Integrated Breeding Platform (IBP) aims to provide both the means for data integration and the tools necessary for the detection of marker-trait correlations, and to assist in their implementation in breeding. Genome-wide selection (GWS) is a novel approach compared to traditional marker-assisted selection where selections are made based on few markers. Rather than seeking to identify individual loci significantly associated with a trait, GWS uses all marker data as predictors of performance and consequently delivers more accurate predictions. Selection can be based on genomic selection predictions, potentially leading to more rapid and lower cost gains from breeding. Genomic prediction combines marker data with phenotypic and pedigree data (when available) in an attempt to increase the accuracy of the prediction of breeding and genotypic values.

Crop and agro-ecosystem modeling: Crop and agro-ecosystem modeling and computer and electronic application in agriculture are other areas ready for cross learning. ICARDA's application of the Focused Identification of Germplasm Strategy (FIGS) system and ICRISAT's mini-core approach help to identify useful material in the vast germplasm banks or even in the field. CIAT has a strong geospatial capability developed together with the GCP that will help all the CRP 3.5 GRAIN LEGUMES partners to more effectively diagnose grain legume systems and accompanying social variables of poverty and nutritional status. ICRISAT and the North Carolina State University (Raleigh) are currently collaborating in a modeling effort to pinpoint adaptive traits in soybean and groundnut that are critical to drought tolerance across legumes. These traits and the methods to evaluate them are already being tested in common bean.

The value chain perspective: The value chain perspective (Objective 5) will convey a systems perspective to CRP 3.5 that will provide a stronger basis for opportunity identification and priority setting. By seeking to understand how perceptions of value influence the adoption of new technology, especially for women, it will enhance the effectiveness of impact pathway analysis as well.

Innovative R4D initiatives

Much innovation is embedded in the Outputs described in Chapter 5. We compile some of the most innovative areas here in order of their relationship to our Strategic Objectives.

STRATEGIC OBJECTIVE 1

Exploiting Genomic Resources to identify desirable alleles to overcome biotic constraints

- Genetically map genes for resistance to diseases that attack several grain legume species to identify alleles that might be able to be 'awakened' in susceptible crops. This will help to manage similar pest management strategies over different legumes.

As large-scale genomic resources, including genome sequences, become available in several legume crops (Varshney et al. 2010), resistance genes to a range of diseases across the legumes will be mapped using linkage mapping or association mapping approaches. These genes or markers associated with the genes may be used for screening the breeding lines as well as introgressing resistance in leading varieties, if they have become susceptible, or by pyramiding resistance genes with other traits through molecular breeding approaches. Mining of genome sequences available for several legume crops and model legume species for disease resistance genes and their characterization can identify candidate genes. These candidate genes can be used for screening the subsets or entire collection of germplasm of legume species in the genebanks for the identification of superior haplotypes for enhanced resistance to diseases.

Exploiting primary and secondary gene pools as sources for variability and adaptation traits

- *Pre-breeding to use primary and secondary gene pools to introgress genes for adaptation to new niches and to improve climate resilience, biotic/abiotic stress tolerance and nutritional quality as medium to long term perspectives.*

For example, wild *Arachis* species show wide diversity at the molecular, genetic and phenotypic level and constitute an important resource for variability for various adaptation traits; however utilization of wild *Arachis* species needs pre-breeding efforts to eliminate the linkage drag. Genome-wide introgression of a small genomic region from wild species while keeping the genetic background of the cultivated is a good means to explore the largely untapped reservoir of useful alleles of interest in wild species. This approach has been widely utilized for introgression of favourable QTLs for various traits in tomato (Fridman et al. 2004), rice (Xu et al. 2005), wheat (Liu et al. 2006) and barley (Schmalenbach et al. 2009). The *Phaseolus* genus includes species that span the ecological range from arid deserts to tropical rainforests, and the species that can be crossed with common bean cover most of this range. These sister species are pools of genetic diversity that can help confront the looming challenges of climate change. In chickpea, nine annual species exist in the primary and secondary gene pool of which only two species (*C. reticulatum*, *C. echinospermum*) are currently widely exploited. In lentil, eight species exist in the primary and secondary gene pool of which only *L. orientalis* and *L. odemnenis* are exploited.

Breeding methods

- *Development of a strategy to implement a doubled haploid conventional and transgenic technology in grain legumes.*

Doubled haploid production in legumes could tremendously benefit genomic and breeding efforts by generating 100% homozygous lines quickly and efficiently. Introducing doubled haploid technology will increase the speed of developing new varieties of grain legumes by

reducing the average breeding cycle by up to 40%. A recent study in Nature reported a new approach to induce haploid production in the model plant *Arabidopsis thaliana* by introduction of a single genetic alteration (manipulating the centromere-specific histone CENH3). The study indicated that manipulating a centromeric histone makes it possible to reliably create haploid plants (Copenhaver and Preuss 2010). The other possible approach is by centromere-mediated genome elimination (Ravi and Chan 2010). Haploids are spontaneously converted into fertile diploids through meiotic non-reduction, allowing their genotype to be perpetuated. Maternal and paternal haploids can be generated through reciprocal crosses. This centromere-mediated genome elimination was also exploited to convert a natural tetraploid *Arabidopsis* into a diploid, reducing its ploidy to simplify breeding.

We propose to translate this approach of haploid transgenic technique to grain legume crop species to shorten the crop breeding programs by years, to develop mapping populations much faster and to reduce ploidy level. This process has key advantages over current methods for producing haploid plants: no tissue culture is needed; the same inducer produces maternal and paternal haploids; crossing a *cenh3* mutant as the female transfers the nuclear genome of the male parent into a heterologous cytoplasm, this could accelerate production of cytoplasmic male sterile lines for making hybrid seed and genome elimination occurs between parents that belong to the same species, avoiding fertility barriers inherent to wide crosses.

Alternatively, doubled haploids can be produced in legumes using conventional doubled haploid technology copied from Brassica and cereal species. In the next 3-5 years, the technology is likely to become routinely available for chickpea and perhaps other legumes species. A non-transgenic doubled haploid system is likely to be easily adopted by breeding programs.

STRATEGIC OBJECTIVE 2

Integrated cross-legume approach to stress tolerance: Utilizing crop modeling, physiological analysis, and data mining approaches to determine the key traits that confer adaptation to different environments. This will aid the development of novel phenotyping methodologies to increase the success of varietal development, targeting particular environmental niches.

Water is limiting in many of the environments where grain legumes are grown. The success of crops across an array of environments with different water availability needs to balance water use to water availability. Therefore, in each environment, cultivars would have a set of “optimum” characteristics with regards to water use that make them the most suited to each specific environment. Innovation will consist of combining a physiological approach of understanding critical traits that affect plant water use with crop simulation modelling to decipher and identify when and where any of these traits, or trait combinations, lead to a significant yield improvement.

Current research using both a water-centered framework and crop simulation modelling point to several plant traits that could have a major role to play for the crop’s adaptation to climate change and/or drought conditions (Sinclair et al. 2010; Zaman-Allah et al. 2011; Vadez et al. 2011). For example, on-going crop simulation modelling clearly indicate in soybean (Sinclair et al. 2010) and chickpea (Vadez et al. unpublished) that the sensitivity of transpiration to vapour pressure deficit contribute to major water savings and lead to yield benefits under drought conditions. While germplasm having these characteristics in soybean have been identified, there is only limited evidence of the same in chickpea, although common bean shows potentially useful genetic variability (unpublished data). Therefore, there is a need for a systematic simulation testing of the value of several putative adaptive traits in different crops, followed by a

systematic search in the germplasm collection for such characteristics. Since some potential germplasm would likely have some undesirable agronomic characteristics, there will be a need for pre-breeding of desirable characteristics (possibly from wild species) into suitable background.

Other knowledge regarding mechanisms of reproductive stress tolerance for drought, heat and salinity across crops can be used to identify marker-trait associations that can be screened in breeding populations. Knowledge gained from cowpea, pigeonpea, and chickpea drought tolerance research, both in physiology and in identification of genomic regions governing drought tolerance, can serve to improve drought tolerance in common bean and soybean. Salinity tolerance in chickpea is largely explained by differences in how reproduction (flowering, podding and seed set) occurs under salt stress, with tolerant genotypes having a larger number of flowers and a lower seed abortion rate. Under heat stress, reproduction also appears to be the factor most affected, whereas biomass production seems to be less affected (Wahid et al. 2007; Beebe et al. 2011). Under drought, the functions of pollen, and particularly the style, are disrupted (Salem et al. 2007). Desi chickpea appears to have better tolerance to salinity and drought than kabuli types. Furthermore, as reproduction is affected by these different abiotic stresses, elucidation of the sensitive components/mechanisms of tolerance, and whether genotypes could have “cross-stress tolerance” of reproduction under abiotic stress, need to be evaluated to provide the basis of future breeding programs for stress tolerance. Elucidating the reproductive processes most susceptible to heat, drought and salinity stress will lead to testing whether mechanisms of tolerance are common for different abiotic stresses, and whether the same mechanisms operate across crops. This knowledge will aid breeders to enhance stress tolerance in sensitive crops.

- *Utilize bio-economic modelling to understand the climate resilience potential of heat and drought tolerance*

The analysis described above is essentially a genetic-physiological analysis. This can be expanded to estimate the effects of heat and drought tolerance in legumes on climate resilience, on household welfare, and on quality of natural resources such as soil, water and biodiversity, under a set of biophysical conditions (soil quality, length of growing period, pest and disease incidence, drought, etc.) and socioeconomic factors (access to market, policies, institutions, etc.). The bio-economic models are capable of simultaneously addressing the various dimensions of agriculture, technology changes and the resulting trade-offs among economic, environmental and sustainability.

STRATEGIC OBJECTIVE 3

- *Explore the potential use of natural enemies of insect pests (parasitoids and entomopathogens) across continents for biological control to help in the sustainable management of pests for which little or no sources of resistance are available.*

Introduction and use of natural enemies of insect pests across continents can have both positive and negative consequences. Fungal entomopathogens can directly regulate populations of various insects. For example, the entomopathogen *Beauveria bassiana* can influence growth and fecundity of insect herbivores, and has been successfully used to control the Sun insect pest in wheat in West Asia. Another entomopathogen, *Metarhizium anisopliae*, using soybean oil formulation is being used for the control of cotton stainer bug, *Dysdercus peruvianus*, and can be explored for the control of pests of legumes crops. Perhaps best known, *Bacillus thuringiensis* (a bacterial biological control) has been used commercially to control pests of Lepidoptera, Diptera and Coleoptera. Also, the genes encoding the Bt-toxins have been successfully transferred into cotton, corn, soybean and rice conferring resistance to insect pests. This technology is considered to be one of the most successful models in agricultural biotechnology. These entomopathogenic bacteria represent a new and rich source of secondary metabolites that needs to be explored.

STRATEGIC OBJECTIVE 4

- *Model seed systems to identify obstacles for quality seed supply of improved varieties of grain legumes.*

In most countries, well over 95% of legume seeds are managed by farmers. Thus, informal seed systems are important for legume seed supply chains. Country/location and crop specific sustainable seed systems need to be developed and promoted. Several players such as researchers, farmer associations, NGOs, seed agencies, government agencies, private sector and linkages among them and with formal seed systems have a crucial role in legume seed supply systems. The dynamics arising from them need to be identified and addressed.

Research on multiple models of legume seed systems and multiple legumes was initiated under the Tropical Legumes-II (TL-II) project. Under the CRP 3.5, research will extend the results of TL-II to additional countries and contexts. Dissemination of multiple and diverse models of seed systems is an innovation that has not been attempted previously. This will be facilitated in the TL-2 project by the development of country strategies that integrate efforts across legumes. Any research on seed systems must take into account how seed systems operate, and strengthen them to increase the supply of new materials. Ideally, the program will reflect farmers' knowledge and experience, and will strengthen the linkages between farmers and researchers from different areas to serve dynamic and changing needs. Seed systems involve many actors and this raises the issue of modelling interactions between social dynamics (decisions or practices of actors or groups of actors, exchanges or communications between these actors or groups of actors), and physical dynamics (natural dynamics of the resources).

STRATEGIC OBJECTIVE 5

- *Induce mutations for herbicide tolerance in key grain legumes and identify the gene(s) underlying this tolerance to be able to move these into wider germplasm to facilitate the adoption of no-till and conservation farming techniques with subsequent reduction in the daily manual labour, primarily by women, of hand weeding.*

Weeds are a problem across crops, and legumes are no exception. Weeds compete with the crop for light and nutrients; and often lead to significant yield losses. Selective herbicides that do not harm the crop are often not effective in eliminating all types of weeds. Non-selective herbicides are effective in removing all types of weeds in a single application, but a pre-requisite is to have herbicide resistant varieties. Transgenic crops resistant to herbicides are currently available in several crops, e.g., soybean, maize, and cotton (Roundup Ready, active agent: glyphosate; and Liberty Link, active agent: glufosinate). Non-transgenic approaches could also be used and are likely to have better acceptance and use. Herbicide tolerant genotypes can be identified by exploiting already available genetic variability (spontaneous mutations) in the germplasm or by inducing variability. Mutagens that have been used in *Arabidopsis* to generate herbicide resistance could be used in legumes; the concentrations and time of exposure would need to be optimized. The availability of non-transgenic herbicide resistant legumes would contribute to reduce the use of farm labor and operating costs. Thus, we need to develop mutagen-based herbicide tolerance in several legumes (i.e. chickpea (Taran et al. 2010), lentil (Slinkard et al. 2007). In parallel, novel herbicides will be tested to provide alternative options to more effectively control weeds in legumes crops. BASF Canada developed the lentil line RH44, which is tolerant to imidazolinone herbicides. This lentil variety was developed through a process of mutagenesis combined with conventional breeding. No novel DNA has been introduced into the line to achieve herbicide tolerance. The variety is promoted under the Clearfield technology that has been applied to a number of crops such as corn, canola, rice, and wheat.

STRATEGIC OBJECTIVE 6

- *Cross legume databases.*

The volume of genetic/genomic data that is being generated currently demands great creativity to manage, but at the same time represents an opportunity never before known to legume scientists. The sort of cross legume research that is outlined in the proposal has its complement in cross legume data management. Discussions for the creation of a database for cross legume comparisons are underway with the soybean community in the United States (USDA), and with CIAT, IITA and ICRISAT.

- *Integration with the legume nutrition community.*

Another innovative dimension of cross legume research that has vast potential is in the further exploration of the health effects of legume consumption. The research that is necessary to elucidate these benefits goes beyond the disciplinary capacity of CRP 3.5, and beyond even that of CRP 4, and must be accessed in the broader nutrition community. Furthermore, the specific benefits of legumes are attracting a specialized group of nutritionists who are creating a *de facto* community of practice. These include scientists from Michigan State University, Colorado State University, the University of Saskatchewan, University of California-Davis, among others. To date, the attention of most of these scientists has been focused on the developed countries. By establishing communication with these scientists, by facilitating linkages with developing country nutritionists, and by supplying the raw material (i.e., the necessary tonnage of specific legumes), it will be possible to leverage this capacity to address health issues of the developing

countries. This will be done in collaboration with CRP 4, but is a specialized area that requires the active participation of legume experts who have access to relevant genetic diversity and knowledge of local preferences.

Table 8.1. Summary of Innovations in CRP 3.5 and their potential benefits.

Strategic Objective	Innovations	Crop/ region to be applied	Potential Economic/Other benefits
General	Partnership among stakeholders	All crops and regions	Overcome institutional and disciplinary barriers; enhancement of cross-institution, -region and -crop learning; streamlining CGIAR and other partners' interface; efficient use/sharing of facilities, human resources and competencies
Strategic Objective 1			
Conserving and characterizing genetic resources and developing novel breeding methods/tools for improving efficiency of crop improvement	Exploiting genomic resources to identify desirable alleles to overcome biotic constraints	CP, CB, CW, FB, GN, LN, PP, SB in all regions (SSEA, ESA, WCA, CWANA, LAC)	Global annual grain yield losses due to various diseases (29 – 45%) and pests (12 to 34%) were estimated to be 4.8 million tonnes (Toker et al, 2007). These losses could be substantially minimised
	Wide Crosses (Exploiting primary and secondary gene pools as sources for variability and adaptation traits)	CB, CP, LN in ESA, WCA, LA, CWANA, SSEA	Broaden genetic base to bring in new gene(s)/alleles for improved resistance / tolerance to biotic and abiotic stresses (Kumar et al 2011), and enhanced nutritional qualities
	Development of a strategy to implement a doubled haploid transgenic technology in grain legumes.	CP, GN and PP in SSEA	Hasten the speed of developing new varieties of grain legumes by reducing the average breeding cycle by 40%.
Strategic Objective 2			
Accelerating the development of more productive and nutritious cultivars for resilient cropping systems of smallholder farmers	Utilizing crop modeling, physiological analysis, and data mining approaches to determine key traits that confer adaptation to different environments	CP, CB, CW, FB, GN, LN, PP, SB in all regions (SSEA, ESA, WCA, CWANA, LAC)	Improved adaptation to abiotic stress (avoidance of 10% yield reduction)
	Utilizing bio-economic modeling to understand the climate resilience potential of heat and drought tolerance	CP, CB, CW, FB, GN, LN, PP, SB in all regions (SSEA, ESA, WCA, CWANA, LAC)	More profitable (potential) legume production through better targeting, for climate resilience (heat and drought)
Strategic Objective 3			
Identifying and promoting crop and pest management practices for sustainable legume production	Identifying and exploiting natural enemies of insect pests (parasitoids and entomopathogens) for biocontrol	All legumes and regions for identified insect pests and countries	Yield loss of 18 to 35% across priority legumes and regions can be avoided.
Strategic Objective 4			
Developing and facilitating efficient legume seed production and delivery systems for smallholder farmers	Model seed systems for ensuring quality seed supply of improved varieties of grain legumes	CP, CB, CW, FB, GN, LN, PP in all regions (SSEA, ESA, WCA, CWANA, LAC)	More effective seed system for providing better quality seed to farming community

Strategic Objective	Innovations	Crop/ region to be applied	Potential Economic/Other benefits
Strategic Objective 5			
Enhancing grain legume value chain benefits captured by the poor, especially women	Exploitation of natural and Induced mutations for herbicide tolerance in key grain legumes and identify the gene(s) underlying this tolerance to be able to move these into wider germplasm	Clearfield technology (lentils) Metribuzine tolerance in chickpea	Can avoid up to 30% yield losses through weed competition
Strategic Objective 6			
Partnerships, capacities, and knowledge sharing to enhance grain legume R4D impacts	Development of cross legume databases.	CP, CB, CW, FB, GN, LN, PP in all regions (SSEA, ESA, WCA, CWANA, LAC)	One-stop shop to source/provide legume information and data
	Integration with the wider legume nutrition community.in coordination with CRP4	CP, CB, CW, FB, GN, LN, PP in all regions (SSEA, ESA, WCA, CWANA, LAC)	More synergy and information sharing through networks, etc.

9. Interactions of CRP 3.5 GRAIN LEGUMES with other CRPs

CRP 3.5 GRAIN LEGUMES strives to complement other CRPs, and will be working with: CRP 1.1 – Integrated Agriculture Production Systems for the Dry Areas; CRP 1.2 – Integrated Systems for the Humid Tropics; CRP 2 – Policies, Institutions, and Markets to Strengthen Assets and Income for the poor; CRP 3.1 – WHEAT; CRP 3.2 – MAIZE, CRP 3.3 – GRiSP; A Global Rice Science Partnership; CRP 3.6 – DRYLAND CEREALS; CRP 3.7 – Sustainable Staple Productivity Increases for Global Food Security: Livestock and Fish; CRP 4 – Agriculture for improved Nutrition and Health; CRP 5 – Durable Solutions for Water Scarcity and Land Degradation; and CRP 7 – Climate Change, Agriculture and Food Security.

CRP 1.1: CRP 1.1 will work on five common legumes (CP, GN, CB, CW and FB) in various agro-ecological regions of Asia, ESA, and WCA that are common with CRP 3.5. The new improved varieties coming from CRP 3.5 will plug into CRP 1.1 as inputs. The feedback loops from CRP 1.1 will enable the researchers of strategic objectives 1 & 2 of CRP 3.5 to prioritize the traits for crop improvement. CRP 3.5 will conduct joint research with CRP 1.1 to accomplish strategic objective 3 on Identifying and promoting crop and pest management practices for sustainable legume production, possibly using common test locations. Farming-system level value chain R4D in CRP 1.1 and 1.2 will complement the grain legume-focused analyses of CRP 3.5 (see details in Appendix 12).

CRP 1.2: CRP 3.5 will contribute strategic knowledge, technologies and research tools, for example improved legume varieties and crop management practices (such as IPM/IDM) for different cropping systems and niches in CRP 1.2. Improved legume varieties from CRP 3.5 will be tested plug in CRP1.2 at common test locations. Learning gained from CRP1.2 on testing of legume varieties will help CRP 3.5 revise and improve the relevance of its work. Knowledge sharing and capacity building will be an important activity integrated with CRP 1.2 (see details in Appendix 12).

CRP 2: CRP 3.5 GRAIN LEGUMES will contribute in-depth practical understanding of grain legume value chains to complement the global and methodological value chain work of CRP2. CRP3.5 will also inform CRP2 on relevant legume-specific dimensions of policy, institutional, and market access work. CRP3.5 will establish and maintain regular interaction with CRP2's strategic activities such as constraint identification, evaluation, feedback to enhance priority setting at the CGIAR System level. Knowledge on research methods, models and data on crop productivity, value chain analysis and policy advocacy for identification of new market opportunities for grain legumes will be an important input for CRP2 to develop policy advocacy and promote conducive markets for more profitable grain legume production systems. We will work with CRP 2 for ex-ante priority setting, input-output market linkages for reducing transactions costs, agricultural policies and regulations, and impact assessment (see details in Appendix 18).

CRP 3.1: Breeding methodologies and genomics are major areas of collaboration between the two CRPs. Joint activities with CRP 3.1 WHEAT would include development of wheat- legume cropping systems in poverty hot spots where wheat is a dominant crop.

CRP3.2: Considering that legumes are intercropped or rotated with maize, CRP 3.5 will work with CRP 3.2 MAIZE to test improved legume varieties for varied MAIZE ecosystems, where possible at common test locations/sites. Feedback from MAIZE in terms of crop duration will help CRP 3.5 to tailor legume varieties to fit maize crop cycle and vice-versa. Breeding methods and genomic tools from MAIZE will also be helpful for grain legume research.

CRP 3.3: CRP 3.5 will benefit from GRiSP with enhanced knowledge base through newer tools, techniques for genetic enhancement and phenotyping for drought and waterlogging. Grain legumes are a major component in diversification of rice based cropping systems for improving productivity and sustainability. CRP 3.5 GRAIN LEGUMES will test improved legume cultivars and production technologies suitable for rice-legume cropping systems, at GRiSP test locations.

CRP 3.6: Dryland cereals and the grain legumes are intercropped in many regions of the semi- arid tropics. CRP 3.5 will test improved legume varieties for intercropping and vice-versa at common test sites. Advances in genomics and molecular breeding, hybrid seed technology, crop modeling and feed quality analysis in many of these crops can benefit similar developments in grain legumes.

CRP 3.7: Legume Fodder is an important component of mixed crop livestock farming. Legumes with high protein content, low anti-nutritional factors, tannins, etc. can increase livestock production and thereby improve the living standard of the resource poor. CRP 3.5 will provide dual-purpose legume varieties for evaluation in crop-livestock systems. Supplementing cereals with legume crop residues has high synergistic effects on livestock productivity.

CRP 4: Common bean is the only legume crop to be researched extensively in CRP 4. CRP 3.5 will take experiences of HarvestPlus (housed in CRP 4) and extend to other legumes. CRP 3.5 works within the criteria set by CRP 4/HarvestPlus in other legumes, and in the case of common bean, in other geographic regions that are in need of nutritional improvement. Studies on nutritional impact are not foreseen in CRP 3.5, but we may be jointly engaged with ARIs and CRP 4, based on need.

CRP 5: CRP 5 on Water and Land will complement much of the farm-scale work being done on production systems in grain legumes and provides required inputs such as information on water, land, ecosystems and soil fertility management practices. CRP 3.5 will test durable legume-based solutions for addressing water scarcity and land degradation and focuses on developing region specific legume varieties, which improve soil health as well as best bet management practices for different grain legume production systems, using common test locations where feasible.

CRP 7: Interaction of CRP 7 CCAFS and CRP 3.5 will be through testing of climate resilient varieties and technologies as inputs fitting into climate change adaptive strategies. Identification of key target areas and traits for future challenges of climate change (through modeling) will feed into CRP 3.5 to prioritize the legume traits for breeding. Research on effects of elevated CO₂ on legume physiology and growth will be carried out in collaboration with CRP 7. Thus, the exchange of information and learning between these two CRPs is very important.

More detailed description of specific interactions of CRP 3.5 GRAIN LEGUMES with other CRPs is given in Table 9.1.

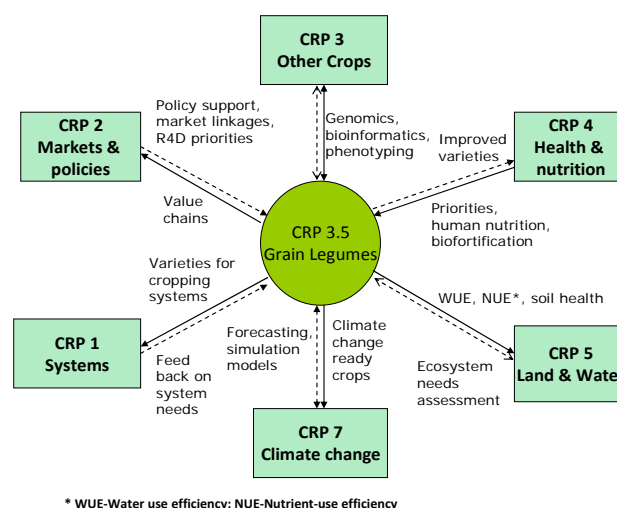


Figure 9.1. Linkages with other CRPs

Table 9.1. Interactions of CRP 3.5 GRAIN LEGUMES with other CRPs

CGIAR Research Program	Outputs from CRP 3.5	Inputs to CRP 3.5	Joint Actions with other CRPs
CRP 1.1 Integrated Agricultural Production Systems for the Dry Areas	Two agro-ecosystems of CRP 1.1, namely, mixed crop-livestock system in South Asia, and rainfed agro-ecosystem of North Africa, and West and Central Asia would benefit from the improved varieties of legumes of CRP 3.5. For example, early maturing legumes for short-window cropping season, nutrient efficient varieties, and varieties with resistance to biotic and abiotic stresses.	Feedback from CRP 1.1 will enable prioritizing the traits and /or including new traits in legume breeding.	<ul style="list-style-type: none"> • Joint meetings to identify and prioritize the traits in legume crops suitable for target dry land agro-ecosystems of Asia, ESA and WC • Joint research to develop production technologies for legumes in target agro-ecosystems of Asia, ESA and WCA, possibly at common research sites • Evaluate and disseminate integrated crop management strategies in legumes in target ecosystems of Asia, ESA and WCA
CRP 1.2 Integrated Systems for Humid Tropics	Improved legume varieties and crop management practices including methodologies, technologies and research tools for different cropping systems and niches	Feedback on technologies that fit into different systems and research needs for better adaption/use of grain legumes	<ul style="list-style-type: none"> • Joint planning meetings to identify suitable cropping systems, technologies and implications for system integration in target humid tropics, using common research sites • Evaluate best bet technologies for growing grain legumes in target ecosystems • Joint workshops for knowledge sharing and capacity building on best bet technologies that fit into different cropping systems

CGIAR Research Program	Outputs from CRP 3.5	Inputs to CRP 3.5	Joint Actions with other CRPs
CRP 2 Policies, Institutions, and Markets to Strengthen Assets and Agricultural Incomes for the Poor	<p>Identification of improved grain legume cultivars, information on productivity, value chains, market access, and gender issues related to grain legumes-based production and processing technologies.</p> <p>Knowledge on research methods, models and data for value chain analysis and policy advocacy for identification of new market opportunities for grain legumes</p>	<p>Policy advocacy and promoting conducive markets for more profitable grain legume production systems</p> <p>Methods for value chain analysis, and tools for impact assessment</p> <p>Predict market demand for legumes and their products</p> <p>Conduct periodic strategic analyses from a focused regional, commodity or systems perspective</p>	<ul style="list-style-type: none"> • Work together with CRP2 on policies, institutions, and market access that integrate producers of key commodities and devise efficient value chain system • Developing policy briefs that promote farmer-friendly, particularly women, marketing infrastructure and protocols for enhancing value of grain legumes • Promoting the interface between food processors and legume growers and train stakeholders along the value chain • Jointly identifying policy interventions for ensuring availability of quality seed of legume varieties to farmers at affordable price • Promoting institutional arrangements for enhancing production and utilization of grain legumes through networking, including women self-help groups
CRP3.1 WHEAT	Information and feedback on performance of wheat varieties in legume based cropping systems	Information on wheat genomics, molecular breeding, and bioinformatics.	<ul style="list-style-type: none"> • Joint research on wheat-legume systems in developing countries • Joint strategy for developing and disseminating resource-conserving technologies in cereal and legume systems
CRP3.2 MAIZE	Legume varieties and production technologies suitable for maize-legume intercropping, and crop rotations	Maize varieties and production technologies suitable for maize-legume and crop-livestock production systems	<ul style="list-style-type: none"> • Evaluating legumes in the maize-based systems in southern and eastern Africa, S and S E Asia and in Central and South America at MAIZE testing sites/locations • Improved integrated crop management practices for ensuring high quality of legumes, and promote safe storage practices at farm level for legumes • Adoption of improved legume varieties and agronomic practices for improved soil fertility in maize-based systems, using MAIZE test sites/locations
CRP3.3 GRiSP: A Global Rice Science Partnership	Improved and region specific legume cultivars for rice based cropping systems to improve sustainability	Cutting edge science and biotechnological applications that are part of rice genome initiative	<ul style="list-style-type: none"> • Development and testing of legumes for sustainability of the rice-legume cropping system, in South Asia, Indo-Gangetic plains and other eco-systems, preferably using GRiSP test sites

CGIAR Research Program	Outputs from CRP 3.5	Inputs to CRP 3.5	Joint Actions with other CRPs
CRP 3.6 Dryland Cereals	Performance of dryland cereals in legume based cropping systems	Suitable dryland cereals that can be intercropped in target areas. Advances in genomics, gene synteny, and molecular breeding. Feed and stover quality management	<ul style="list-style-type: none"> • Establishment of molecular breeding platform. • Hybrid seed technology • Exchange of information on phenotyping and genotyping and breeding methodologies • Joint research on cereal – legume systems for fodder/feed for small holder farmers, using common research sites
CRP 3.7 Livestock and Fish	High yielding legumes with low tannins and anti-nutritional factors	Feedback on desired fodder quality traits, e.g., legumes with higher forage nitrogen content to maximize livestock productivity	<ul style="list-style-type: none"> • Providing improved dual purpose legume varieties with better fodder quality traits, and promote safe storage practices at farm level for legume fodder • Development of legumes with higher forage nitrogen content • Dual purpose legumes that give both grain yield and fodder and ameliorate the soil for system sustainability
CRP 4 Agriculture for Improved Nutrition and Health	Nutritionally enhanced grain legume cultivars and legume food products for improved health and nutrition	<p>Promotion of nutritionally enhanced grain legumes and products, and interaction of gender, nutrition, and health.</p> <p>Creation value chains and demand for nutritionally safer foods would become an important input to CRP 3.5</p>	<ul style="list-style-type: none"> • Participate in meetings to prepare joint workplans on role of legumes in nutrition and health • Collating information on consumer demand and nutrition and health benefits of nutritious/ biofortified legumes • Developing new products and processing methods in partnership with stakeholders for enhanced nutritional value of legumes, especially for women and children • Studying the effects of legume consumption on non-communicable diseases (NCDs) • Advocating the consumption of nutritious legumes and their value added products for nutrition and health
CRP 5 Water, Land, and Ecosystems	Improved cultivars best-bet management practices with better water and nutrient use efficiencies for different grain legume production systems	<p>Information on water, land, and ecosystems for promoting legumes intensification in different production systems.</p> <p>Access to water and land policies at national and global levels</p>	<ul style="list-style-type: none"> • Evaluating improved legume varieties with better water and nutrient use efficiency for water and nutrient conservation at common test sites • Exploiting productive legume varieties with better N-fixing abilities for reducing demand for chemical N • Participation in annual work plan meetings

CGIAR Research Program	Outputs from CRP 3.5	Inputs to CRP 3.5	Joint Actions with other CRPs
CRP 7 Climate Change, Agriculture and Food Security	Climate resilient legume varieties and production technology that fit into climate change adaptive strategies	Feedback on strategic foresight on the potential impact of climate change on patterns of biotic and abiotic stresses to prioritize traits for strategic objectives 2, 3, & 4 of CRP 3.5	<ul style="list-style-type: none"> • Joint meetings to prioritize the legume traits for climate change effects based on the above learning • Training of CRP 3.5 researches about the future potential impacts of climate change, • Joint activities to help disseminate appropriate climate-ready varieties and management practices; and minimizing the effects of climate variability on grain legume productivity • Conduct joint research using common test locations

10. Governance and Management

We have based the governance and management of CRP 3.5 GRAIN LEGUMES on the principles outlined in the CGIAR Strategy and Results Framework. The CRP is being implemented by four CGIAR Centers – CIAT, ICARDA, IITA and ICRISAT – with ICRISAT as the designated Lead Center. The Generation Challenge Program will play a key role until its termination in 2014. In addition, the CRP will be supported through key partnerships with the Brazilian Agricultural Research Corporation (EMBRAPA), the Ethiopian Institute of Agricultural Research (EIAR), the Indian Council of Agricultural Research (ICAR), the Turkish General Directorate of Agricultural Research (GDAR), the USAID-supported Dry Grain Pulses Collaborative Research Support Program, as well as other NARS, public and private sector institutes in target and developed countries. We have thus designed a management structure that provides effective governance and oversight by the Lead Center, strategic oversight by key partners, management by contributing partners and independent evaluation and input by outside experts. We recognize that the proposed structure (Figure 10.1) may require refinements as the CRP develops, both in terms of membership, responsibilities and the configuration itself. Such possibilities will be continually evaluated and changes implemented as required.

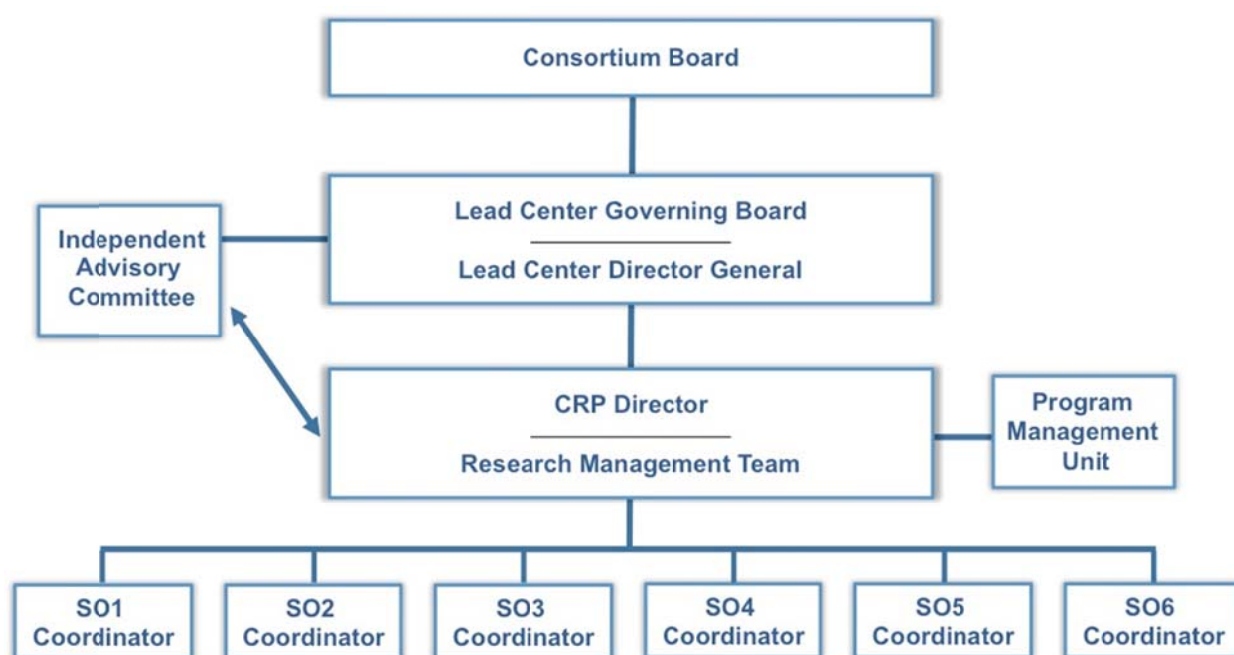


Figure 10.1. GRAIN LEGUMES Governance and Management Structure

Roles and Responsibilities

The **Lead Center** (ICRISAT) will sign a Program Implementation Agreement (PIA) with the Consortium of International Agricultural Research Centers for implementation of the CRP. The Lead Center, represented by its Director General and Governing Board, will be responsible for the overall performance of GRAIN LEGUMES by providing a clear vision, direction, priorities and focus through an inclusive, consultative and transparent partnership process. Participant Program Agreements (PPAs) will be signed with all key participants according to Consortium procedures and policies.

The **Governing Board of ICRISAT** will have the fiduciary and legal responsibility and accountability for the implementation of the CRP. Through the Director General, it will monitor management and implementation, including the performance of the CRP Director, Independent Advisory Committee and Research Management Team. The governance and/or management entities of the other partners will be expected to provide similar oversight of their respective institute's involvement in GRAIN LEGUMES. This would include ensuring that their institution's policies, vision and mission are in agreement with the CRP, that GRAIN LEGUMES is appropriately reflected in their strategic plans, and that their institution assumes fiduciary and legal responsibilities and accountabilities for implementing the agreed research agenda of the CRP.

The **Director General** of ICRISAT will ensure the success of GRAIN LEGUMES by working with the Directors General of partner CGIAR Centers to:

- Provide oversight on the overall operations of the CRP through the CRP Director,
- Ensure implementation of the CRP, including the effective integration of existing and new bilateral projects,
- Assign required staff to the GRAIN LEGUMES management committees/teams,
- Appoint and empower the CRP Director and Strategic Objective Coordinators and provide required support, and
- Ensure that performance contracts are successfully managed, including the management of risks.

A **Research Management Team (RMT)** will be chaired by the CRP Director and will include the six Strategic Objective Coordinators (see below) plus the Directors of Research (or their designates) from each key partner. It is expected that the Coordinators will be selected to provide effective regional representation across the target regions of the CRP. The RMT will be the key entity responsible for the establishment, execution and monitoring of the GRAIN LEGUMES research portfolio, strategy, work plans and annual budgets. The RMT will meet regularly, with at least one meeting being in-person. The RMT will:

- Coordinate strategic foresight, planning and reporting of the R4D portfolio;
- Monitor and evaluate research progress across the CRP
- Develop annual research plans and budget allocations;
- Prepare required reports for submission to the Consortium Board;
- Identify necessary resources (financial and otherwise) to meet the goals of the CRP;
- Communicate and represent the CRP globally (e.g., at major events);
- Organize periodic research reviews, including external reviews and impact assessments; and
- Conduct annual meetings of the CRP that include meetings of the Independent Advisory Committee.

The CRP **Director**, who will report to the Lead Center Director General, will be internationally recruited by the Lead Center in consultation with the other partners. The Director will lead the development and implementation of the CRP's R4D agenda with the RMT, ensuring the highest quality and relevance of the program's outputs, and have decision-making authority over the day-to-day operations of the CRP. This position will require a full-time commitment and be compensated accordingly; she/he will be covered by the policies of the Lead Center. The Lead Center Director General will oversee the recruitment, approve the Terms of Reference for, and annually evaluate the performance of the CRP Director. The Director will organize RMT, Independent Advisory Committee and other meetings and reviews for GRAIN LEGUMES, chairing such meetings where required. Specific responsibilities will include:

- Developing a clear and shared vision for CRP 3.5 among all partners and stakeholders and communicate this vision to all stakeholders;
- Providing intellectual leadership to, and coordinate implementation of, the CRP;
- Developing strong partnerships among participating centers, partners and other stakeholders, including those active in development;
- Representing the CRP in international fora to ensure that the CRP is highly visible and strongly supported by investors and other stakeholders;
- Guiding fundraising efforts for the GRAIN LEGUMES CRP together with the Centers and other partners; and
- Ensuring that the CRP has well developed and articulated gender and capacity strengthening strategies, defined work plans, clear deliverables, and that the CRP meets its programmatic and financial targets.

A **Program Management Unit (PMU)** will support the CRP Director, who will supervise its staff and operations. The PMU will consist initially of a senior administrative officer and a communications manager (to provide support in various communications matters including the CRP website, newsletters, reports, etc.). ICRISAT will assign a part-time financial manager and contracts officer in its respective departments to provide the required assistance to the CRP Director. Support for resource mobilization will be provided by ICRISAT's Resource Planning and Marketing Office, coordinated with similar units in the partner institutes and at the Consortium level. Program evaluation will be assisted by ICRISAT's Impact Assessment Office and through externally managed reviews and evaluations. ICRISAT and the CRP Director will monitor the requirements for additional administrative assistance and make adjustments as required.

GRAIN LEGUMES is structured into six Strategic Objectives, each of which will be coordinated by a **Strategic Objective Coordinator**, who will be at least a half-time appointment and will continue to be affiliated with their home institution, with the agreement of the institution. It is expected that CIAT, ICARDA, IITA and ICRISAT will host at least one coordinator each, with efforts made to have partner and regional coordination across the Strategic Objective Coordinators. Partners will nominate the Coordinators, with appointments being made by the Lead Center. The Coordinators will ensure that activities for delivering agreed outputs within each region are effectively implemented, coordinated, and monitored/assessed. Coordinators will also maintain close relationships with the CRP Director, participating in all RMT meetings, as well as with other Coordinators, relevant partners, donors and stakeholders involved in the CRP.

An **Independent Advisory Committee**, reporting to the Lead Center Governing Board, will provide input and advice to the ICRISAT Governing Board and RMT on the quality and relevance of the GRAIN LEGUMES research portfolio, priority setting and allocation of resources. The committee will be composed of 5-6 independent R4D experts with relevant experience and expertise in grain legumes and the target regions. Nominations will be sought from CRP partners with final appointments made by the Lead Center Director General. Appointments will be for an initial three-year period. The committee will meet at least once a year in person, with other meetings conducted virtually as required. The committee will elect its chair from among its membership. Written reports will be provided to the ICRISAT Governing Board and the RMT following each meeting and as part of the CRP annual evaluation.

Dispute resolution among GRAIN LEGUMES partners or with external parties will be handled, if within the domain of R4D (including partnerships), according to policies established by the RMT. If disputes fall in the domain of institutional and legal responsibilities, the Lead Center Director General will resolve them in accordance with the principles established in the Consortium Constitution. Should the RMT be unable to resolve any given dispute, the matter will be referred to the Lead Center for a decision and the respective party will be expected to take any actions deemed necessary.

Management of Intellectual Property

CRP intellectual property (IP) management is based on the overall CGIAR Consortium Guiding Principles on the Management of Intellectual Property, which are driven by the mission of the CGIAR and the imperative that the products of the Centers' research should be international public goods.

As the CRP will work with a wide range of partners, including national agricultural research systems (NARS), advanced research institutes (ARIs), civil society organizations, private sector companies, and regional and international intergovernmental organizations, the CRP will develop an IPR regime that allows all partners to honor their own IP policies without compromising the CGIAR principles. Ultimately, the Centers must produce, manage and provide access to the products of their research for use by, and for the benefit of the poor, especially farmers in developing countries.

Centers hold their in-trust collections of germplasm for the benefit of the world community, in accordance with agreements signed by Centers and the Governing Body of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). All such germplasm exchanges will be conducted using the Standard Material Transfer Agreement (SMTA). All other material transfers will be done under an appropriate MTA that follows the guidelines of the Consortium's Policy on Intellectual Property.

Knowledge Sharing and Communications

Knowledge sharing (KS) involves a variety of strategies and practices used to identify, create, represent, distribute, and enable adoption of insights and experiences with a wide range of stakeholders. IARCs have developed a number of innovative methods and practices over the last decade using the power of ICT. Many non-profit organizations dedicate significant resources to knowledge sharing, often as a part of their fundamental business plan.

Internally focused KS typically concentrates on management-related objectives, such as improved organizational performance, clarity about competitive advantages and innovations, and the sharing of lessons learned. In the context of GRAIN LEGUMES, KM efforts will overlap with Monitoring & Evaluation (M&E) and will both reinforce and draw on M&E efforts.

Given the organizational complexity of GRAIN LEGUMES, we must be willing to invest time and effort to help partners obtain and share valuable insights, reduce redundancies (increasingly rely on task specialization), increase the efficiency of R4D activities and capacity strengthening efforts, retain intellectual capital, adapt to rapidly changing operational environments and take advantage of new opportunities.

However, to be effective and oriented towards impact, KS systems require to be aligned towards the users furthest in the knowledge value chain- the smallholder farmers. The range of information producers typically is not small in agriculture R4D. A careful analysis and expert advice is needed in the design and development of viable KM systems. Over the past few decades, rapid developments in genomic and other molecular research technologies, as well as brisk advancements in information technologies, have combined to produce and enable the effective management of vast amounts of information related to molecular biology. Bioinformatics tools and geo-spatial mapping will be critical components of CRP3.5's knowledge sharing efforts, but even these high-end information technologies will be oriented towards resolving practical problems arising from the management and analysis of very large amounts of agro-biological data and information.

Agricultural R4D communication is also undergoing a transformation that is driven by the spread of high-speed Internet connectivity; the advent of digital media; the development of new tools, platforms and methodologies; and changes in the ways the world accesses and uses information. We, thus have an opportunity to implement a rapid, highly targeted and efficient transfer of research results into practice and policy – while simultaneously capturing them in peer-reviewed journals and publications.

The CRP Director will have general responsibility for communicating on behalf of CRP partners to a wide variety of audiences, and will help establish and monitor (in concert with the CRP Steering Committee and Strategic Objective Coordinators) the CRP's communication action plan. Implementation of that plan will occur at all levels and will be carried out by many of those involved in the R4D work, but regardless of their organizational affiliation, their communication efforts will rest on the strategic needs, interests and achievements of CRP GRAIN LEGUMES.

Communications will be made an integral part of the R4D process, and not be just a by-product of it. CRP GRAIN LEGUMES will invest in developing the communication skills of key individuals and partners – especially their ability to interact effectively with the media, particularly the internet-enabled social media. The communications work will be periodically evaluated to ensure optimum impact.

As noted earlier, advocacy on behalf of increased investments in legumes AR4D (and in markets and other needed rural infrastructure) is seen as a vital activity for CRP 3.5. Such advocacy must be based on the best information available, and capitalize on the most effective communications technologies and pathways. This advocacy role will be fully integrated in the Knowledge Sharing and Communication plan that will be developed in the early days of implementing CRP 3.5.

11. Time Frame

CRP 3.5 GRAIN LEGUMES initiated the proposal development process in 2010 during a brainstorming session with scientists from the major core partner centers. We began with visioning of what we would like to achieve by 2020, especially looking at the impacts that we envisage in the smallholder farmers' fields. We outlined an initial 10 year frame work, but delineated into three phases. We then focused on the first three years to develop milestones (through 2014 as we will most likely start CRP activities in April 2012). Each year, the partners will conduct an extensive analysis of progress achieved relative to projected milestones and in the context of our initial priorities. Based on the results of those annual reviews, we may modify our priorities, planned activities and anticipated milestones as we go, creating a rolling three-year action plan.

As we developed this document, for ease of reference we decided to keep our 2012-2014 projected milestones close to the strategic objectives to which they relate and the R4D outputs that are meant to achieve them.

CRP 3.5 will continue the extensive discussions that have already been held among the initial partners and, at the same time, bring other key partners on board to help map out specific work plans for first three years of the initiative. In developing this proposal, the current partners identified general areas where they believe collaboration can be more effective. Our focus during the first six months will be elaborating and clarifying relative roles and responsibilities of those involved in order to effectively implement collaborative efforts and more fully realize the potential efficiencies we see, and hopefully identify others. Thus, in the first six months, a detailed workplan will be developed – one that reflects our plans for mainstreaming important gender dimensions of CRP 3.5 GRAIN LEGUMES R4D, capacity strengthening, and details regarding different R4D activities, technologies to be developed and/or promoted, and the relative roles of different partners and their contribution to achieving the objectives of CRP 3.5.

12. Mitigating Risks

CRP 3.5 GRAIN LEGUMES is innovative in a number of areas so it is likely that there will be some risks involved. The learning curve associated with doing business in new ways involving more diverse partners may slow our progress (at least initially). A streamlined management structure and careful selection of partners involved in CRP 3.5, however, should help mitigate this risk, as will the goodwill and enlightened self-interest that we anticipate all partners will bring to the table.

Related to this is the need to accentuate accountability and promote ownership of CRP 3.5 GRAIN LEGUMES. As many activities related to impact are beyond the expertise and control of our research staff, we must also emphasize the inclusion of development agencies and extension services, NGOs, the private sector companies and processors and traders, and farming communities in planning and implementation. Doing so may increase transaction costs, but should help to mitigate the risk of limited impact on the ground.

As alluded to in other CRPs, the main risks to all CRPs are global in nature, i.e., such things as continued global financial challenges and the resulting political pressure to cut aid financing, especially to agriculture R&D. Strong monitoring and evaluation, broad-based expert advice, and an emphasis on consensus decision-making and conflict resolution should help to ameliorate management-related risks.

Legume production systems in many developing countries are often located in areas that experience high social and political volatility, and these could affect the implementation of R&D efforts, especially adoption of interventions in targeted areas. In such countries, CRP 3.5 will emphasize ownership by local partners to minimize this risk. While legume production systems have always been characterized by risk, many of these risks are changing and in some cases increasing. At the same time, the capacity to manage risk has declined as a result of restricted access to resources, lack of information, land degradation and land tenure insecurity faced by the smallholder farmers. Resource conflicts characterize developing country cropping systems and could be severe in some cases (e.g. the availability and control of water resources in Central Asia). Mitigating such risks will be difficult, and will depend on the wise counsel and full participation in activities at the community level, with priorities being driven locally.

Continued government policy bias against the support of smallholder farmers in marginal areas, even in the face of growing evidence of the value and importance of their enterprises, is also an important risk factor. Efforts to speak with a unified voice to policymakers and other influential leaders should help reduce this risk, but policy decisions are usually not made on the basis of well-reasoned arguments or even solid scientific evidence. CRP 3.5 partners will therefore need to identify local, regional and even international 'champions' who have the ear of key policymakers and who might, over time, influence the course of political decisions that limit legume production, processing and marketing. Finally, important risks to longer-term sustainability of CRP3.5 GRAIN LEGUMES could include insufficient interest on the part of private sector organizations needed to push commercialization of new technologies, as well as insufficient capacity on the part of national AR4D institutions to sustain the initiative. By including public and private organizations during the early stages of research planning and implementation, we believe that sustainability risks will be diminished due to a stronger sense of ownership and accountability for success. Finally, there are risks associated with climate—erratic rainfall, prolonged droughts or floods, can affect the success of CRP efforts in the target areas, both R4D activities and adoption of technologies by smallholder farmers.

13. Monitoring and Evaluation System

Introduction

Monitoring and Evaluation for CRP GRAIN LEGUMES will conform to the CGIAR consortium guidelines on 'Monitoring and Evaluation System' that will be developed in the near future. Monitoring tracks key indicators of progress over the course of CRP implementation as a basis to evaluate outcomes of the interventions. Operational evaluation examines how effectively programs were implemented and whether there are gaps between planned and realized outcomes. Impact evaluation tells us whether the changes in the well-being of the beneficiaries are indeed due to the CRP interventions.

M&E in the context of international agricultural research

Evaluation is a periodic assessment of the relevance, performance efficiency and impact (both expected and unexpected) of the project in relation to stated objectives. The monitoring and evaluation play complementary roles. The donors and the research leaders are interested in the contributions of research according to the CRP committed goals, so as to make key decisions on prioritizing the research products. Accordingly, information on impact is highly demanded by the donors to know the value additions to their investments. In the private sector, there is a well-defined mechanism to capture this. However, in public sector, market feedback channels are limited. As a result, it is imperative that agricultural research evaluation needs to be oriented towards outcomes and impact evaluation.

Monitoring and Evaluation Framework for CRP GRAIN LEGUMES

As indicated earlier, the overall monitoring and evaluation system of GRAIN LEGUMES will be fully aligned with the monitoring principles of the CGIAR consortium. CRP 3.5 will generate a number of diverse outputs, including genetic and genomic resources, improved crop varieties, crop management technologies, information exchange, capacity building tools, and value added products along the value chain. These outputs, which are detailed in previous sections, should result in desired outcomes that ultimately lead to the intended impacts of reducing poverty and malnutrition, enhancing livelihood security, and reducing environmental degradation. A recent study of impact of legumes research in CGIAR (Tripp, 2011) has documented some of the major impacts of legume research by the centers, and will guide future impact studies.

Our priorities are based on suggestions in the CGIAR Strategy and Results Framework. Each partner will conduct their own internal M&E of agreed research activities. The Research Management Team (RMT) will have responsibility for ensuring that proposed outputs are delivered and that expected outcomes are successful. This will require formal, annual project evaluations, as well as mid-term and end-of-program reviews by independent experts including evaluation by end users (farmers) and consumers.

We also expect that the proposed R4D Advisory Panel (Chapter 10) will conduct focused short-term reviews and provide feedback. Given the breadth and scope of the CRP, additional experts will be commissioned to provide inputs into specific activities. These will be considered by the RMT and required adjustments will be made as needed in our research planning.

Some of the major indicators to be used for M&E include:

- Enhanced use of genetic resources and new sources of resistance to abiotic and biotic stresses, improved nutritional quality and productivity, and enhanced product quality including palatability and consumer acceptance available as international public goods.
- Cutting-edge scientific knowledge on genetics and genomics of legume crops published.
- Cultivars derived from IARC germplasm released by NARS and grown on a large-scale using

recommended crop management practices.

- Efficient private sector and informal seed production and delivery systems/models operating in target countries, supported by harmonized national and regional regulatory frameworks.
- Crop and region specific post-harvest technologies utilized in project regions to increase profitability.
- Novel and innovative value added products identified and pilot tested that increase the value capture by smallholder farmers;
- Capacity-building and technology delivery frameworks enhanced to facilitate farmers' access to validated technology such as quality seed of improved crop cultivars, crop management practices and other farm inputs.
- Farmer and consumer acceptance of final products; and
- Publication of peer reviewed research articles, curated data sets and learning materials in granulated form to support use in multiple contexts by the partners and stakeholders.

In addition, CRP GRAIN LEGUMES intends to incorporate into our evaluation learning processes tools that provide feedback loops so that lessons learned can be quickly adopted and incorporated in our research planning. M&E, while vital to our enterprise, is not an end in itself, but rather a part of a larger effort to help set realistic priorities that ultimately lead to impact in the field. Relating M&E to the value chain framework connects it to development drivers that can help reveal key bottlenecks to the uptake and impact of innovations. The impact pathway for the CRP Grain Legume (Figure 4.1) provides a simplified diagram of how CRP Grain Legume research objectives are expected to produce the outputs that will lead to desired outcomes on intended stakeholders (both immediate and final users) leading to impacts at the farm level and finally to regional and national level impacts. The monitoring and evaluation (M&E) framework is given in Table 13.1.

Measurable Results/Outputs

Some examples of measurable results are:

- An increase in profitability over the existing level (20%)
- Improvement in protein intake in diet or reduction in mal-nutrition (5-10%)
- Improvement in crop productivity (20%)
- Reduction in cost of production due to synergy effect such as atmospheric nitrogen fixation IPM, etc.
- Increasing seed replacement ratio (5-20%)
- Improvement in support services like credit, market and others
- Capacity building in production technology, post-harvest management and value addition (1500 households per target country)

Table 13.1. Monitoring and Evaluation (M&E) framework (process and performance indicators)

M&E Indicators	Type of output	Measurement	Method of M&E	Implementing Agency	Frequency	M&E Agency
Enhanced use of genetic resources and new sources of resistance to abiotic and biotic stresses and improved nutritional and product quality, and productivity	<ul style="list-style-type: none"> Well characterized germplasm Seed material 	<ul style="list-style-type: none"> No. of accessions screened and characterized Core and mini core sets Crop productivity and nutritional composition Consumer acceptance of product quality 	<ul style="list-style-type: none"> Field and laboratory inspection Collection of production data from test fields and research stations Feedback surveys of improved seed material recipients such as seed companies Review meetings with project scientist 	IARC NARS ARIs Private Sector	Seasonal & Annually	Implementing, Executing, & Independent
Leading edge scientific knowledge on genetics and genomics published	<ul style="list-style-type: none"> Publications Genomic databases Genetic maps 	<ul style="list-style-type: none"> Cultivars/varieties released at the regional and national level, Performance over time No. of scientific articles published books, reports, monographs. Website hits/downloads 	<ul style="list-style-type: none"> Analysis of data on performance of crop variety at different locations. Peer reviewed articles. Classification of publications by type, author, collaborator, citation index 	IARC NARS ARIs	Annually	Implementing & Executing

M&E Indicators	Type of output	Measurement	Method of M&E	Implementing Agency	Frequency	M&E Agency
Cultivars derived from IARC germplasm released by NARS and grown on a large scale along with recommended crop management practices	<ul style="list-style-type: none"> Cultivar seeds Crop management technology 	<ul style="list-style-type: none"> No. of improved cultivars released Effectiveness and cost of crop management practices/technologies recommended Productivity and returns per ha BC ratio Area covered and % of farmers adopting technologies 	<ul style="list-style-type: none"> Visits to field trails, farmers' field days and demonstration plots Focused farmers' group discussion GIS maps to track adoption based on data generated from adoption studies Baseline surveys in target regions Cost of cultivation surveys in target sites Initial adoption surveys Surveys/ FGD with farmers to gauge the adoption of crop management technologies 	IARC NARS NGOs	Quarterly	Implementing & Executing

M&E Indicators	Type of output	Measurement	Method of M&E	Implementing Agency	Frequency	M&E Agency
Efficient private sector and informal seed production and delivery systems/ models established and operating in each target country, supported by nationally reformed and regionally harmonized regulatory frameworks	<ul style="list-style-type: none"> • Availability of breeder, foundation and certified seed 	<ul style="list-style-type: none"> • Quantity of seed produced and distributed at right time, place, and at affordable price • Increased seed replacement ratio • Reduced transaction cost of seed distribution at agency and farmer levels 	<ul style="list-style-type: none"> • Field visits and inspection • Certification/Quality accreditation • Seed market surveys, number of dealer/agencies involved in seed supply • Surveys of informal seed systems in target sites • Common platform (workshops/ ground discussion) with multiple stakeholders regarding farmer perceptions and policy issues 	Private Sector CSOs NGOs NARS IARC	Semi-Annually	Implementing, Executing & Independent
Capacity building and technology delivery frameworks and options enhanced to facilitate farmers' access to validated technology such as quality seed of improved crop cultivars, crop management approaches and other farm inputs	<ul style="list-style-type: none"> • Enhanced capacity of human resources • Increased gender participation 	<ul style="list-style-type: none"> • No. of trainings organized • No. of partners/ collaborators/ clients trained • Dissemination of gained knowledge • Gender wise receptivity • Impact on farmers' fields due to capacity building 	<ul style="list-style-type: none"> • Review of capacity building activities • Interactive workshops/ meetings/opinion survey of beneficiaries • Survey of participants on knowledge gained through capacity building and its implementation on the ground. 	IARC NARS NGOs CSOs	Annually	Implementing, Executing & Independent

M&E Indicators	Type of output	Measurement	Method of M&E	Implementing Agency	Frequency	M&E Agency
Post-harvest technologies developed to increase the quality of grain	<ul style="list-style-type: none"> Post-harvest technology (threshing, cleaning, storing, etc.) 	<ul style="list-style-type: none"> Impact on farmers' incomes Reduction in post-harvest losses 	<ul style="list-style-type: none"> Field visits and inspection Survey of existing post-harvest technologies used Baseline surveys Estimates of reduction of post-harvest losses 	IARC NARS NGOs CSOs	Project Start & End	Implementing & Executing
Nutritious and novel value added products developed and promoted using innovative institutional linkages	<ul style="list-style-type: none"> Niche and novel products identified Pilot scale value chains operating in project regions 	<ul style="list-style-type: none"> Impact on farmers' incomes Impact on nutrition of target consumers 	<ul style="list-style-type: none"> Mapping of pilot scale value chains Consumer surveys 	IARC NARS NGOs CSOs	Project Start & End	Implementing & Executing
Publication of peer reviewed research articles, curated data sets and learning materials in highly granulated form to support use in multiple contexts by the partners and stakeholders	<ul style="list-style-type: none"> Publications Data sets Learning materials 	<ul style="list-style-type: none"> No. of peer reviewed articles, books, reports, monographs, policy briefs No. of users of curated datasets/ learning material 	<ul style="list-style-type: none"> Peer review Classification of publications by type, author, collaborator Citation index, and segregation by institution 	IARC NARS ARIs	Annually	Implementing & Executing
Impact analysis of new technology released	<ul style="list-style-type: none"> Data on impacts Reports on impacts 	<ul style="list-style-type: none"> Impact analysis using primary and secondary data Sustainability of technology released 	<ul style="list-style-type: none"> Economic impact analysis at farmer/ primary level 	IARC NARS NGOs	Project End	Implementing & Executing

14. Budget

The CRP 3.5 GRAIN LEGUMES budget for the first three-year phase has been developed following guidelines from the Consortium in terms of Window 1 and 2 funding and based on existing bilateral project funding for CIAT, ICARDA, ICRISAT, IITA and the GCP. Bilateral project activities and corresponding budgets were first allocated across the CRP outputs. Additional funding from Windows 1 and 2 were then allocated based on priorities and projected expenses for each output (for each crop in each region). Each output budget represents the requirements for CIAT, ICARDA, ICRISAT, IITA and the GCP and partners to be initially funded by CRP 3.5.

CRP 3.5 is projecting a budget of US\$ 139.1 million for the initial three-year period (Table 14.1). We are requesting that US\$ 61.6 million (44%) be provided from CGIAR Windows 1 and 2 (US \$57.0 million for research and US\$ 4.6 million for CRP management). The Year 1 Window 1 and 2 funding is based on the guidelines received at the time of the initiation of the CRP process. Window 1 and 2 funding in years 2 and 3, is based on a 5% increase over the previous year budget level. Additional funding will come from already secured bilateral projects (US\$ 44.0 million; 32%; see Appendix 9 for a list of the major bilateral projects included in the CRP). This leaves a current funding gap of US\$ 33.5 million (24%). The funding gap could be met by additional funds being allocated by the Fund Council through the Consortium to Windows 1 and 2, or by the CRP Centers seeking additional bilateral projects if such Window funding is not available. Note that the Generation Challenge Program (GCP) is not requesting financial support through the CRP but will continue to receive funds directly from CGIAR donors until 2013, as indicated in the GCP transition strategy, to ensure a smooth transition of its ongoing research activities and contractual obligations. GCP's financial support to CGIAR Centers is reported under their respective budget as secured bilateral funding and resources reported under GCP indicates funds allocated to non-CGIAR Center partners.

The CRP 3.5 GRAIN LEGUMES research budget (including gender research) represents 97% of the expenses and is based on projected research costs for each Strategic Objective Output (Table 14.2). The costs for each output represent the collective costs for CIAT, ICARDA, ICRISAT, IITA and the GCP. Note that funding for the genebank core activities, except identifying gaps, collecting and conducting training courses and developing germplasm subsets, described under Strategic Objective 1, Output 1.1 are provided from funds approved in the Genebank Funding proposal for CIAT, ICARDA, ICRISAT and IITA. Support for acquisition, conservation, distribution, and genebank data management is available from genebank funding (Table 14.2). A separate budget for gender research and analysis is indicated and more details provided below. For completeness, we have included the CRP management budget in the table.

Table 14.1. GRAIN LEGUMES Funding Budget (USD '000s)

Funding Source	Year 1	Year 2	Year 3	Total	
CIAT					
CGIAR Window 1 & 2: Research	3,600	3,780	3,969	11,349	33%
Bilateral Funding (secured)*	4,663	2,511	2,364	9,538	28%
Funding Gap	-	5,878	7,661	13,539	39%
Totals	8,263	12,169	13,994	34,426	100%
* includes Other Center Income					
ICARDA					
CGIAR Window 1 & 2: Research	3,330	3,496	3,671	10,497	65%
Bilateral Funding (secured)*	1,081	570	550	2,201	14%
Funding Gap	1,059	1,112	1,168	3,338	21%
Totals	5,470	5,178	5,389	16,037	100%
* includes Other Center Income					
ICRISAT					
CGIAR Window 1 & 2: Research	4,422	4,643	4,875	13,940	28%
Bilateral Funding (secured)*	8,429	6,920	3,843	19,192	39%
Funding Gap	-	5,873	10,792	16,665	33%
Totals	12,851	17,436	19,510	49,797	100%
* includes Other Center Income					
IITA					
CGIAR Window 1 & 2: Research	6,342	7,051	7,806	21,199	67%
Bilateral Funding (secured)*	3,433	3,598	3,260	10,291	33%
Funding Gap	-	-	-	-	-
Totals	9,775	10,649	11,066	31,490	100%
* includes Other Center Income					
Generation Challenge Program					
CGIAR Window 1 & 2: Research	-	-	-	-	-
Bilateral Funding (secured)*	1,020	1,029	691	2,740	100%
Funding Gap	-	-	-	-	-
Totals	1,020	1,029	691	2,740	100%
* includes Other Center Income					
TOTAL					
CGIAR Window 1 & 2: Research	17,694	18,970	20,321	56,986	41%
CGIAR Window 1 & 2: CRP Management	1,474	1,547	1,625	4,645	3%
Total CGIAR Window 1 & 2	19,167	20,518	21,946	61,631	44%
Bilateral Funding (secured)*	18,626	14,628	10,708	43,962	32%
Funding Gap	1,059	12,863	19,620	33,542	24%
Totals	38,852	48,008	52,274	139,135	100%
* includes Other Center Income					

Table 14.2. Budget by Strategic Objective (USD '000s)

	Year 1	Year 2	Year 3	Total	
SO1 Genetic resources and novel breeding methods/tools					
1.1 Genetic resources collected, conserved and made available *	404	434	453	1,291	1%
1.2 Genetic resources characterized and documented	1,347	1,570	1,644	4,561	3%
1.3 Novel and efficient breeding methods/tools	1,884	2,358	2,550	6,791	5%
1.4 Novel genes/traits accessed/mobilized	1,937	2,302	2,405	6,643	5%
Total Strategic Objective 1	5,572	6,664	7,052	19,287	14%
SO2 More productive and nutritious cultivars					
2.1 Lines with higher yield potential	2,670	3,187	3,438	9,295	7%
2.2 Lines with enhanced biotic and abiotic resistance	5,161	6,309	6,534	18,005	13%
2.3 Methods for targeting germplasm to niches	1,464	1,769	1,790	5,024	4%
2.4 Lines with enhanced nutritional composition	1,471	1,843	2,041	5,355	4%
2.5 Lines with enhanced nutrient use efficiency	1,877	2,266	2,662	6,805	5%
Total Strategic Objective 2	12,644	15,374	16,465	44,483	32%
SO3 Crop and pest management practices					
3.1 Strategies to optimize Biological Nitrogen Fixation	851	980	1,047	2,878	2%
3.2 Methods to increase productivity and profitability	836	995	1,077	2,909	2%
3.3 Tools and protocols for pest & disease management	1,864	2,289	2,398	6,551	5%
3.4 Strategies to adapt to climate change	1,214	1,408	1,673	4,255	3%
Total Strategic Objective 3	4,725	5,671	6,196	16,593	12%
SO4 Better access to seed					
4.1 Decentralized seed systems	2,818	3,813	4,103	10,734	7%
4.2 Capacity of public and private sector	1,101	1,397	1,673	4,171	3%
4.3 Enabling seed policies	701	861	940	2,502	2%
4.4 Framework for national seed security	794	993	1,090	2,877	2%
Total Strategic Objective 4	5,320	6,954	7,686	19,960	14%
SO5 Increasing value quality and capture					
5.1 Enhancing grain legume value chains	1,207	1,479	1,649	4,336	3%
5.2 Institutional innovations	631	695	765	2,091	2%
5.3 Value-adding products	676	830	904	2,409	2%
5.4 Drudgery/cost-saving small scale machinery	722	881	960	2,563	2%
Total Strategic Objective 5	3,236	3,885	4,278	11,399	8%
SO6 Partnerships, capacities and knowledge-sharing					
6.1 Partnership models	1,789	2,427	2,721	6,937	5%
6.2 Enhancing women's' and others' capacities	1,378	1,913	2,129	5,420	4%
6.3 Knowledge-sharing platforms	1,203	1,755	2,193	5,152	4%
Total Strategic Objective 6	4,371	6,095	7,044	17,509	13%
Total Strategic Objectives	35,868	44,642	48,721	129,231	93%
Gender Research & Analysis	1,512	1,818	1,930	5,260	4%
CRP Management	1,474	1,547	1,625	4,645	3%
Total Budget	38,853	48,008	52,276	139,135	100%

*NOTE: Genebank funding covers only acquisition, conservation, and distribution of germplasm and data management of genebank; it does not cover identification of gaps, collecting, conducting training programs and developing germplasm subsets

Each Strategic Objective and Output is based on projected research costs for each crop in each region. Table 14.3 presents the total expense budget by region and crop. Largest budget expenditure is targeted for bean in ESA, although significant funding for beans in LAC; chickpea, groundnut and pigeonpea in SSEA; cowpea and groundnut in WCA; and soybean in ESA is proposed.

Table 14.3. Total Three-Year CRP Research Budget by Region and Crop (USD '000s)

Strategic Objective	LAC	CWANA			SSEA			
	Bean	Chickpea	Faba Bean	Lentil	Chickpea	Groundnut	Lentil	Pigeonpea
SO1 Genetic resources and methods/tools	2,803	692	355	495	1,586	859	448	1,145
SO2 More productive and nutritious cultivars	3,289	1,519	838	1,112	4,176	2,242	1,194	2,987
SO3 Crop and pest management practices	1,377	402	305	366	1,230	748	281	996
SO4 Better access to seed	344	264	134	219	2,117	1,493	136	1,992
SO5 Increasing value quality and capture	-	92	55	79	1,016	748	32	996
SO6 Partnerships, capacities and knowledge-sharing	618	122	92	101	1,541	1,119	50	1,494
Total Strategic Objectives	8,431	3,091	1,779	2,372	11,667	7,209	2,142	9,610
Gender Research & Analysis	12	70	70	70	419	261	70	349
Total Research Budget	8,443	3,161	1,849	2,442	12,086	7,470	2,213	9,959
	6%	2%	1%	2%	9%	6%	2%	7%

Strategic Objective	WCA				ESA						
	Bean	Cowpea	Groundnut	Soybean	Bean	Cowpea	Chickpea	Faba Bean	Groundnut	Pigeonpea	Soybean
SO1 Genetic resources breeding methods/tools	72	2,888	994	1,260	1,008	315	917	447	621	572	1,889
SO2 More productive and nutritious cultivars	1,309	2,897	2,377	1,260	9,234	1,260	2,403	1,143	1,545	1,495	2,204
SO3 Crop and pest management practices	140	1,889	748	1,260	1,783	1,260	866	366	500	500	1,575
SO4 Better access to seed	-	1,417	1,493	945	3,725	945	1,141	183	997	997	1,417
SO5 Increasing value quality and capture	-	1,102	748	630	2,575	630	544	50	500	500	1,102
SO6 Partnerships, capacities and knowledge-sharing	492	1,021	1,134	630	5,182	630	794	55	748	742	945
Total Strategic Objectives	2,013	11,215	7,494	5,983	23,507	5,038	6,665	2,245	4,911	4,806	9,132
Gender Research & Analysis	8	706	276	315	1,335	315	244	70	180	174	315
Total Research Budget	2,021	11,921	7,770	6,298	24,842	5,353	6,909	2,315	5,091	4,980	9,447
	2%	9%	6%	5%	18%	4%	5%	2%	4%	4%	7%

Partners are critical for the success of CRP 3.5 GRAIN LEGUMES and a total of US\$ 20.8 million (15%) of the three-year budget has been allocated for them (Table 14.4). The budget for the Generation Challenge Program (GCP) is entirely designated for partners (non-CGIAR Centers). Several partners, especially EIAR, EMBRAPA, GDAR, ICAR and the USA Dry Grain Pulse CRSP will also make significant in-kind contributions to GRAIN LEGUMES. These institutes and/or programs have their own source of funding to support infrastructure, salaries and operational expenses. Through better coordination of efforts under the CRP, these opportunities will be tapped to greatly enhance the progress towards the goals of GRAIN LEGUMES. We will also work with each partner to help identify additional funding resources to support the work of partners in the CRP.

Table 14.4. Budget by Partner (USD '000s)

Partner	Year 1	Year 2	Year 3	Total	
CIAT	6,499	10,229	11,860	28,588	21%
ICARDA	5,055	4,786	4,980	14,822	11%
ICRISAT	11,145	15,122	16,920	43,187	31%
IITA	8,411	9,163	9,522	27,096	19%
GCP Partners	1,020	1,029	691	2,740	2%
Center Partners	5,249	6,132	6,676	18,057	13%
CRP Management	1,474	1,547	1,625	4,645	3%
Total Budget	38,852	48,008	52,274	139,135	100%

Personnel costs (scientific and technical salaries and supporting costs) represent the largest percentage of the budget (37%). Institutional management has been kept at 15%, while the CRP management is only 3% of total CRP costs (Table 14.5).

Table 14.5. Budget by Category (USD '000s)

Research	Year 1	Year 2	Year 3	Total	
Personnel Costs	14,186	17,717	19,345	51,248	37%
Supplies and Services	6,594	9,066	10,020	25,679	19%
Travel	2,567	3,012	3,273	8,852	6%
Workshops/Conferences/Training	799	884	1,195	2,878	2%
Capital Expenditures	1,107	1,308	1,420	3,836	3%
Partners	6,269	7,161	7,367	20,797	15%
Institutional Management	5,860	7,311	8,030	21,200	15%
CRP Management	1,474	1,547	1,625	4,645	3%
Total Budget	38,852	48,008	52,274	139,135	100%

Costs for gender research and analysis are budgeted separately and include scientists' time and operating expenses across the partners (Table 14.6). Approximately 4% (US\$ 5.3 million) of the total three-year budget has been specifically allocated for gender-related research. CIAT, ICRISAT and ICARDA have gender specialists who will devote approximately 35% time to GRAIN LEGUMES researching gender aspects of targeting, planning, design and implementation.

Table 14.6. Gender Research & Analysis Budget (USD '000s)

Partner	Year 1	Year 2	Year 3	Total
CIAT	367	460	488	1,315
ICARDA	156	164	172	492
ICRISAT	449	611	682	1,742
IITA	489	532	553	1,575
GCP	51	51	35	137
Total Gender Research Budget	1,512	1,818	1,930	5,261

Given the need to effectively manage the CRP across all partners, including a number of non-CGIAR partners, a specific budget for CRP management is proposed (Table 14.7). The budget includes costs (salaries, travel and operations) for the CRP Director (1.0 FTE), 6 Strategic Objective Coordinators (0.5 FTE each), the Program Management Unit (1.0 FTE administrative, 1.0 FTE communications, 0.5 FTE financial and 0.5 FTE HR managers), Research Management Team meetings twice each year, and travel and honoraria costs for R4D Advisory Committee members to meet twice each year. The total management budget is 3% of the total CRP budget for the three-year period.

Table 24.7. CRP Management Budget (USD '000s)

Category	Year 1	Year 2	Year 3	Total	
CRP Director (salary, travel, operations)	280	294	309	883	19%
Strategic Objective Coordinators (salaries, travel, operations)	768	806	847	2,421	52%
Program Management Unit (salaries, operations)	208	218	229	656	14%
Research Management Team (travel, operations)	128	134	141	402	9%
Independent Advisory Committee (honorarium, travel, operations)	90	95	99	284	6%
Total CRP Management Budget	1,474	1,547	1,625	4,645	100%

List of References

- ACC/SCN. 2004. Fifth report on the World Nutrition Situation. Nutrition for improved development outcomes. United Nations Standing Committee on Nutrition. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.
- Acosta-Gallego JA, Kelly JD and Gepts P. 2007. Prebreeding in common bean and uses of genetic diversity from wild germplasm. *Crop Science* 47(S3): S44-S59.
- Adrian Montanez. 2000. Overview and case studies on biological nitrogen fixation: Perspectives and Limitations: Work prepared for FAO. Available at: <http://www.fao.org/ag/agl/agll/soilbiod/cases/caseB1.pdf> downloaded on 9th July 2011.
- Adu-Gyamfi JJ, Myaka FA, Sakala WD, Odgaard R, Vesterager JM and Høgh-Jensen H. 2007. Biological nitrogen fixation and phosphorus budgets in farmer-managed intercrops of maize-pigeonpea in semi-arid southern and eastern Africa. *Plant and Soil* 295: 127-136.
- Agunbiade T, Steele L, Coates B, Gassmann A, Margam V, Ba M, Dabiré-Binso C, Baoual, Bello-Bravo J, Seufferheld F, Sun W, Tamò M and Pittendrigh B. 2011. IPM-Omics: from genomics to extension for integrated pest management of cowpea. Paper presented at the 5th world cowpea conference, 26 Sep-2 Oct 2010, Saly, Dakar, Senegal.
- Ajeigbe HA, Oseni TO and Singh BB. 2006. Effect of planting pattern, insecticide application and crop variety on the productivity of cowpea-cereal systems in northern Guinea savanna of Nigeria. *Journal of Food, Agricultural and Environment* 4: 101-107.
- Akibode S and Maredia M. 2011. Global and regional trends in production, trade and consumption of food legume crops. Report Submitted to CGIAR Special Panel on Impact Assessment, 27 March 2011. 83 pp. <http://impact.cgiar.org/sites/default/files/images/Legumetrendsv2.pdf>
- Alene A and Manyong V. 2006b. Farmer-to-farmer technology diffusion and yield variation among adopters: the case of improved cowpea in northern Nigeria. *Agricultural Economics* 35: 203-211.
- Alene A and Manyong V. 2007. Gains from high yielding varieties with and without complimentary technology: The case of improved cowpea in northern Nigeria. *Journal of Agricultural and Food Economics* 2: 1-14.
- Alene AD, Coulibaly, O and Abdoulaye T. 2012. The world cowpea and soybean economies: Facts, trends, and outlook. Lilongwe, Malawi: International Institute of Tropical Agriculture.
- Alene AD, Manyong VM, Tollens E and Abele S. 2009. Efficiency–equity tradeoffs and the scope for resource reallocation in agricultural research: evidence from Nigeria. *Agricultural Economics* 40: 1-14.
- Ali M, Joshi PK, Pande S, Asokan M, Virmani SM, Kumar R and Kandpal BK. 2000. Legumes in the Indo-Gangetic Plain of India. Pages 35-70 in *Legumes in Rice and Wheat Cropping Systems of the Indo-Gangetic Plain-Constraints and Opportunities* (Johansen C, Duxbury JM, Virmani SM, Gowda CLL, Pande S and Joshi PK. eds.). ICRISAT, Patancheru and Cornell University, New York, Ithaca.
- Ali MAM, El Tinay AH, Mohamed Ahmed IA and Babiker EE. 2009. Supplementation of pearl millet with soybean: Changes in protein digestibility, amino acid composition and sensory quality during processing. *Electronic Journal of Environmental, Agricultural and Food Chemistry* 8(11):1068-1076. ISSN: 1579-4377.
- Almekinders CJM, Thiele G and Danial LD. 2007. Can cultivars from participatory plant breeding improve seed provision to small-scale farmers? *Euphytica* 153: 363-372.
- Alschul SF, Gish W, Miller W, Myers EW and Lipman DJ. 1990. Basic local alignment search tool. *Journal of Molecular Biology* 215: 403-410.
- Alston JM, Norton GW and Pardey PG. 1995. *Science under scarcity: principles and practice for agricultural evaluation and priority setting*. Cornell University Press, New York.
- Alves BJR, Boddy RM and Urquiaga S. 2003. The success of BNF in soybean in Brazil. *Plant and Soil* 252: 1-9.
- Amede T and Kirkby R. 2004. Guidelines for Integration of legumes into the farming systems of East African Highlands. Pages 43-64 in *Managing nutrient cycles to sustain soil fertility in Sub-Saharan Africa* (Bationo A ed.). Academic Science Publishers.
- Ampire E, Karia S and Njuki J. 2008. PABRA capacity assessment report. Unpublished research report.
- ASARECA's Strategic Plan 2006-2015. Agricultural Research-for-Development in Eastern and Central Africa.
- Aw-Hassan A, Regassa S, Islam Q and Sarker A. 2009. The impact of improvement research. The case of Bangladesh and Ethiopia. In: *The Lentil. Botany Production and Uses* (Erskine W, Muehlbauer F, Sarker A and Sharma B. eds.), Wallingford, UK: CABI.
- Aw-Hassan A, Shideed K, Sarker A, Tutwiler R and Erskine W. 2003. Economic impact of international and national lentil improvement research in developing countries. Pages 275-291 in *Crop variety improvement and its effect on productivity: The impact of international agricultural research* (Evenson RE and Gollin D. eds.). CABI, Wallingford, UK. 522 pp.
- Ayappan S. 2011. Slide #56 at <http://www.icar.org.in/files/Dg-Presentation-83rd-ICAR-Foundation-Day.pdf>

- Ba NM, Margam VM, Dabire-Binso CL, Sanon A, McNeil J, Murdock LL and Pittendrigh BR. 2009. Seasonal and regional distribution of the cowpea pod borer, *Maruca vitrata* Fabricius (Lepidoptera: Crambidae), in Burkina Faso. *International Journal of Tropical Insect Science* 29(3): 109-113.
- Badiger C, Hasalkar S and Huilgol S. 2004. Drudgery of farm women in agriculture and animal husbandry operations. *Karnataka Journal of Agricultural Sciences* 17: 787-790.
- Bado BV, Bationo A and Cescas MP. 2006. Assessment of cowpea and groundnut contributions to soil fertility and succeeding sorghum yields in the Guinean savannah zone of Burkina Faso (West Africa). *Biology and Fertility of Soils* 43: 171-176.
- Bantilan M and Parthasarathy D. 1999. Efficiency and sustainability gains from adoption of short-duration pigeonpea in nonlegume-based cropping systems, Patancheru 502 324, Andhra Pradesh, India: ICRISAT.
- Bantilan MCS and Joshi PK. 1996. Returns to research and diffusion investments on wilt resistance in pigeonpea. *Impact Series No. 1*. Hyderabad, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). 30 pp.
- Bationo A, Waswa B, Okeyo JM, Maina F, Kihara J and Mokwunye U (eds.). 2011. *Fighting poverty in Sub-Saharan Africa: The multiple roles of legumes in integrated soil fertility management*. 1st Edition. 350 pp.
- Bayuelo-Jiménez JS, Debouck DG and Lynch JP. 2002. Salinity tolerance in Phaseolus species during early vegetative growth. *Crop Science* 42: 2184-2192.
- Bazzalupo M and Fani R. 1995. The use of RAPD for generating specific DNA probes for microorganisms. Pages 112-124 in *Methods in molecular biology, species diagnostic protocols: PCR and other nucleic acid methods* (Clap JP. ed.). Humana Press Inc, Totowa NJ, USA.
- Beebe S, Gonzalez AV and Rengifo J. 2000. Research on trace minerals in the common bean. *Food and Nutrition Bulletin* 21: 387-391.
- Beebe S, Lynch J, Galwey N, Tohme J and Ochoa I. 1997. A geographical approach to identify phosphorus-efficient genotypes among landraces and wild ancestors of common bean. *Euphytica* 95: 325-336.
- Beebe S, Ramirez J, Jarvis A, Rao IM, Mosquera G, Bueno GM and Blair M. 2011. Genetic improvement of common beans and the challenges of climate change. Pages 356-369 in *Crop adaptation to climate change* (Yadav SS, Redden RJ, Hatfield JL, Lotze-Campen H and Hall AE. eds.). John Wiley & Sons, Ltd., Published by Blackwell Publishing Ltd, Richmond, Australia.
- Beebe S. 2012. Breeding common bean for the tropics. *Plant Breeding Review* (in press).
- Beebe SE, Rao IM, Cajiao C and Grajales M. 2008. Selection for drought resistance in common bean also improves yield in phosphorus limited and favorable environments. *Crop Science* 48: 582-592.
- Bekunda MA, Bationo A and Sali H. 1997. Soil fertility management in Africa. A review of selected research trials. Pages 63-80 in *Replenishing soil fertility in Africa* (Buresh RJ, Sanchez PA and Calhoun F. eds.). Soil Science Society of America Special Publication No. 51. Madison, Wisconsin, USA.
- Bernsten RH, Donovan C, Kiala D, Mazuze F and Rosas JC. 2009. Expanding pulse supply and demand in Africa and Latin America: Identifying constraints and new strategies. Pages 31-36 in *Dry Grain Pulses Collaborative Research Support Program (CRSP) 2009 Technical Highlights*. East Lansing: Michigan State University. <http://www.pulsecrsp.msu.edu/Publications/FY2009TechnicalReports/tabid/139/Default.aspx>.
- Bhatia VS, Singh P, Wani SP, Kesava Rao AVR and Srinivas K. 2006. Yield gap analysis of soybean, groundnut, pigeonpea and chickpea in India using simulation modeling. *Global Theme on Agro-ecosystems, Report no. 31*. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). 156 pp.
- Bhatnagar-Mathur P, Devi J, Lavanya M, Vadez V, Serraj R, Yamaguchi-Shinozaki K and Sharma KK. 2007. Stress-inducible expression of At DREB1A in transgenic peanut (*Arachis hypogaea* L.) increases transpiration efficiency under water-limiting conditions. *Plant Cell Reports* 26: 2071-2082.
- Bhullar NK, Street K, Mackay M, Yahiaoui N and Keller B. 2009. Unlocking wheat genetic resources for the molecular identification of previously undescribed functional alleles at the Pm3 resistance locus. *Proceedings of the National Academy of Sciences* 106: 9519-9524.
- Birthal PS, Nigam, SN, Narayanan AV and Kareem KA. 2011. An economic assessment of the potential benefits of breeding for drought tolerance in Crops: A case of groundnut in India. *Research Bulletin no. 25*, ICRISAT, Patancheru 502 324, Andhra Pradesh, India.
- Birthal PS, Parthasarathy Rao P, Nigam SN, Bantilan MCS and Bhagavatulu S. 2010. Groundnut and soybean economies in Asia: Facts, trends and outlook. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 92 pp.
- Bishaw Z and van Gastel AJG. 2008. ICARDA's approach to seed delivery in less favorable areas through village-based seed enterprises: conceptual and organizational issues. *Journal of New Seeds* 9: 68-88.
- Bishaw Z, Makkawi M and Niane A. 2009. Seed quality and alternative seed delivery systems. In: Erskine W, Muehlbauer F, Sarker A and Sharma B. (eds.). *The Lentil. Botany Production and Uses*, Wallingford, UK: CABI.
- Bishaw Zewdie, van Gastel AJ and Bill R Gregg. 2008. Sustainable Seed Production of Cool Season Food Legumes in CWANA Region. Pages 231-257 in *Proceedings of the fourth International Food Legumes Research Conference (IFLRC-IV)*, (Kharkwal MC. ed.). 18-22 October 2005, New Delhi, India, ISGPP, New Delhi, India.

- Bohra A, Mallikarjuna N, Saxena KB, Upadhyaya H, Vales MI and Varshney R. 2011. Harnessing the potential of crop wild relatives through genomics tools for pigeonpea improvement. *Journal of Plant Biology* 37: 83-98.
- Bonabana-Wabbi J. 2002. Assessing factors affecting adoption of agricultural technologies: The case of integrated pest management (IPM) in Kumi District, eastern Uganda. Unpublished MS thesis, Virginia Polytechnic Institute and State University.
- Bond DA, Lawes DA, Hawtin GC, Saxena MC and Stephens JS. 1985. Faba Bean (*Vicia faba* L.). Pages 199-265 in Grain legume crops (Summerfield RJ and Roberts EH. eds.). William Collins Sons Co. Ltd. 8 Grafton Street, London, W1X 3LA, UK.
- Bongaarts, J. 2001. Household size and composition in the developing world in the 1990s. *Population Studies* 55: 263-279.
- Bourgault M and Smith DL. 2010. Comparative study of common bean (*Phaseolus vulgaris* L.) and mung bean (*Vigna radiata* (L.) Wilczek) response to seven watering regimes in a controlled environment. *Crop and Pasture Science* 11: 918.
- Boys K, Faye M, Fulton J and Lowenberg-DeBoer J. 2007. The economic impact of cowpea research in Senegal: an *ex-post* analysis with disadoption. *Agricultural Economics* 36(3): 363-375.
- Broughton WJ, Hernandez G, Blair MW, Beebe SE, Gepts P and Vanderleyden J. 2003. Beans (*Phaseolus* spp.) – Model Food Legumes. *Plant and Soil* 252: 55-128.
- Bumb BL, Johnson M and Fuentes PA. 2011. Policy options for improving regional fertilizer markets in West Africa. IFPRI Discussion Paper 01084, May 2011. Table 3.1. Washington DC: International Food Policy Research Institute. 73 pp.
- Burslem C. 2004. Obesity in Developing Countries: People are overweight but still not well nourished. <http://www.ifpri.org/pubs/newsletters/ifpriforum/if200410.htm>.
- Buruchara AR, Chirwa R, Sperling L, Mukankusi C, Rubyogo JC, Muthoni R and Abang MM. 2011. Development and delivery of bean varieties in Africa: The Pan–Africa Bean Research Alliance (PABRA) model. *African Crop Science Journal* 19: 227-245.
- Butare L, Rao IM, Lepoivre P, Polania J, Cajiao C, Cuasquer JB and Beebe S. 2011. New sources of resistance in *Phaseolus* species to individual and combined aluminium toxicity and progressive soil drying stresses. *Euphytica* DOI 10.1007/s10681-011-0468-0. (In press).
- Byerlee D and White R. 1997. Agricultural systems intensification and diversification through food legumes: technological and policy options. Presented at the III International Food Legumes Research Conference, 22-26 Sep 1997, Adelaide, Australia.
- Catroux G, Hartmann A and Revellin C. 2001. Trends in rhizobial inoculant production and use. *Plant and Soil* 230: 21-30.
- Caviglia OP, Sadras VO and Andrade FH. 2004. Intensification of agriculture in the Southeastern Pampas. In Capture and efficiency in the use of water and radiation in double-cropped wheat-soybean. *Field Crops Research* 87: 117-129.
- Central Statistics Agency (CSA)/MoARD-Ethiopia. 2010. Agricultural Sample Survey Reports on Farm Management Practices for various years: 2003-2010.
- CGIAR. 2011. A Strategy and Results Framework for the CGIAR. 180 pp. <http://consortium.cgxchange.org/home/strategy-and-results-framework>
- Chamango AMZ. 2001. Improving grain yield of smallholder cropping systems: a farmer participatory research (FPR) approach with legumes for soil fertility improvement in central Malawi. Seventh eastern and southern Africa regional maize conference, pp 413-417.
- Chandrashekar G. 2011. Will India Repeat Bumper Harvest of Pulses. *PulsePoint Magazine* (June 2011):36-37. Saskatoon, Saskatchewan, Canada: Saskatchewan Pulse Growers. http://www.saskpulse.com/media/pdfs/Will_India_Repeat_Bumper_Harvest_of_Pulses.pdf
- Chen W, Sharma, HC and Muehlbauer F (eds.). 2011. Chickpea and lentil crop protection compendium. American Phytopathological Society, St Paul, Minnesota, USA. 164 pp.
- Chirwa RM, Aggarwal VD, Phiri MAR and Mwenda ARE. 2007. Experiences in Implementing the Bean Seed Strategy in Malawi. *Journal of Sustainable Agriculture* 29(2): 43-69.
- Christian H, Schweizer A, Kuhnhold V and Sikora RA. 2010. Remote sensing for the detection of soil-borne plant parasitic nematodes and fungal pathogens. In: Precision crop protection- the challenge and use of heterogeneity (Oerke EC et al. eds.). Springer Science + Business Media, Dordrecht, The Netherlands.
- CIAT. 2008. The impact of improved bush bean varieties in Uganda. Highlights. CIAT in Africa, no. 43. Kampala: CIAT.
- Clansey B. 2009. World Pulse Outlook: Report to the Saskatchewan Pulse Growers. Stat Publishing, September 2009.
- Clark KW, Brockwell J and Thompson JA. 1988. Role of inoculants in improving nitrogen fixation in legumes. In: Collaborative maize breeding strategies in the subcontinent. *Euphytica* 145: 123-132.
- Copenhaver GP and Preuss D. 2010. Haploidy with histones. *Nature Biotechnology* 28: 423-424.
- Correa P. 1981. Epidemiological correlations between diet and cancer frequency. *Cancer Research* 41: 3685-3689.
- Coulbaly O, Alene AD, Abdoulaye T, Chianu C, Manyong V, Aitchedji C, Fatokun D, Kamara A, Ousmane B, Tefera H and Boahen S. 2010. Baseline assessment of cowpea breeding and seed delivery efforts to enhance poverty impacts in sub-Saharan Africa. In collaboration with NARS from Mali, Niger, Nigeria, Tanzania, Malawi, Kenya and Mozambique. Tropical Legumes II Project report at <http://www.icrisat.org/what-we-do/imp/imp/imp/projects/tl2-publications/research-reports/rr-cwp-sbean.pdf>

- Coulibaly O, Mbila D, Sonwa DJ, Adesina A and Bakala J. 2002. Responding to economic crisis in Sub-Saharan Africa: new farmer developed pest management strategies in cocoa-based plantation in Southern Cameroon. *Integrated Pest Management Reviews* 7: 165-172.
- Crawford Eric W, Jayne TS and Valerie A Kelly. 2006. Alternative approaches for promoting fertilizer use in Africa: Agriculture and Rural Development Discussion Paper 22. World Bank, Washington, DC, USA.
- Crews TE and Peoples MB. 2005. Can the synchrony of nitrogen supply and crop demand be improved in legume and fertilizer-based agroecosystems?: A review. *Nutrient Cycling Agroecosystems* 72: 101-120.
- CRSP. 2010. http://pulsecrsp.msu.edu/pulsecrsp/projects/uiuc_1
- Cubero JI. 1974. On the evolution of *Vicia faba* L. *Theoretical and Applied Genetics* 45: 47-51.
- Cutforth HW, McGinn SM, McPhee KE and Miller PR. 2007. Adaptation of pulse crops to the changing climate of the Northern Great Plains. *Agronomy Journal* 99: 1684-1699.
- Dadi L, Regassa S, Fikre A, Mitiku D, Gaur P, Gowda C and Bantilan M. 2005. Adoption studies on improved chickpea varieties in Ethiopia. Addis Ababa and Patancheru: EIAR and ICRISAT.
- Dar WD, Winslow M, Abate T and Mgonja M. 2010. Food vs. cash crops—what should be the balance? Paper presented at The Nippon Foundation Borlaug Symposium, UN Conference Centre, Addis Ababa, Ethiopia, 13-14 July 2010. http://www.nippon-foundation.or.jp/eng/speeches/_20100713BorlaugSymposium.html Paper available from ICRISAT, Patancheru, India. 6 pp.
- David S and Sperling L. 1999. Improving technology delivery mechanisms: lessons from bean seed systems research in Eastern and Central Africa. *Agriculture and Human Values* 6: 381-388.
- David S, Kirkby R. and Kasozi S. 2000. Assessing the impact of bush bean varieties on poverty reduction in sub-Saharan Africa: Evidence from Uganda. Network on Bean Research in Africa, Occasional Publications Series No. 31. Kampala, Uganda: CIAT. 31 pp.
- David S, Mukandala L and Mafuru J. 2002. Seed availability, an ignored factor in crop varietal adoption studies: a case study of beans in Tanzania. *Journal of Sustainable Agriculture* 21: 5-20.
- David S. 1997. Dissemination and adoption of new technology: A review of experiences in bean research in Eastern and Central Africa, 1992-1996. Network of Bean Research in Africa Occasional Publications Series No. 21, CIAT: Kampala.
- DeGroot H, Vanlauwe B, Rutto E, Odhiambo G, Kanampiu F and Khan Z. 2010. Economic analysis of different options in integrated pest and soil fertility management in maize systems of Western Kenya. *Agricultural Economics* 41: 471-482.
- Delannay X, McLaren G and Ribaut JM. 2011. Fostering molecular breeding in developing countries. *Molecular Breeding* DOI 10.1007/s11032-011-9611-9.
- Devi JM, Sinclair TR and Vadez V. 2010. Genotypic variability among peanut (*Arachis hypogaea* L.). In: Sensitivity of nitrogen fixation to soil drying. *Plant and Soil* 330: 139-148.
- Diallo M. 2009. Diagnostic study of farmers' seed quality and variety preferences in southern Mali. Unpublished PhD dissertation, Michigan State University.
- Dionissios P Kalivas, Garifalia Economou and Christos E Vlachos. 2010. Using geographic information systems to map the prevalent weeds at an early stage of the cotton crop in relation to abiotic factors. *Phytoparasitica* 38: 299-312.
- Dixon J and Gulliver A. 2001. Farming systems and poverty: improving farmers' livelihoods in a changing world Rome: FAO. ISBN: 9251046271.
- Douthwaite B, Alvarez BS, Cook S, Davies R, George P, Howell J, Mackay R and Rubiano J. 2007. Participatory impact pathways analysis: a practical application of program theory in research-for development. *Canadian Journal of Program Evaluation* 22: 127-159.
- Doyle JJ and Luckow MA. 2003. The Rest of the iceberg. Legume diversity and evolution in a phylogenetic context. *Plant Physiology* 131: 900-910.
- Duke SO. 2005. Taking stock of herbicide-resistant crops ten years after introduction. *Pest Management Science* 61: 211-218.
- Dwivedi SL, Jambunathan R, Nigam SN, Raghunath K, Shankar KR and Nagabhushanam GVS. 1990. Relationship of seed mass to oil and protein contents in peanut (*Arachis hypogaea* L.). *Peanut Science* 17(2): 48-52.
- Ehlers JD and Hall AE. 1997. Cowpea (*Vigna unguiculata* L. Walp). *Field Crops Res.* 53: 187-204.
- Ejigui J, Savoie L, Marin J and Desrosiers T. 2007. Improvement of the nutritional quality of a traditional complementary porridge made of fermented yellow maize (*Zea mays*): Effect of maize-legume combinations and traditional processing methods. *Food and Nutrition Bulletin* 28(1): 23-34.
- Ekesi S. 1999. Insecticide resistance in field populations of the legume pod-borer, *M. vitrata*, Fabricius (Lepidoptera: Pyralidae), on cowpea, *Vigna unguiculata* (L.), Walp in Nigeria. *International Journal of Pest Management* 45: 57-59.
- El-Bouhssini M, Street K, Amri A, Mackay M, Ogonnaya FC, Omran A, Abdalla O, Baum M, Dabbous A and Rihawi F. 2010. Sources of resistance in bread wheat to Russian wheat aphid (*Diuraphis noxia*) in Syria identified using the Focused Identification of Germplasm Strategy (FIGS). *Plant Breeding* 130: 96-97.

- El-Bouhssini M, Street K, Joubi A, Ibrahim Z and Rihawi F. 2009. Sources of wheat resistance to Sunn pest, *Eurygaster integriceps* Puton, in Syria. *Genetic Resources and Crop Evolution* 56: 1065-1069.
- Elboutahiri N, Thami-Alami I, Zaïd E and Udupa SM. 2009. Genotypic characterization of indigenous *Sinorhizobium meliloti* and *Rhizobium sullae* by rep-PCR, RAPD and ARDRA analyses. *African Journal of Biotechnology* 8: 979-985.
- Erskine W, Muehlbauer F, Sarkar A and Sharma G (eds.). 2009. *The Lentil. Botany Production and Uses*, Wallingford, UK: CABI.
- Erskine W, Rihaw S and Capper BS. 1990. Variation in lentil straw quality. *Animal Feed Science and Technology* 28: 61-69.
- Erskine W, Sarker A and Kumar S. 2011. Crops that feed the world 3. Investing in lentil improvement toward a food secure world. *Food Security* 3(2): 127-139. DOI 10.1007/s12571-011-0124-5.
- FAO. 1995. Sustainable dry land cropping in relation to soil productivity—FAO soils bulletin, vol 72. Food and Agriculture Organization, Rome, Italy.
- FAO. 2005. Food and Agriculture Organization of the United Nations. FAO Stat statistical database. <http://faostat.fao.org/default.htm>.
- FAO. 2006. Quality Declared Seed. FAO Plant Production and Protection Paper 185. PP243. Publishing Management Service, Information Division, FAO, Viale delle Terme di Caracalla, 00100 Rome, Italy.
- FAO. 2007a. Gender and food security. Synthesis Report of Regional Documents: Africa, Asia and Pacific, Europe, Near East, Latin America. FAO, Rome, Italy.
- FAO. 2007b. Women and Food Security. FAO, Rome, Italy.
- FAO. 2008. State of food insecurity in the world. High food prices and food security – threats and opportunities.
- FAO. 2009. FAOSTAT database, Food and Agriculture Organization, Rome, Italy, <http://faostat.fao.org>.
- FAO. 2010. 2000 World Census of Agriculture: Main Results and Metadata by Country (1996-2005), FAO Statistical Development Series 12. Food and Agriculture Organization of the United Nations, Rome, Italy.
- FAO. 2010. FAOSTAT database, Food and Agriculture Organization, Rome, Italy, <http://faostat.fao.org>
- FAOSTAT, 2008.
- Feed the Future 2010. The US Government's Global Hunger and Food Security Initiative. Country Strategic Review papers. <http://www.feedthefuture.gov/countries>
- Feldstein 1998. An inventory of gender-related research and training in the consultative group on international agricultural research (CGIAR) centers 1996-1998. At <http://www.PRGA.POGRAM.ORG> accessed on 20 July 2011.
- Ferris S and Kaganzi E. 2008. Evaluating market opportunities for haricot beans in Ethiopia. IPMS (Improving Marketing Success) of Ethiopian Farmers Project Working Paper 7. ILRI (International Livestock Research Institute), Nairobi, Kenya. 68 pp.
- FIDA. 2001. Reflexiones Metodológicas sobre Seguimiento y Evaluación de Proyectos. Unidad de Publicación del FIDA. 164 páginas.
- Food Agriculture and Natural Resource Policy Analysis Network. 2011. Harmonized Seed Security Project. 2010 Annual report Pg. 6 – Pretoria, South Africa.
- Foster-Powell K, Holt SHA and Brand-Miller JC. 2002. International table of glycemic index and glycemic load values. *American Journal of Clinical Nutrition* 76: 5-56.
- Fowler RM. 2000. Animal-drawn herbicide applicators for use in small-scale farmer weed control systems. In *Animal power for weed control: A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA)*, (Starkey P and Simalenga T. eds.). Wageningen, The Netherlands; Technical Centre for Agricultural and Rural Cooperation (CTA). ISBN 92-9081-136-6. <http://www.atnesa.org>.
- Frankel OH. 1984. Genetic perspective of germplasm conservation. Pages 161-170 in *Genetic manipulations: impact on man and society* (Arber W, Limensee K, Peacock WJ and Stralinger P. eds.). Cambridge, UK: Cambridge University Press.
- Fridman E, Carrari F, Liu Y-S, Fernie AR and Zamir D. 2004. Zooming in on a quantitative trait for tomato yield using interspecific introgressions. *Science* 305: 1786-1789.
- Funk C, Dettlinger MD, Michaelsen JC, Verdin JP, Brown ME, Barlow M and Hoell A. 2008. Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. *Proceedings of the National Academy of Sciences* 105: 11081-11086.
- Gates Foundation 2011. Agricultural development strategy overview. Global Development Program, August 2011. <http://www.gatesfoundation.org/agriculturaldevelopment/Documents/agricultural-development-strategy-overview.pdf>
- Gaur PM, Gour VK and Srinivasan S. 2008. An induced brachytic mutant of chickpea and its possible use in ideotype breeding. *Euphytica* 159: 35-41.
- Gaur PM, Gowda CLL, Knights EJ, Warkentin TD, Acikgoz N, Yadav SS and Kumar J. 2007. Chapter 19: Breeding Achievements. Pages 391-416 in *Chickpea Breeding and Management* (Yadav SS, Redden B, Chen W and Sharma B, eds.), CABI, UK.
- Gaur PM, Krishnamurthy L and Kashiwagi J. 2008. Improving drought-avoidance root traits in chickpea (*Cicer arietinum* L.): Current status of research at ICRISAT. *Plant Production Science* 11: 3-11.

- Gepts P. 2006. Plant genetic resources conservation and utilization: the accomplishments and future of a societal insurance policy. *Crop Science* 46: 2278-2292.
- Gepts P, Beavis WD, Brummer EC, Shoemaker RC, Stalker HT, Weeden NF and Young ND. 2005. Legumes as a model plant family. *Plant Physiology* 137: 1228-1235.
- Ghosh S, Suri D and Jaury R. 2012. Assessment of protein adequacy in developing countries: Quality matters. *British Journal of Nutrition* (in press).
- Giller KE and Dashiell KE. 2006. Glycine max (L.) Merr. In: *Plant Resources of Tropical Africa 1. Cereals and Pulses* (Brink M and Belay G. eds.), 76-82, PROTA Foundation, Wageningen, Netherlands/Backhuys Publishers, Leiden, Netherlands/CTA, Wageningen, Netherlands.
- Giller KE. 2001. Nitrogen fixation in tropical cropping systems. CAB International, Wallingford, U.K. pp. 56-92.
- Giller, K. 2009. Putting nitrogen fixation to work for smallholder farmers in Africa (N2fixAfrica). Proposal to the Bill & Melinda Gates Foundation. Wageningen, The Netherlands: Wageningen University. 68 pp.
- Glaszmann JC, Kilian G, Upadhyaya HD and Varshney RK. 2010. Accessing genetic diversity for crop improvement. *Current Opinion in Plant Biology* 13: 167-173.
- Goergen E, Chambers JC and Blank R. 2009. Effects of water and nitrogen availability on nitrogen contribution by the legume, *Lupinus argentsus* Pursh. *Applied Soil Ecology* 42: 200-208.
- Gómez LA, Vadez V, Hernández G, Sánchez T, Toscano V and Sánchez M. 2002. Evaluación de la Tolerancia al estrés de fósforo en caupí (*Vigna unguiculata* L. Walp) en Cuba. I. Cultivo en Solución Nutritiva. *Agronomía Mesoamericana* 13: 59-65.
- Gopalan C, Rama Sastri BV and Balasubramanian SC. 2004. Nutritive value of Indian foods. National Institute of Nutrition, Hyderabad, Andhra Pradesh, India.
- Gowda CLL and Gaur PM. 2004. Global scenario of chickpea research present status and future thrusts. Pages 1-22 in *Pulses in New Perspective* (Masood Ali, Singh BB, Shiv Kumar and Vishwa Dhar, eds.). Indian Society of Pulses Research and Development, IIPR, Kanpur, India. 543 pp.
- Gowda CLL, Upadhyaya HD, Dronavalli N and Singh S. 2011. Identification of large-seeded high-yielding stable kabuli chickpea germplasm lines for use in crop improvement. *Crop Science* 51: 198-209.
- Graham PH and Vance CP. 2003. Legumes: Importance and constraints to greater utilization. *Plant Physiology* 131: 872-877.
- Grichar WJ, Besler BA and Jaks AJ. 1998. Peanut (*Arachis hypogaea* L.) cultivar response to leaf spot disease development under four disease management programs. *Peanut Science* 25: 35-39.
- Grings EE, Tarawali SA, Blummel M, Musa A, Fatokun C, Hearne S and Boukar O. 2012. Cowpea in evolving livestock systems. In: *Improving livelihoods in the cowpea value chain through advancement in science. Proceedings of 5th World Cowpea Research Conference 2010*, Saly, Senegal.
- Grisley W and Shamambo M. 1993. An analysis of the adoption and diffusion of carioca beans in Zambia resulting from an experimental distribution of seed. *Experimental Agriculture* 29: 379-386.
- Grzywacz D, Richards A, Rabindra RJ, Saxena H and Rupela OP. 2005. Efficacy of biopesticides on natural plant products on *Heliothis/Helicoverpa* control. Pages 371-389 in *Heliothis/Helicoverpa management-emerging trends and strategies for future research* (Sharma HC. ed.). New Delhi, Oxford & IBH.
- Gwata ET, Wofford DS, Boote KJ, Blount AR and Pfahler PL. 2005. Inheritance of promiscuous nodulation in soybean. *Crop Science* 45: 635-638.
- Gwata ET, Wofford DS, Pfahler PL and Boote KJ. 2004. Genetics of promiscuous nodulation in soybean: Nodule dry weight and leaf color score. *Journal of Heredity* 95: 154-157.
- Haas JD, Villalpando S, Shamah T, Beebe S and Boy E. 2010. The effect of consuming biofortified beans on the iron status of Mexican school children. Poster presented at the Bioavailability 2010 Conference, 26-30 Sep 2010. University of California, Davis, CA.
- Hall A. 2006. New insights into promoting rural innovation: Learning from civil society organisations about the effective use of innovation in development. Maastricht: UNU-MERIT. <http://www.research4development.info/SearchResearchDatabase.asp?OutputID=172912>
- Hall AE, Thiaw S, Ismail AM and Ehlers JD. 1997. Water-use efficiency and drought adaptation of cowpea. Pages 87-98 in *Advances in cowpea research* (Singh BB, Mohan Raj DR, Dashiell KE and Jackai LEN. eds.). Nigeria, Ibadan: IITA.
- Hall AE. 2004. Comparative ecophysiology of cowpea, common bean, and peanut. Pages 271-325 in *Physiology and Biotechnology Integration for Plant Breeding* (Nguyen HT and Blum A, eds.). Marcel Dekker Inc, New York, USA.
- Hall AJ and Yoganand B. 2004. New institutional arrangements in agricultural research and development in Africa: Concepts and case studies. Pages 105-131 in *Innovations in innovation: reflections on partnership, institutions and learning* (Hall AJ, Yoganand B, Sulaiman RV, Raina RS, Prasad CS, Naik GC and Clark NG. eds.). Crop Postharvest Research Programme/ICRISAT/National Centre for Agricultural Economics and Policy Research. New Delhi and Andhra Pradesh, India.

- Hall AJ, Yoganand B, Crouch JH and Clark NG. 2004. The evolving culture of science in the Consultative Group on International Agricultural Research: Concepts for building a new architecture of innovation in agri-biotechnology. Pages 135-62 in *Innovations in Innovation: Reflections on Partnership, Institutions and Learning* (Hall AJ, Yoganand B, Sulaiman RV, Rajeswari Raina S, Prasad CS, Guru C Naik and Clark NG. eds.). Andhra Pradesh, India: CPHP, ICRISAT and NCAP.
- Hamidou F, Ratnakumar P, Halilou O, Mponda O, Kapewa T, Monyo E, Faye I, Ntare BR, Nigam SN, Upadhyaya HD, Vadez V. 2012. Selection of intermittent drought tolerant lines across years and locations in the reference collection of groundnut (*Arachis hypogaea* L.). *Field Crop Research* 126: 189-199.
- Hammer GL. 2006. Pathways to prosperity: breaking the yield barrier in sorghum. *Agricultural Science* 19: 16-22.
- Hangen LA and Bennink MR. 2003. Consumption of black beans and navy beans (*Phaseolus vulgaris*) reduced azoxymethane-induced colon cancer in rats. *Nutrition and Cancer* 44: 60-65.
- Herridge DF and Danso SKA. 1995. Enhancing crop legume N₂ fixation through selection and breeding. *Plant and Soil* 174: 51-82.
- Herridge DF, Peoples MB and Boddey RM. 2008. Global inputs of biological nitrogen fixation in agricultural systems. *Plant and Soil* 311: 1-8.
- Hodson DP and White JW. 2007. Use of spatial analyses for global characterization of wheat based production systems. *Journal of Agricultural Science* 145: 115-125.
- Horton D and Mackay R. 2003. Special issue learning for the future: Innovative Approaches for evaluating agricultural research and development. *Agricultural Systems* 78: 119-336.
- Horton D, Prain G and Thiele G. 2009. Perspectives on partnership: A literature review. International Potato Center (CIP), Lima, Peru. Working Paper 2009-3.111 pp. http://www.cgiar-ilac.org/files/workshops/Partnership/Resources/Horton_Perspectives.pdf
- Hubert Schmitz. 2005. Value Chain Analysis for Policy-Makers and Practitioners Geneva, International Labour Office, 2005.
- Hungria M, Franchini JC, Campo RJ, Crispino CC, Moraes JZ, Sibaldelli RNR, Mendes IC and Arihara J. 2006. Nitrogen nutrition of soybean in Brazil: Contributions of biological N₂ fixation and N fertilizer to grain yield. *Canadian Journal of Plant Science* 86: 927-939.
- IAASTD 2009. Agriculture at a crossroads. Central & West Asia & North Africa (CWANA) report. McIntyre BD, Herren HR, Wakhungu J and Watson RT (eds.), Volume 1. International Assessment of Agricultural Knowledge, Science and Technology for Development. Washington DC: Island Press. 184 pp.
- ICARDA 2008. Food, income and livelihoods: Impact of new agricultural technologies in Africa. ICARDA Impact Brief 3. Aleppo, Syria: International Center for Agricultural Research in Dry Areas.
- ICRISAT. 2010. A "C-Change" in Southern India. Pages 8-9 in ICRISAT Annual Report 2010: Inclusive Market-Oriented Development. Patancheru, India: International Crops Research Institute for the Semi-Arid Tropics. Published in 2011.
- IFPRI 2010. Pulses value chain in Ethiopia: Constraints and opportunities for enhancing exports. Working Paper, July 2010. Washington DC: International Food Policy Research Institute. 44 pp.
- IFPRI. 2010. Cooperatives for staple crop marketing evidence from Ethiopia. Research Monograph. International Food Policy Research Institute (IFPRI). 164. <http://dx.doi.org/10.2499/9780896291751RR164>
- IFPRI. 2011a. The way forward. Preliminary conclusions of an international conference on "Leveraging agriculture for improving nutrition and health", February 10-12, 2011, New Delhi, India. Washington DC. http://2020conference.ifpri.info/files/2011/02/2020anh_wayforward.pdf.
- IFPRI. 2011b. Country fact sheets: Key facts and findings from the conference on Transforming African Economies for Sustained Growth, Poverty Reduction, Accra, Ghana, 10 May 2011. <http://www.ifpri.org/pressroom/briefing/transforming-economies-promote-sustained-growth-poverty-reduction>.
- Imtiaz MA. 2010. Quantitative genetics approach to drought tolerance in chickpea. ASA, CSSA and SSSA International Annual Meetings. 31 Oct-4 Nov, Long Beach, California, USA.
- IPCC. 2007. IPCC Fourth Assessment Report: Climate Change 2007 (AR4). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml
- James Clive. 2010. Global Status of Commercialized Biotech/GM Crops: 2010. ISAAA Brief No. 42. ISAAA: Ithaca, NY, USA.
- Jeranyama P, Waddington SR, Hesterman OB and Harwood RR. 2007. Nitrogen effects on maize yield following groundnut in rotation on smallholder farms in sub-humid Zimbabwe. *African Journal of Biotechnology* 6: 1503-1508.
- Jiang HF, Ren XP, Wang SY, XZhang XJ, Huang JQ, BoShou L, Holbrook CC and Upadhyaya HS. 2010. Development and evaluation of peanut germplasm with resistance to *Aspergillus flavus* from core collection. *Acta Agronomica Sinica* 36: 428-434.
- Jones P, Beebe S, Tohme J and Galwey N. 1997. The use of geographical information system in biodiversity exploration and conservation. *Biodiversity and Conservation* 6: 947-958.
- Jones R, Freeman H and Lo Monaco G. 2002. Improving the access of small farmers in eastern and southern Africa to global pigeonpea markets. AgREN Network Paper No 120, London: ODI. pp. 1-16.

- Jones RB, Audi PA and Tripp R. 2001. The role of informal seed systems in disseminating modern varieties. The example of pigeonpea from a semi-arid area of Kenya. *Experimental Agriculture* 37: 539-548.
- Joshi PK, Parthasarathy Rao P, Gowda CLL, Jones RB, Silim SN, Saxena KB and Kumar J. 2001. The world chickpea and pigeonpea economies: Facts, trends, and outlook. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). 62 pp.
- Joshi PK. 1998. Performance of grain legumes in the Indo-Gangetic Plain. Pages 3-31 in Residual effects of legumes in rice and wheat cropping systems of the Indo-Gangetic Plain (Kumar Rao JVDK, Johansen C and Rego TJ. eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi- Arid Tropics; and New Delhi 110 001, India: Oxford & IBH Publishing Co. Pvt. Ltd.
- Kabagambe EK, Baylin A, Ruiz-Narvarez E, Siles X and Campos H. 2005. Decreased consumption of dried mature beans is positively associated with urbanization and nonfatal acute myocardial infarction. *Journal of Nutrition* 135: 1770-1775.
- Kalyebara R and Andima D. 2006. The impact of improved bean technologies in Africa. Evaluation report submitted to the PABRA Steering Committee, Lumbumbashi, DRC, 27-29 March 2006.
- Kalyebara R, Andima D, Kirkby R and Buruchara R. 2008. Improved Bean Varieties and Cultivation in East and Central Africa-Economic and Social Benefits. PABRA-CIAT Kampala.
- Kamara AY, Ellis-Jones J, Amaza P, Omoigui LO, Helsen J, Dugie IY, Kama N, Menkir A and White RW. 2008. A participatory approach to increasing productivity of maize through *Striga Hermonthica* control in northeast Nigeria. *Experimental Agriculture* 44: 349-364.
- Kaschuk G, Kuyper TW, Leffelaar PA, Hungria M and Giller KE. 2009. Are the rates of photosynthesis stimulated by the carbon sink strength of rhizobial and arbuscular mycorrhizal symbioses? *Soil Biology & Biochemistry* 41: 1233-1244.
- Kashiwagi J, Krishnamurthy L, Serraj R, Upadhyaya HD, Krishna H, Chandra S and Vadez V. 2005. Genetic variability of drought-avoidance root traits in the mini-core germplasm collection of chickpea. *Euphytica* 146: 213-222.
- Kashiwagi J, Upadhyaya HD, Krishnamurthy L and Singh S. 2007. Identification of high-yielding large-seeded kabuli chickpeas with drought tolerance root traits. *Journal of SAT Agricultural Research* 3: 14-15.
- Katungi E and Gebeyehu S. 2011. Enhanced seed accessibility and adoption of improved common bean varieties in Ethiopia: Monitoring early adoption of improved varieties, unpublished TL2 project report.
- Katungi E, Sperling L, Karanja D, Farrow A and Beebe S. 2011. Relative importance of common bean attributes and variety demand in the drought areas of Kenya. *Journal of Development and Agricultural Economics* 3: 411-422.
- Kavitha K, Padmaja R, Deepthi H, Anand Babu P, Mula RP and Bantilan MCS. 2009. Strategic Partnership @ ICRISAT: Global Partnerships for Strategic Impact. ICRISAT, Patancheru, 502 324. Andhra Pradesh, India.
- Keneni G and Imtiaz M. 2010. Demand-driven breeding of food legumes for plant-nutrient relations in the tropics and the sub-tropics: Serving the farmers; not the crops! *Euphytica* 175: 267-282.
- Kenya Plant Health Inspectorate Service (KEPHIS). Annual Report 2006. KEPHIS: Nairobi, Kenya.
- Key N and Runsten D. 1999. Contract farming, smallholders, and rural development in Latin America: the organization of agroprocessing firms and the scale of outgrower production. *World Development* 27: 381-401.
- Khan HR, Paull JG, Siddique KHM and Stoddard FL. 2010. Faba bean breeding for drought-affected environments: A physiological and agronomic perspective. *Field Crops Research* 115: 279-286.
- Kharkwal MC. 2008. Food legumes for nutritional security and sustainable agriculture. Proceedings of the fourth International Food Legumes Research Conference (IFLRC-IV), (Kharkwal MC. ed.). 18-22 October 2005, New Delhi, India, ISGPB, New Delhi, India. 967 pp.
- Kharrat M, Abbes Z and Amri M. 2010. A new faba bean small seeded variety Najeh tolerant to orobanche registered in the Tunisian catalogue. *Tunisian Journal of Plant Protection* 5: 125-130.
- Khatib F, AntoniosMakris, Kasuko Yamaguchi-Shinozakic, Shiv Kumar, Sarker A, William Erskine and Michael Baum. 2011. Expression of DREB1A gene in lentil (*Lens culinaris* Medik. *culinaris*) transformed with the *Agrobacterium* system. *Crop & Pasture Science* 62: 488-495.
- Kholová J, Hash CT, Kocová M and Vadez V. 2010b. Constitutive water conserving mechanisms are correlated with the terminal drought tolerance of pearl millet (*Pennisetum americanum* L.). *Journal of Experimental Botany* 61: 369-377.
- Kholová J, Hash CT, Kumar LK, Yadav RS, Kocová M and Vadez V. 2010a. Terminal drought tolerant pearl millet [*Pennisetum glaucum* (L.) R. Br.] have high leaf ABA and limit transpiration at high vapor pressure deficit. *Journal of Experimental Botany* 61: 1431-1440.
- Kimaro A, Timmer V, Chamshama S, Ngaga Y and Kimaro D. 2009. Competition between maize and pigeonpea in semi-arid Tanzania: Effect on yields and nutrition of crops. *Agriculture, Ecosystems and Environment* 134: 115-125.
- Kolli RD and Bantilan MCS. 1997. Gender-related impacts of improved agricultural technologies: Identification of indicators from a case study. *Gender, Technology and Development* 1: 371-393.
- Kormawa P, Ezendinma C and Singh B. 2004. Factors influencing farmer-to-farmer transfer of an improved cowpea variety in Kano State, Nigeria. *Journal of Agriculture and Rural Development in the Tropics and Subtropics* 105(1): 1-13.

- Kornegay J, Cardona C and Posso CE. 1993. Inheritance of resistance to Mexican bean weevil in common bean, determined by bioassay and biochemical tests. *Crop Science* 33: 589-594.
- Kotecha PV. 2008. Micronutrient malnutrition in India: Let us say "no" to it now. *Indian Journal of Community Medicine* 33: 9-10.
- Krishnamurthy L, Gaur PM, Basu PS, Chaturvedi SK, Tripathi S, Vadez V, Rathore A, Varshney RK and Gowda CLL. 2011a. Large variation for heat stress tolerance in the reference collection of chickpea (*Cicer arietinum* L.) germplasm. *Plant Genetic Resources* 9: 59-69.
- Krishnamurthy L, Kashiwagi J, Gaur PM, Upadhyaya HD and Vadez V. 2010. Sources of tolerance to terminal drought in the chickpea (*Cicer arietinum* L.) minicore germplasm. *Field Crops Research* 119: 322-330.
- Krishnamurthy L, Upadhyaya HD, Saxena KB and Vincent Vadez. 2011b. Variation for temporary waterlogging response within the mini core pigeonpea germplasm. *Journal of Agricultural Science* 1-8; doi:10.1017/s0021859611000682.
- Krishnamurthy L, Vadez V, Turner NC, Siddique KHM, Upadhyaya HD, Gaur PM and Varshney RK. 2011c. Consistent variation across soil types in salinity resistance of a diverse range of chickpea (*Cicer arietinum* L.) genotypes. *Journal of Agronomy and Crop Science* 197: 214-227.
- Kristjanson P, Okike O, Tarawali S, Singh B and Manyong V. 2005. Farmers' perceptions of benefits and factors affecting the adoption of improved dual-purpose cowpea in the dry savannas of Nigeria. *Agricultural Economics* 32: 195-210.
- Kristjanson P, Tarawali S, Okike I, Singh BB, Thornton PK, Manyong VM, Kruska RL and Hoogenboom G. 2002. Genetically improved dual-purpose cowpea: Assessment of adoption and impact in the dry savanna region of West Africa. ILRI Impact Assessment Series No. 9. ILRI, Nairobi, Kenya.
- Kumar P, Joshi PK and Birthal PS. 2009. Demand projections for food grains in India. *Agricultural Economics Research Review* 22: 237-243.
- Kumar Rao JVDK, Johansen C and Mu K. 1995. Nitrogen requirements at different growth stages of short-duration pigeonpea (*Cajanus cajan* L. Millsp.). *Journal of Agronomy and Crop Science* 175: 15-28.
- Kumar Rao JVDK, Johansen C and Rego TJ (eds.). 1998. Residual effects of legumes in rice and wheat cropping systems of the Indo-Gangetic Plain. ICRISAT, Patancheru 502 324, Andhra Pradesh, India, and New Delhi: Oxford and IBH Publishing Co. Pvt. Ltd.
- Kumar S, Imtiaz M, Sanjeev Gupta and Pratap A. 2011. Distant hybridization and alien gene introgression. In *Biology and breeding of food legumes*. Pratap, A. Kumar, J. CABI (H ISBN 9781845937669).
- Kumar S, Kumar J, Singh S, Ahmed S, Chaudhary RG and Sarker A. 2010b. Vascular Wilt Disease of Lentil: A Review. *Journal of Lentil Research* 4: 1-14.
- Kumar S, Nayyar H, Bhanwara RK and Upadhyaya HD. 2010a. Chilling stress effects on reproductive biology of chickpea. *Journal of SAT Agricultural Research* 8.
- Kumar SK. 1985. Women's Role and Agricultural Technology. A chapter in *The Users' Perspective*. A seminar sponsored by the International Service for National Agricultural Research and the Rockefeller Foundation, Bellagio, Italy, March 1985.
- Kumari SG, Makkouk KM and Attar N. 2006. An improved antiserum for sensitive serologic detection of Chickpea chlorotic dwarf virus. *Journal of Phytopathology* 154(3): 129-133.
- Kusuma VP, Yugandhar G, Ajay BC, Gowda MVC and Upadhyaya HD. 2007. Identification of sources of multiple disease resistance in groundnut (*Arachis hypogaea* L.) mini core. Pages 31-32 in ISOR National Seminar, 29-31 January 2007, Directorate of Oilseeds Research, Rajendranagar, Hyderabad, India.
- Ladizinsky G. 1985. Founder effect in crop-plant evolution. *Economic Botany* 39: 191-199.
- Langyintuo A, Lowenberg-DeBoer J, Faye M, Lambert D, Ibro G, Moussa B, Kergna A, Kushwaha S, Musa S and Ntoukam G. 2003. Cowpea supply and demand in West and Central Africa. *Field Crops Research* 82: 215-231.
- Langyintuo AS. 2003. Cowpea trade in west and central Africa: A spatial and temporal analysis. Doctoral dissertation, Purdue University.
- Lather VS. 2000. Promising chickpea ideotype for higher plant density. *International Chickpea and Pigeonpea Newsletter* 7: 26-27.
- Leterme P. 2002. Recommendations by health organizations for pulse consumption. *British Journal of Nutrition* 88: S239-S242.
- Li SM, Li L, Zhang FS and Tang C. 2004. Acid phosphatase role in chickpea/maize intercropping. *Annals of Botany* 94: 297-303.
- Liener IE. 1994. Implications of antinutritional components in soybean foods. *Critical Reviews in Food Science and Nutrition* 34: 31-67.
- Litzenberger SC. 1973. The improvement of food legumes as a contribution to improved human nutrition. In papers presented at the international symposium on the potential of field beans and other legumes in Latin America, Cali, Colombia. Centro Internacional de Agricultura Tropical, CIAT, 1975. Cited in Edje OT, Mughogho LK, Rao YP and Msuku WAB. 1980. Bean production in Malawi. In potential of field beans and other legumes in Eastern Africa. Proceedings of a Regional Workshop, 9-14 Mar 1980, Lilongwe, Malawi.
- Liu S, Zhou R, Dong Y, Li P and Jia J. 2006. Development, utilization of introgression lines using synthetic wheat as donor. *Theoretical and Applied Genetics* 112: 1360-1373.

- Lobell DB, Marshall BB, Tebaldi C, Mastrandrea MD, Falcon WP and Naylor RL. 2008. Prioritizing climate change adaptation needs for food security in 2030. *Science* 319: 607-610.
- Lopes H. 2010. Adoption of improved maize and common bean varieties in Mozambique. Graduate Research Masters Degree Plan B Papers 97838, Michigan State University, Department of Agricultural, Food, and Resource Economics.
- López CE, Acosta IF, Jara C, Pedraza F, Gaitán-Solís E, Gallego G, Beebe S and Tohme J. 2003. Identifying resistance gene analogs associated with resistance to different pathogens in common bean. *Phytopathology* 93: 88-95.
- Lowenberg-DeBoer J and Ibro G. 2008. A study of the cowpea value chain In Kano State, Nigeria from a pro-poor and gender perspective. Washington, DC: USAID, Nigeria, GATE Project, http://www.nigeriamarkets.org/files/GATE_Cowpeas_Final%5B1%5D.pdf
- Ludwig DDS. 2002. The glycemic index - Physiological mechanisms relating to obesity, diabetes, and cardiovascular disease. *Jama-Journal of the American Medical Association* 287: 2414-2423.
- Lupwayi NZ, Kennedy AC and Chirwa RM. 2011. Grain legume impacts on soil biological processes in sub-Saharan Africa. *African Journal of Plant Science* 5: 1-7.
- Lynch JP. 2011. Root phenes for enhanced soil exploration and phosphorus acquisition: Tools for future crops. *Plant Physiology* 156: 1041-1049.
- M4P. 2008. Making Value Chain work for the poor: a toolbox for Practitioners of Value Chain Analysis, Version 3. Making Markets Work Better for the Poor (M4P) Project, UK Department for International Development (DFID). Agricultural Development International: Phnom Penh, Cambodia.
- MacRobert F John. 2009. Seed Business Management in Africa. Harare Zimbabwe CIMMYT, 233 pp.
- Mahalakshmi V, Ng Q, Lawson M and Ortiz R. 2007. Cowpea (*Vigna unguiculata* (L.) Walp.) core collection defined by geographical, agronomical and botanical descriptors. *Plant Genetic Resources: Characterization and Utilization* 5: 113-117.
- Makkouk KM, Kumari S, Sarker A and Erskine W. 2001. Registration of six lentil germplasm lines with combined resistance to viruses. *Crop Science* 41(3): 931-932.
- Malawi Ministry of Agriculture 2011. Malawi Agricultural Sector Wide Approach. A prioritised and harmonised agricultural development agenda: 2011-2015. Lilongwe, Malawi: Ministry of Agriculture and Food Security. www.moafsmw.org
- Malhotra RS, El Bouhssitii M and Joubi A. 2007. Registration of seven improved chickpea breeding lines resistant to leaf miner. *Journal of Plant Regulations* 1: 145-146.
- Malhotra RS. 2009. The CWANA countries have two well defined seasons, namely winter and spring, and chickpea is traditionally grown in the spring season (on conserved soil moisture) as most of the local land races grown in these countries are highly susceptible to Ascochyta blight and cold/frost which are the main constraints in the winter (Malhotra et al. 2009).
- Mallikarjuna N, Clarice Coyne, Seungho Cho, Sheri Rynearson, Rajesh PN, Deepak R Jadhav and Fred J Muehlbauer. 2011. Cicer. In *Wild Crop Relatives: Genomic and Breeding Resources, Legume Crops and Forages* (Kole C. ed.). Springer-Verlag Berlin Heidelberg (DOI:10.1007/978-3-642-14387-8_4).
- Mallikarjuna N, Senthilvel S and Hoisington D. 2010. Development of new sources of tetraploid Arachis to broaden the genetic base of cultivated groundnut (*Arachis hypogaea* L.). *Genetic Resources and Crop Evolution* (DOI: 10.1007/s10722-010-9627-8).
- Mallikarjuna N, Senthilvel S, Jadhav DR, Saxena KB, Sharma HC, Upadhyaya HD, Rathore A and Varshney RK. 2011. Progress in the utilization of *Cajanus platycarpus* (Benth.) Maesen in pigeonpea improvement. *Plant Breeding* doi:10.1111/j.1439-0523.2011.01870.x
- Manary M. 2006. Local production and provision of ready-to-use therapeutic food (RUTF) spread for the treatment of severe childhood malnutrition. *Food and Nutrition Bulletin* 27(3) (supplement):S83-S89.
- MAPM 2007. Situation alimentaire et nutritionnelle au Maroc : Eléments pour une politique alimentaire. Ed. CGDA.
- MAPM 2010. Plan Maroc Vert. Rapport d'étape 2008-2010.
- Marufu L, Karanja N and Ryder M. 1995. Legume inoculants production and use in east and southern Africa. *Soil Biology and Biochemistry* 27: 735-738.
- Materne M and Reddy AA. 2007. Commercial cultivation and profitability of lentil. Pages 173-186 in *Lentil: An ancient crop for modern times* (Yadav SS, McNeil D and Stevenson PC. eds.). Dordrecht, The Netherlands: Springer.
- Mazid A, Amegbeto K, Shideed K and Malhotra R. 2009. Impact of crop improvement and management: winter-sown chickpea in Syria. ICARDA, Aleppo, Syria.
- Mazur R, Nakimbugwe D, Ugen M, Musoke H and Vasanthakalaam H. 2009. Enhancing nutritional value and marketability of beans through research and strengthening key value chain stakeholders in Uganda and Rwanda. Pages 14-23 in *Dry Grain Pulses Collaborative Research Support Program (CRSP) 2009 Technical Highlights*. East Lansing: Michigan State University. <http://www.pulsecrsp.msu.edu/Publications/FY2009TechnicalReports/tabid/139/Default.aspx>
- McKnight Foundation. 2008. Increasing phosphorus efficiency and production of grain legumes in China and Africa. http://mcknight.ccrp.cornell.edu/program_docs/project_documents/SAF_05-780_plegumes/05780_plegumes_yr7_07-08_vweb.pdf; http://mcknight.ccrp.cornell.edu/projects/saf_cop/SAF_legumes/plegumes_project.html

- Meister G and Tuschl T. 2004. Mechanisms of gene silencing by double-stranded RNA. *Nature* 431: 343-349.
- Messina M. 1999. Legumes and soybeans: overview of their nutritional profiles and health effects. *American Journal of Clinical Nutrition* 70 (Suppl.): 439S-450S.
- Michaelsen KF, Hoppe C, Roos N, Kaestel P, Stougaard M, Lauritzen L, Mølgaard C, Girma T and Friis F. 2009. Choice of foods and ingredients for moderately malnourished children 6 months to 5 years of age. *Food and Nutrition Bulletin* 30 (3) (supplement):S343-S403.
- Miklas PN, Kelly JD, Beebe SE and Blair MW. 2006. Common bean breeding for resistance against biotic and abiotic stresses: from classical to MAS breeding. *Euphytica* 147: 105-131.
- Morales F. 1994. Bean golden mosaic. Research advances. Profrijol-CIAT. Cali, Colombia. 193 pp.
- Moussa B, Otoo M, Fulton J and Lowenberg-DeBoer J. 2009. Evaluating the effectiveness of alternative extension methods: triple-bag storage of cowpeas by small-scale farmers in West Africa. Selected paper prepared for presentation at the Journal Annual Meeting of the Agricultural & Applied Economics Association and the American Council on Consumer Interests, 26-29 July 2009. Milwaukee, WI, USA.
- Moyo S, Norton G, Alwang J, Rhinehart I and Deom C. 2007. Peanut research and poverty reduction: Impacts of variety research to control peanut viruses in Uganda. *American Journal of Agricultural Economics* 89: 448-460.
- Muehlbauer FJ and Chen W. 2007. Resistance to *Ascochyta* blights of cool season food legumes. *European Journal of Plant Pathology* 119: 135-141.
- Murray-Kolb LE, Welch R, Theil EC and Beard JL. 2003. Women with low iron stores absorb iron from soybeans. *American Journal of Clinical Nutrition* 77: 180-184.
- Nanda BBKS, Rao BTS and Moorthy LSB. 1994. Oil, protein, yield and seed characters of some groundnut cultivars grown in rice fallows in Orissa, India. *International Arachis Newsletter* 14: 19-20.
- NASFAM 2011. Strategic Development Plan III 2011-2016: Improved Rural Livelihoods through Smallholder Innovation and Productivity. Lilongwe, Malawi: National Smallholder Farmers Association of Malawi. 45 pp.
- Nasirumbi L, Rubyogo JC, Ugen M, Namayanja A and Luyima G. 2008. Reaching farmers in remote areas with improved bean varieties: lessons from Uganda. Pages 113-118 in *Farmers, seeds and varieties: supporting informal seed supply in Ethiopia* (Thijssen M, Bishaw Z, Beshir A and de Boef WS. eds.). Wageningen International, Programme for Capacity Development and Institutional Change, Wageningen University and Research Centre. PO Box 88, 6700 AA Wageningen, The Netherlands.
- Nathaniels NQR. 2005. Cowpea, farmer field schools and farmer-to-farmer extension: a Benin case study. *Agricultural Research & Extension Network (AgREN)*. Network Paper No. 148: 15.
- Ndjeunga J and Bantilan MCS. 2005. Uptake of improved technologies in the semi-Arid Tropics of West Africa: why is agriculture transformation lagging behind? *Journal of Agricultural and Development Economics* 2: 85-102.
- Ndjeunga J, Ntare B, Waliyar F, Echekwu C, Kodio O, Kapran I, Diallo A, Amadou A, Bissala H and Da Syliva A. 2008. Early adoption of modern groundnut varieties in West Africa, Socioeconomics and Policy Program Working Paper 24, Patancheru: ICRISAT.
- Nigam SN and Blummel M. 2010. Cultivar-dependent variation in food-feed-traits in groundnut (*Arachis hypogaea* L). *Animal Nutrition and Feed Technology* 10S: 39-48.
- Nigam SN, Waliyar F, Aruna R, Reddy SV, Lava Kumar P, Craufurd PQ, Diallo AT, Ntare BR and Upadhyaya HD. 2009. Breeding peanut for resistance to aflatoxin contamination at ICRISAT. *Peanut Science* 36: 42-49.
- Nkonya E, Ndakidemi P, Mushi C and Normman D. 1998. Adoption and environmental impact of an improved bean variety in Northern Tanzania. A paper submitted for presentation at the AFSRE Symposium, Pretoria, South Africa, 30 Nov-4 Dec 1998.
- Noriharu A, Arihara J, Okada K, Yoshihara T and Johansen C. 1990. Phosphorus Uptake by pigeonpea and Its role in cropping systems of the Indian Subcontinent. *Science* 248: 477-480.
- Nyiraneza J and Snapp S. 2007. Integrated management of inorganic and organic nitrogen and efficiency in potato systems. *Soil Science Society of America* 71(5): 1508-1515.
- Olorunju PE, Kuhn CW, Demski JW, Misari SM and Ansa OA. 1992. Inheritance of resistance in peanut to mixed infections of groundnut rosette virus (GRV) and groundnut rosette assistor virus and a single infection of GRV. *Plant Disease* 76: 95-100.
- Opio F. 1999. Management of bean root rot in Uganda. A Technical Report of sub-project funded by African Highland Initiative.
- Osofski AL and Kennelly EJ. 2003. Phytoestrogens: a review of the present state of research. *Phytotherapy Research* 17: 845-869.
- Oumarou H, Ejoh R, Ndjouenkeu R and Tanya A. 2005. Nutrient content of complementary foods based on processed and fermented sorghum, groundnut, spinach, and mango. *Food and Nutrition Bulletin* 26(4): 385-392.
- PABRA. 2008. Pan Africa Bean Research Alliance Annual Report 2008. Kampala, Uganda. 32 pp.
- PABRA. 2009. <http://dapa.ciat.cgiar.org/pabra-climate-change-symposium/>

- Pande S, Gupta R, Dahiya SS, Chauhan YS, Singh S, Singh UP, Jat ML, Singh SS, Sharma HC, Rao JN and Chandna PC. 2006. Identification, Adoption and Expansion of Extra Short Duration Pigeonpea Variety ICPL 88039 in Rice and Wheat Cropping Systems of the Indo-Gangetic Plains of India. Technical Bulletin Series No. 8. New Delhi, India: Rice-Wheat Consortium, International Wheat and Maize Research Center (CIMMYT). 48 pp.
- Pande S, Kishore GK, Upadhyaya HD and Rao JN. 2006. Identification of sources multiple disease resistance in mini-core collection of chickpea. *Plant Disease* 90: 1214-1218.
- Pande S, Stevenson PC, Rao JN, Neupane RK, Grzywacz D, Bourai VA and Kishore GK. 2005. Reviving chickpea production in Nepal through integrated crop management, with emphasis on *Botrytis* Gray Mold. *Plant Disease* 89(12): 1252-1262.
- Pandey P, Kang SC and Maheswari DK. 2005. Isolation of endophytic plant growth-promoting *Burkholderia* spp. MSSP from root nodules of *Mimosa pudica*. *Current Science* 89: 177-180.
- Parra-Quijano M, Iriondo JM, de la Cruz M and Torres E. 2011. Strategies for the development of core collections based on ecogeographical data. *Crop Science* 51: 656-666.
- Parthasarathy Rao P, Birtal PS, Bhagavatula S and Bantilan MCS. 2010. Chickpea and pigeonpea economics in Asia: Facts, trends and outlook. ICRISAT, Patancheru 502 324, Andhra Pradesh, India. 76 pp. ISBN: 978-92-9066-530-4. Order code: BOE 049.
- Patrick I. 2003. Contract Farming in Indonesia: Smallholders and Agribusiness Working Together. ACIAR Technical Reports No. 54. Canberra, Australian Centre for International Agricultural Research.
- Paul C, Bowen CR, Bandyopadhyay R, Tefera H, Adeleke R, Sikora E, Pegues MD and Hartman GL. 2010. Registration of three soybean germplasm lines resistant to *Phakopsora pachyrhizi* (soybean rust). *Journal of Plant Registrations* 4: 244-248.
- Pellett PL. 1996. World essential amino acid supply with special attention to South-East Asia. *Food and Nutrition Bulletin* 17(3): 204-34.
- Phiri M, Chirwa R, Kandoole S and Tripp R. 2000. Introducing new bean varieties with small seed packs: Experience from Malawi. Network on Bean Research in Africa, Occasional Publications Series, No. 32, CIAT, Kampala, Uganda.
- Pimentel D and Patzek T. 2008. Ethanol production using corn, switchgrass and wood; Biodiesel production using soybean. Chapter 15. Pages 375-396 in *Biofuels, solar and wind as renewable energy systems: Benefits and risks* (Pimentel D. ed.). Springer: Dordrecht, The Netherlands.
- Poats S. 1991. The role of gender in agriculture development. *Issues in Agriculture Research* No.3. The Consultative Group on International Agriculture Research, CGIAR Library, J4-034.
- Potts Michael and Nagujja Stella. 2007. A review of agricultural and health policies in Uganda with implications for the dissemination of the biofortified crops. Harvest Plus Working Paper No1. Harvest Plus C/O IFPRI, 2033 K Street, NW Washington, USA.
- Prensa Libre.com 2012. Precio del frijol se mantiene alto. http://prensalibre.com/economia/Precio-frijol-mantiene-alto_0_623337661.html
- PROSAB (Promoting Sustainable Agriculture in Born State, Nigeria) 2010. Annual report. International Institute of Tropical Agriculture, Ibadan, Nigeria.
- Quan Liang, Xiaohui Cheng, Mantong Mei, Xiaolong Yan and Hong Liao. 2010. QTL analysis of root traits as related to phosphorus efficiency in soybean. *Annals of Botany* 106: 223-234.
- Quiñones MA, Borlaug NE and Dowsell CR. 1997. A fertilizer-based green revolution for Africa. Pages 81-96 in *Replenishing soil fertility in Africa* (Buresh RJ and Sanchez PA. eds.). SSSA Special Publication 51. SSSA, Madison, WI, USA.
- Ramaekers L, Remans R, Rao IM, Blair MW and Vanderleyden J. 2010. Strategies for improving phosphorus acquisition efficiency of crop plants. *Field Crops Research* 117: 169-175.
- Ramírez-Villegas J, Khoury C, Jarvis A, Debouck DG and Guarino L. 2010. A gap analysis methodology for collecting crop gene pools: a case study with *Phaseolus* beans. *PLoS ONE Biology* 5: 1-18.
- Ranga Rao GV and Gopalakrishnan S. 2009. Bio-pesticides research at ICRISAT: A consortium model. In *Proceedings of Expert Consultation on Biopesticides and Biofertilizers for Sustainable Agriculture*, Organized by Asia-Pacific Association of Agricultural Research Institutions (APAARI) & Council of Agriculture, Taipei (COA), Taiwan Agricultural Research Institute, Taichung, 27-29 October 2009. 17 pp.
- Rao IM. 2002. Role of physiology in improving crop adaptation to abiotic stresses in the tropics: The case of common bean and tropical forages. Pages 585-613 in *Handbook of Plant and Crop Physiology* (Pessaraki M. ed.). Marcel Dekker, Inc., New York, USA.
- Ravi M and Chan SWL. 2010. Haploid plants produced by centromere-mediated genome elimination. *Nature* 464: 615-618.
- Reddy AA and Reddy GP. 2010. Supply side constraints in production of pulses in India: Case study of lentils. *Agricultural Economics Research Review* 23: 129-136.
- Reddy AA. 2004. Consumption pattern, trade and production potential of pulses. *Economic and Political Weekly* 39(44): 4854-4860.
- Reddy AA. 2009. Pulses production technology: Status and way forward. *Economic and Political Weekly* 44(52): 73-80.

- Reddy MV, Nene YL, Raju TN, Sheila VK, Nandita Sarkar, Remanandan P and Amin KS. 1990. Disease debris field inoculation technique for phytophthora blight of pigeonpea. *International Pigeonpea Newsletter* 12: 25-26.
- Reddy MV, Raju TN and Lenne JM. 1998. Diseases of Pigeonpea. Pages 517-558 in *The pathology of food legumes* (Allen DJ and Lenne JM, eds.). Cambridge: CAB International 1998.
- Republic of Niger 2011. Directory on the availability of improved seed. Ministry of Agriculture and Livestock.
- Ribaut JM, de Vicente MC and Delannay X. 2010. Molecular breeding in developing Countries: challenges and perspectives. *Current Opinion in Plant Biology* 13: 213-218.
- Rubyogo JC, Dickinson M, Mayes S and Assefa T. 2009b. Seed-health assessment of different bean seed grades and sources from Ethiopia using molecular tools. *Journal of New Seeds* 10: 293-310.
- Rubyogo JC, Gebeyehu S, Tumsa K, Negash K, Habte E, Katungi E, Sperling L and Wozemba D. 2011. Increased bean productivity through increased access to improved seeds and use of improved bean management techniques in Ethiopia. Paper presented at conference "Increasing Agricultural Productivity and Enhancing Food Security in Africa", 1-3 November 2011, Addis Ababa, Ethiopia: International Food Policy Research Institute. http://addis2011.ifpri.info/files/2011/10/Paper_1A_Jean-Claude-Rubyogo.pdf
- Rubyogo JC, Magreta R, Kambewa D, Chirwa R and Mazuma E. 2011. Private Public Partnership in Bean Seed Delivery: Experience from Malawi. *African Crop Science Journal* (in press).
- Rubyogo JC, Sperling L and Assefa T. 2007. A new Approach for facilitating farmers access to bean seed. *LEISA Magazine* 23: 27-29.
- Rubyogo JC, Sperling L, Karanja DR, Seward P and Leakey J. 2009a. Public-Private Sector Partnerships: the power of small seed packs for reaching 100,000s of Kenyan bean farmers. Poster presented during CIAT Annual Review Meeting in Cali-Colombia.
- Rubyogo JC, Sperling L, Muthoni R and Robin Buruchara. 2010. Bean seed delivery for small farmers in Sub-Saharan Africa: The power of partnerships. *Society and Natural Resources* 23: 285-302.
- Rysavy A, Dumet D, Sonder K and Sauerborn J. 2009. GIS based gap analysis as a tool for biodiversity conservation optimisation: The IITA Cowpea Collection. In *Proceeding of Biophysical and Socio-economic Frame Conditions for the Sustainable Management of Natural Resources: International research on food security, natural resource management and rural development* (Eric Tielkes. ed.), Tropentag, 6-8 October 2009, Hamburg, Germany.
- Sadok W and Sinclair TR. 2010. Transpiration response of 'slow-wilting' and commercial soybean (*Glycine max* (L.) Merr.) genotypes of three aquaporin inhibitors. *Journal of Experimental Botany* 61(3): 821-829.
- Saitou N and Nei M. 1987. The neighbor-joining method: a new method for reconstructing phylogenetic trees. *Molecular Biology and Evolution* 4: 406-425.
- Sakai T and Kogiso M. 2008. Soy isoflavones and immunity. *Journal of Investigative Medicine* 55(3-4): 167-173.
- Salem MA, Kakani VG, Koti S. et al. 2007. Pollen-based screening of soybean genotypes for high temperatures. *Crop Science* 47: 219-231.
- Salomé PA, Bomblies K, Laitinen RAE, Yant L, Mott R and Weigel D. 2011. Genetic architecture of flowering time variation in *Arabidopsis thaliana*. *Genetics* 188: 421-433.
- Sanchez PE. 2002. Soil fertility and hunger in Africa. *Science* 295: 2019-2020.
- Saxena KB and Nadarajan N. 2010. Prospects of pigeonpea hybrids in Indian agriculture. *Electronic Journal of Plant Breeding* 1(4): 1107-1117.
- Saxena KB, Kumar RV and Sultana R. 2010. Quality nutrition through pigeonpea—a review. *Health* 2(11): 1335-1344.
- Saxena KB, Kumar RV, Srivastava N and Shiyong B. 2005. A cytoplasmic-nuclear male-sterility system derived from a cross between *Cajanus cajanifolius* and *Cajanus cajan*. *Euphytica* 145: 291-296.
- Saxena KB. 2008. Genetic improvement of Pigeonpea—A Review. *Tropical Plant Biology* 1: 159-178.
- Schmalenbach I, Leon J and Pillen K. 2009. Identification and verification of QTLs for agronomic traits using wild barley introgression lines. *Theoretical and Applied Genetics* 118: 483-497.
- SCN. 2004. 5th Report on the world nutrition situation. Nutrition for improved development outcomes. Standing Committee on Nutrition. United Nations.
- Sedgley RH, Siddique KHM and Walton GH. 1990. Chickpea ideotypes for Mediterranean environments. Pages 87-91 in *Chickpea in the nineties: Proceedings of the Second International Workshop on Chickpea Improvement* (van Rheenen HA, Saxena MC, Walby BJ and Hall SD. eds.). ICRISAT, Patancheru 502 324, Andhra Pradesh, India.
- Serraj R (ed.). 2004. Symbiotic nitrogen fixation. Prospects for enhanced application in tropical agriculture. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi. 367 pp.
- Serraj R and Sinclair TR. 1996. Processes contributing to N₂-fixation insensitivity to drought in the soybean cultivar Jackson. *Crop Science* 36: 961-968.
- Serraj R and Sinclair TR. 1998. N₂ fixation response to drought in common bean (*Phaseolus vulgaris* L.). *Annals of Botany* 82: 229-234.

- Serraj R, Sinclair TR and Purcell LC. 1999. Symbiotic N₂ fixation response to drought. *Journal of Experimental Botany* 50: 143-155.
- Setimela P, Chitalu Z, Jonazi J, Mambo A, Hodson D and Bänziger M. 2005. Environmental classification of maize-testing sites in the SADC region and its implication for collaborative maize breeding strategies in the subcontinent. *Euphytica* 145: 123-132.
- Shapiro B and Sanders J. 2002. Natural resource technologies for semi-arid regions of sub-Saharan Africa. In: Barrett C, Place F and Aboud A (eds.) *Natural Resources Management in African Agriculture*, Wallingford, UK: CABI.
- Sharma HC (ed.). 2005. *Heliothis/Helicoverpa Management: Emerging Trends and Strategies for Future Research*. New Delhi, India: Oxford & IBH, and Science Publishers, USA. 469 pp.
- Sharma HC and Ortiz R. 2000. Transgenics, pest management, and the environment. *Current Science* 79: 421-437.
- Sharma HC, Dhillon MK and Arora R. 2008. Effects of *Bacillus thuringiensis* δ -endotoxin fed *Helicoverpa armigera* on the survival and development of the parasitoid *Camponotus chlorideae*. *Entomologia Experimentalis et Applicata* 126: 1-8.
- Sharma HC, Srivastava CP, Durairaj C and Gowda CLL. 2010. Pest management in grain legumes and climate change. Pages 115-140 in *Climate Change and Management of Cool Season Grain Legume Crops* (Yadav SS, McNeil DL, Redden R and Patil SA, eds.). Springer Science + Business Media, Dordrecht, The Netherlands.
- Sharma HC. 1997. Biology, host plant resistance, and management of the legume pod borer, *Maruca vitrata*-A review. *Crop Protection* 17: 373-386.
- Sharma HC. 2006. Integrated Pest Management Research at ICRISAT: Present Status and Future Priorities. ICRISAT, Patancheru 502 324, Andhra Pradesh, India. 43 pp.
- Sharma HC. 2009. *Biotechnological Approaches for Pest Management and Ecological Sustainability*. CRC Press/Taylor and Francis, New York, USA. 526 pp.
- Sharma KK and Lavanya M. 2002. Recent developments in transgenics for abiotic stress in legumes of the semi-arid tropics. Pages 61-73 in *Genetic engineering of crop plants for abiotic stress* (Ivanaga M. ed.). Working Report 23. JIRCAS, Tsukuba, Japan.
- Sharma KK and Ortiz R. 2000. Program for the application of genetic transformation for crop improvement in the semi-arid tropics. *In Vitro Cellular and Developmental Biology of Plants* 36: 83-92.
- Sharma KK, Bhatnagar-Mathur P and Thorpe TA. 2005. Genetic transformation technology: status and problems. *In Vitro Cellular and Developmental Biology of Plants* 41: 102-112.
- Shiferaw B, Kebede T and You L. 2008a. Technology adoption under seed access constraints and the economic impacts of improved pigeonpea varieties in Tanzania. *Agricultural Economics* 39: 309-323.
- Shiferaw B, Okello J, Muricho G, Omiti J, Silim S and Jones R. 2008b. Unlocking the potential of high-value legumes in the semi-arid regions. *Analyses of the Pigeonpea Value Chain in Kenya*, Nairobi: ICRISAT.
- Shiferaw B, Silim S, Muricho G, Audi P, Mlilo J, Lyimo S, You L and Christiansen JL. 2007. Assessment of the adoption and impact of improved pigeonpea varieties in Tanzania. *Journal of SAT Agricultural Research* 3(1): 1-27.
- Shurtleff W and Aoyagi A. 2007. A special report on the history of soybeans in Africa and around the world, chapter from the unpublished manuscript *History of soybeans and soyfoods: 1100 B.C. to the 1980s*.
- Simtowe F, Asfaw S, Diagne A and Shiferaw B. 2010. Determinants of agricultural technology adoption: the case of improved groundnut varieties in Malawi. Contributed paper at the meeting of African Association of Agricultural Economists, Capetown, September 2010.
- Simtowe F, Shiferaw B, Kassie M, Abate T, Silim S, Siambi M, Madzonga O, Muricho G and Kananji G. 2010. Assessment of the current situation and future outlooks for the pigeonpea sub-sector in Malawi. Nairobi: ICRISAT. 52 pp.
- Sinclair TR and Serraj R. 1995. Legume nitrogen fixation and drought. *Nature* 378: 344.
- Sinclair TR and Vadez V. 2002. Physiological traits for crop yield improvement in low N and P environments. *Plant and Soil* 245: 1-15.
- Sinclair TR, Messina CD, Beatty A and Samples M. 2010. Assessment across the United States of the benefits of altered soybean drought traits. *Agronomy Journal* 102: 475-482.
- Sinclair TR, Purcell LC, King CA, Sneller CH, Chen P and Vadez V. 2007. Drought tolerance and yield increase of soybean resulting from improved symbiotic N₂ fixation. *Field Crops Research* 101: 68-71.
- Sinclair TR, Purcell LC, Vadez V, Serraj R, King CA and Nelson R. 2000. Identification of soybean genotypes with N₂ fixation tolerance to water deficits. *Crop Science* 40: 1803-1809.
- Sinclair TR, Vadez V and Chenu K. 2003. Ureide Accumulation in response to Mn nutrition by eight soybean genotypes with N₂ fixation tolerance to soil drying. *Crop Science* 43: 592-597.
- Singh K, Malhotra R, Saxena M and Bejiga G. 1997. Superiority of winter sowing over traditional spring sowing of chickpea in the Mediterranean region. *Agronomy Journal* 89: 112-118.
- Singh P, Aggarwal PK, Bahatia VS, Murty MVR, Pala M, Oweis T, Benli B, Rao KPC and Wani SP. 2009. Yield gap analysis: Modeling of achievable yields at farm level. Pages 81-123 in *Unlocking the potential. Comprehensive Assessment of Water Management in Agriculture* (Wani SP, Rockstrom J and Oweis T. eds.). London, UK: CABI Publishing.

- Singh P, Vijaya D, Chinh NT, Aroon Pongkanjana, Prasad KS, Srinivas K and Wani SP. 2001. Potential productivity and yield gap of selected crops in the rainfed regions of India, Thailand, and Vietnam. Natural Resource Management Program Report no. 5. ICRISAT, Patancheru 502 324, Andhra Pradesh, India. 50 pp.
- Singh SK, Nene YL and Reddy MV. 1990. Influence of cropping system on *Macrophomina phaseolina* population in soil. *Plant Diseases* 74: 812-814.
- Singh SP and Schwartz HF. 2010. Breeding common bean for resistance to diseases: a review. *Crop Science* 50: 2199-2223.
- Singh SP. 2001. Broadening the genetic base of common bean cultivars: A review. *Crop Science* 41: 1659-1675.
- Singh Y, Chaudhary DC, Singh SP, Bhardwaj AK and Singh D. 1996. Sustainability of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) sequential cropping through introduction of legume crops and green manure crop in the system. *Indian Journal of Agronomy* 41: 510-514.
- Slinkard AE, Vanderberg A and Holm FA. 2007. Lentil plants having increased resistance to imidazolinone herbicides. US patent 7232942. <http://www.uspto.gov/patft/index.html>
- Snapp SS, Kanyama-Phiri GY, Kamanga B, Gilbert R and Wellard K. 2002. Farmer and researcher partnerships in Malawi: developing soil fertility technologies for the near-term and far-term. *Experimental Agriculture* 38: 411-431.
- Snowden D. 2002. Complex acts of knowing: Paradox and descriptive self-awareness. *Journal of Knowledge Management* 6: 100-111.
- Sonnante G, Stockton T, Nodari RO, Becerra Velásquez VL and Gepts P. 1994. Evolution of genetic diversity during the domestication of common bean (*Phaseolus vulgaris* L.). *Theoretical and Applied Genetics* 89: 629-635.
- Specht JE, Hume DJ and Kumudini SV. 1999. Soybean yield potential – a genetic and physiological perspective. *Crop Science* 39: 1560-1570.
- Sperling L and Muyaneza S. 1995. Intensifying production among smallholder farmers: the impact of improved climbing beans in Rwanda. *African Crop Science Journal* 3: 117-125.
- Sperling L and Scheidegger U. 1995. Participatory selection of beans in Rwanda: Results, methods and institutional issues. International Institute for Environment and Development. Gatekeeper Series No. 51. IIED, London.
- Sperling L, Loevinsohn ME and Ntabomvura B. 1993. Rethinking the farmer's role in plant breeding: Local bean experts and on-station selection in Rwanda. *Experimental Agriculture* 29: 509-519.
- Sperling L, Scheidegger U and Buruchara R. 1996. Designing seed systems with small farmers: principles derived from bean research in the Great Lakes Region of Africa. Agricultural Administration (Research and Extension) Network Paper No. 60. London: Overseas Development Institute.
- Spielman D, Hartwich F and von Grebmer K. 2007. Sharing science, building bridges, and enhancing impact: Public-private partnerships in the CGIAR. IFPRI Discussion Paper 708. Washington, DC: International Food Policy Research Institute (IFPRI).
- Srinivasan R, Tamo M, Ooi PAC and Easdown W. 2007. IPM for *Maruca vitrata* on food legumes in Asia and Africa. *Biocontrol News and Information* 28: 34N-37N.
- Srivastava N, Vadez V, Upadhyaya HD and Saxena KB. 2006. Screening for intra and inter specific variability for salinity tolerance in Pigeonpea (*Cajanus cajan*) and its related wild species. *Journal of SAT Agricultural Research* 2(1). [http://icrtest:8080/Journal/crop improvement/v2i1/v2i1screeningfor.pdf](http://icrtest:8080/Journal/crop%20improvement/v2i1/v2i1screeningfor.pdf)
- Srivastava N. 2010. Identification of contrasting parental material for salinity tolerance based on morphological, physiological, and biochemical study and molecular diversity by SSR molecular markers in groundnut (*Arachis hypogaea*). Ph.D. thesis. Jawaharlal Nehru Technological University, Hyderabad, India.
- Stangoulis J and Sison C. 2008. Crop sampling protocols for micronutrient analysis. HarvestPlus Technical Monograph Series #7.
- Stein AJ. 2006. Micronutrient malnutrition and the impact of modern plant breeding on public health in India: How cost-effective is bio-fortification? Göttingen: Cuvillier Verlag. ISBN: 3865379478.
- Tako E, MoisesLaparra J, Glahn RP, Welch RM, Lei XG, Beebe S and Miller DD. 2009. Biofortified black beans in a maize and bean diet provide more bioavailable iron to piglets than standard black beans. *Journal of Nutrition* 139: 1-5.
- Tan S and Bowe SJ. 2009. Developing herbicide-tolerant crops from mutations. Page(s) 315 in *Induced Plant Mutations in the Genomics Era* (Shu QY, ed.). Food and Agriculture Organization of the United Nations, Rome, Italy.
- Tanammal R. 2011. MSc. Thesis, University of Hohenheim, Germany. In preparation.
- Tanksley SD and McCouch SR. 1997. Seed banks and molecular maps: Unlocking genetic potential from the wild. *Science* 277: 1063-1066.
- Tanumihardjo SA, Anderson C, Kaufer, Horwitz M, Bode L, Emenaker NJ, Haqq AM, Satia JA, Silver HJ and Stadler DD. 2007. Poverty, Obesity and Malnutrition: An international perspective recognizing the paradox. *Journal of the American Dietetic Association* 107: 1966-1972.
- Taran B, Warkentin TD, Vanderberg A and Holm FA. 2010. Variation in chickpea germplasm for tolerance to imazathapyr and imazamox herbicides. *Canadian Journal of Plant Sciences* 90: 139-142.
- Tefera H, Kamara AY, Asafo-Adjei B and Dashiell KE. 2010. Breeding progress for grain yield and associated traits in medium and late maturing promiscuous soybeans in Nigeria. *Euphytica* 175: 251-260.

- Tefera H. 2011. Breeding for Promiscuous Soybeans at IITA. Pages 147-162 in Soybean-Molecular Aspects of Breeding (Aleksandra Sudaric ed.). ISBN: 978-953-307-240-1, InTech, Available from: <http://www.intechopen.com/articles/show/title/breeding-for-promiscuous-soybeans-at-IITA>
- Teshale A, Rubyogo JC, Sperling L, Amsalu B, Abate T, Deressa A, Reda F, Kirkby R and Buruchara R. 2006. Creating partnerships for enhanced impact; bean variety delivery in Ethiopia. *Journal of Crop Science Society of Ethiopia* 12: 27-30.
- Than AM, Maw JB, Aung T, Gaur PM and Gowda CLL. 2007. Development and adoption of improved chickpea varieties in Myanmar. *Journal of SAT Agricultural Research* 5(1). Available online at http://ejournal.icrisat.org/volume5/ChickPea_PigeonPea/cp1.pdf
- Thompson JD, Gibbs TJ, Plewniak F, Jeanmougin F and Higgins DG. 1997. The clustalX windows interface: flexible strategies for multiple sequence alignment aided by quality analysis tools. *Nucleic Acids Research* 24: 4876-4882.
- Thompson MD, Thompson HJ, Brick MA, McGinley JN, Jiang W, Zhu Z and Wolfe P. 2008. Mechanisms associated with dose-dependent inhibition of rat mammary carcinogenesis by dry bean (*Phaseolus vulgaris*, L.). *Journal of Nutrition* 138: 2091-2097.
- Timko MP, Ehlers JD and Roberts PA. 2007. Cowpea. Pages 49-67 in Pulses, sugar and tuber crops, genome mapping and molecular breeding in plants (Kole C. ed.), Volume 3. Springer-Verlag, Berlin Heidelberg.
- Tipilda A, Aelne A and Manyong V. 2008. Engaging with cultural practices in ways that benefit women in northern Nigeria. *Development in Practice* 18: 551-563.
- Tiwari BK, Tiwari U, Jagan Mohan R and Alagusundaram K. 2008. Effect of various pre-treatments on functional, physiochemical, and cooking properties of pigeon pea (*Cajanus cajan* L). *Food Science and Technology International* 14: 487-495.
- TLII Project 2010. Tropical Legumes II Project Annual Review Meeting: Seed System: Overview of Results and Future Plans. 17-19 May 2010, Lukenya, Kenya.
- TLII Project Annual Report 2010. Proceedings of the TLII (Tropical Legumes II Project) annual report 2010. Presented during the annual review meeting, 22-25 May 2011, Lilongwe, Malawi. Published in 2011.
- Tohme J, Jones P, Beebe S and Iwanaga M. 1995. The combined use of agroecological and characterization data to establish the CIAT *Phaseolus vulgaris* core collection. Pages 95-107 in Core collections of plant genetic resources (Hodgkin T, Brown AHD, van Hintum Th JL and Morales EAV. eds.). J. Wiley and Sons; Chichester, UK.
- Toker C, Lluch C, Tejera NA. et al. 2007. Abiotic stresses. Pages 474-496 in Chickpea breeding and management (Yadav SS, Redden R, Chen W. et al. eds.). CABI.
- Tripp R and Ali A. 2001. Farmers' access to natural pest control products: Experience from an IPM project in India, AgREN Network Paper No. 113, London: ODI.
- Tripp R and Rohrbach D. 2001. Policies for African seed enterprise development. *Food Policy* 26: 147-161.
- Tripp R, Walker D, Opoku-Apau A, Dankyi A and Delimini L. 1998. Seed Management by Small-Scale Farmers in Ghana. Wallingford, UK: Natural Resources Institute.
- Tripp R. 2011. The impacts of food legume research in the CGIAR. A scoping study for the Standing Panel on Impact Assessment (SPIA) of the CGIAR Independent Science & Partnership Council. 43 pp. <http://impact.cgiar.org/sites/default/files/images/LegumeScoping2011.pdf>.
- Tripp Robert. 2006. The Case for Foundation Seed Enterprises in Sub-Saharan Africa. Overseas Development Institute, 111 Westminster Bridge Road, London SE1 7JD, UK. 30 pp.
- Trivedi TP, Yadav CP, Vishwadhar, Srivastava CP, Dhandapani A, Das DK and Singh J. 2005. Monitoring and forecasting of *Heliothis/Helicoverpa* populations. Pages 119-140 in *Heliothis/Helicoverpa Management: Emerging Trends and Strategies for Future Research* (Sharma HC. ed.). New Delhi, India: Oxford & IBH, and Science Publishers, USA.
- Twizeyimana M, Ojiambo PS, Hartman GL and Bandyopadhyay R. 2010. Dynamics of soybean rust epidemics on an early and late maturing soybean cultivar. *Plant Disease* 95: 43-50.
- Twizeyimana M, Ojiambo PS, Haudenshield JS, Caetano-Anollés G, Pedley KF, Bandyopadhyay R and Hartman GL. 2011. Genetic structure and diversity of *Phakopsora pachyrhizi* isolates from soybean. *Plant Pathology* 60: 719-729.
- Upadhyaya HD and Gowda CLL. 2009. Managing and enhancing use of germplasm- strategies and methodologies. Technical Manual no. 10, ICRISAT, Patancheru 502 324, Andhra Pradesh, India. 236 pp.
- Upadhyaya HD and Ortiz R. 2001. A mini core collection for capturing diversity and promoting utilization of chickpea genetic resources in crop improvement. *Theoretical and Applied Genetics* 102: 1292-1298.
- Upadhyaya HD, Bramel PJ, Ortiz R and Singh S. 2002. Developing a mini core of peanut for utilization of genetic resources. *Crop Science* 42: 2150-2156.
- Upadhyaya HD, Dronavalli N, Gowda CLL and Singh S. 2012a. Mini core collections for enhanced utilization of genetic resources in crop improvement. *Indian Journal of Plant Genetic Resources* 25(1): 111-124.
- Upadhyaya HD, Dronavalli N, Gowda CLL and Sube Singh. 2011a. Identification and evaluation of chickpea germplasm for tolerance to heat stress. *Crop Science* 51: 2079-2094.

- Upadhyaya HD, Dwivedi SL, Baum M, Varshney RK, Udupa SM, Gowda CLL, Hoisington D and Singh S. 2008. Genetic structure, diversity and allelic richness in composite collection and reference set in chickpea (*Cicer arietinum* L.). BMC Plant Biology 8: 106. <http://www.biomedcentral.com/1471-2229/8/106>
- Upadhyaya HD, Dwivedi SL, Gowda CLL and Sube Singh. 2007a. Identification of diverse germplasm lines for agronomic traits in a chickpea (*Cicer arietinum* L.) core collection for use in crop improvement. Field Crops Research 100: 320-326.
- Upadhyaya HD, Dwivedi SL, Nadaf HL and Sube Singh. 2011b. Phenotypic diversity and identification of wild *Arachis* accessions with useful agronomic and nutritional quality traits. Euphytica 182: 103-115.
- Upadhyaya HD, Gowda CLL, Buhariwalla HK and Crouch JH. 2006. Efficient use of crop germplasm resources: identifying useful germplasm for crop improvement through core and mini core collections and molecular marker approaches. Plant Genetic Resources 4: 25-35.
- Upadhyaya HD, Mallikarjuna Swamy BP, Kenchana Goudar PV, Kullaiswamy BY and Sube Singh. 2005. Identification of diverse accessions of groundnut through multienvironment evaluation of core collection for Asia. Field Crops Research 93: 293-299.
- Upadhyaya HD, Mukri G, Nadaf HL and Sube Singh. 2012b. Variability and stability analysis for nutritional quality traits in the mini core collection of peanut. Crop Science 52: 168-178.
- Upadhyaya HD, Nigam SN and Sube Singh. 2001. Evaluation of groundnut core collections to identify sources of tolerance to low temperature at germination. Indian Journal of Plant Genetic Resources 14: 165-167.
- Upadhyaya HD, Pundir RPS, Dwivedi SL and Gowda CLL. 2009. Mini core collections for efficient utilization of plant genetic resources in crop improvement programs. Information Bulletin no 78, ICRISAT, Patancheru 502 324, Andhra Pradesh, India. 52 pp. ISBN 978-92-9066-519-9 Order code IBE 078.
- Upadhyaya HD, Reddy KN, Shivali S, Varshney RK, Bhattacharjee R, Singh S and Gowda CLL. 2011c. Pigeonpea composite collection and identification of germplasm in crop improvement programmes. Plant Genetic Resources: Characterization and Utilization 9(1): 97-108.
- Upadhyaya HD, Reddy LJ, Gowda CLL and Singh S. 2009. Phenotypic diversity in cold-tolerant peanut (*Arachis hypogaea* L.) germplasm. Euphytica 165: 279-291.
- Upadhyaya HD, Reddy LJ, Gowda CLL, Reddy KN and Singh S. 2006. Development of a mini core subset for enhanced and diversified utilization of Pigeonpea germplasm resources. Crop Science 46: 2127-2132.
- Upadhyaya HD, Salimath PM, Gowda CLL and Sube Singh. 2007b. New early-maturing germplasm lines for utilization in chickpea improvement. Euphytica 157: 195-208.
- Upadhyaya HD, Yadav D, Dronavalli N, Gowda CLL and Singh S. 2010. Mini core germplasm collections for infusing genetic diversity in plant breeding programs. e-journal of Plant Breeding 1: 1294-1309.
- Upadhyaya HD. 2005. Variability for drought resistance related traits in the mini core collection of peanut. Crop Science 45: 1432-1440.
- Upadhyaya HD. 2008. Crop germplasm and wild relatives: a source of novel variation for crop improvement. Korean Journal of Crop Science 53: 12-17.
- Upadhyaya, HD, Reddy LJ, Gowda CLL and Sube Singh. 2006. Identification of diverse groundnut germplasm: Sources of early-maturity in a core collection. Field Crops Research 97: 261-271.
- USDA. 2010. <http://www.cnpp.usda.gov/Publications/DietaryGuidelines/2010/PolicyDoc/Chapter4.pdf>
- Vadez V and Sinclair TR. 2001. Leaf ureide degradation and N₂ fixation tolerance to water deficit in soybean. Journal of Experimental Botany 52: 153-159.
- Vadez V, Berger JD, Warkentin T, Asseng S, Ratnakumar P, Chandra Rao KP, Gaur PM, Munier-Jolain N, Larmure A, Voisin A-S, Sharma HC, Pande S, Sharma M, Krishnamurthy L and Zaman M. 2011. Adaptation of grain legumes to climate change: a review. Agronomy for Sustainable Development. DOI 10.1007/s13593-011-0020-6.
- Vadez V, Deshpande SP, Kholova J, Hammer GL, Borrell AK, Talwar HS and Hash CT. 2011a. Staygreen QTL effects on water extraction and transpiration efficiency in a lysimetric system: Influence of genetic background. Functional Plant Biology 38: 553-566.
- Vadez V, Krishnamurthy L, Serraj R, Gaur PM, Upadhyaya HD, Hoisington DA, Varshney RK, Turner NC and Siddique KHM. 2007. Large variation for salinity tolerance in chickpea is explained by differences in sensitivity at reproductive stages. Field Crops Research 104: 123-129.
- Vadez V, Lasso JH, Beck DP and Drevon JJ. 1999. Variability of N₂-fixation in common bean (*Phaseolus vulgaris* L.) under P-deficiency is related to P use efficiency. Euphytica 106(3): 231-242.
- Vadez V, Rao S, Kholova J, Krishnamurthy L, Kashiwagi J, Ratnakumar P, Sharma KK, Bhatnagar-Mathur P and Basu PS. 2008. Roots research for legume tolerance to drought: Quo vadis? Journal of Food Legumes 21: 77-85.
- Vadez V, Rodier F, Payre H and Drevon JJ. 1996. Nodule permeability to O₂ and nitrogenase-linked respiration in bean genotypes varying in the tolerance of N₂ fixation to P deficiency. Plant Physiology and Biochemistry 34: 871-878.
- Value Chain Finance Centre. 2009. Agricultural value chain financing in Kenya: Assessment of potential opportunities for growth. Nairobi. 81 pp.

- van den Brand G. 2011. Towards increased adoption of grain legumes among Malawian farmers- Exploring opportunities and constraints through detailed farm characterization. MSc thesis Plant Production Systems and Sustainable Development. University of Utrecht, Wageningen UR. 78 pp.
- van Emden HF, Ball SL and Rao MR. 1988. Pest, disease and weed problems in pea lentil faba bean and chickpea. Pages 519-534 in *World Crops: Cool season food legumes* (Summerfield RJ. ed.). Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Varshney RK, Close TJ, Singh NK, Hoisington DA and Cook DR. 2009a. Orphan legume crops enter the genomics era! *Current Opinion in Plant Biology* 12: 202-210.
- Varshney RK, Glaszmann JC, Leung H and Ribaut JM. 2010. More genomic resources for less-studied crops. *Trends in Biotechnology* 28: 452-460.
- Varshney RK, Graner A and Sorrells ME. 2005. Genomics-assisted breeding for crop improvement. *Trends in Plant Sciences* 10: 621-630.
- Varshney RK, Nayak SN, May GD and Jackson SA. 2009b. Next-generation sequencing technologies and their implications for crop genetics and breeding. *Trends in Biotechnology* 27: 522-530.
- Vega FE, Posada F, Aime MC, Pava-Ripoll M, Infante F and Rehner SA. 2008. Entomopathogenic fungal endophytes. *Biological Control* 46: 72-82.
- Wahid A, Gelani S, Ashraf M and Foolad MR. 2007. Heat tolerance in plants: An overview. *Environmental and Experimental Botany* 61: 199-223.
- Waliyar F. 1991. Yield losses of groundnut due to foliar diseases in West Africa. Proc. 2nd Reg. Groundnut Workshop, Niamey, Niger, ICRISAT, Patancheru, India.
- Walker BH and Salt DA. 2006. Resilience thinking: Sustaining ecosystems and people in a changing world. Island Press, Washington.
- Wani SP, Rupela OP and Lee KK. 1995. Sustainable agriculture in the semi-arid tropics through biological nitrogen fixation in grain legumes. *Plant Soil* 174: 29-49.
- Warning M and Key N. 2000. The social performance and distributional impact of contract farming: The Arachide de Bouche Program in Senegal. Working paper 00-3. Department of Economics, University of Puget Sound. <http://www.ups.edu/faculty/mwarning/papers.htm>.
- Welch R and Graham R. 2000. A new paradigm for world agriculture: productive, sustainable, nutritious, healthful food systems. *Food and Nutrition Bulletin* 21: 361-366.
- Wenden B and Rameau C. 2009. Systems biology for plant breeding: the example of flowering time in pea. *Comptes Rendus Biologies* 332: 998-1006.
- Wenger E. 1994. Knowledge management as a doughnut: Shaping your knowledge strategy through communities of practice. *Ivey Business Journal*.
- Westlake M. 2001. Final report on strategic crops sub-sector.  Project GCP/SYR/006/ITA Assistance in Institutional Strengthening and Agricultural Policy. FAO and Syrian Ministry of Agriculture and Agrarian Reform. Rome: Food and Agriculture Organization of the United Nations. 60 pp.
- WHO 2008. Worldwide prevalence of anaemia 1993–2005: WHO global database on anaemia. WHO, Geneva.
- Wood JA and Grusak MA. 2007. Nutritional value of chickpea. Pages 101-142 in *Chickpea breeding and management* (Yadav SS, Redden RJ, Chen W and Sharma B. eds.). Oxfordshire, UK: CAB International.
- World Bank 2008. World Development Report. Agriculture for Development. Washington DC: The World Bank, USA.
- Wortmann CS, Kirkby RA, Elude CA and Allen DJ. 1998. Atlas of common bean (*Phaseolus vulgaris* L.) production in Africa. CIAT Publication No.297. 133 pp.
- Xu JL, Lafitte HR, Gao YM, Fu BY, Torres R and Li z K. 2005. QTLs for drought escape and tolerance identified in a set of random introgression lines of rice. *Theoretical and Applied Genetics* 111: 247-259.
- Yadav SS, McNeil DL and Stevenson PC (eds.). 2007. Lentil: an ancient crop for modern times. Springer, Dordrecht, The Netherlands, pp. 173-186.
- Yadav SS, Redden R, Hatfield JL, Lotze-Campen H and Hall A. 2011. Crop adaptation to climate change. John Wiley & Sons, Inc. (In press).
- Yanguba AJ. 2009. Adoption and social impact assessment of soybean production and utilization in southern Borno State, Northern Nigeria. Maiduguri: Promoting Sustainable Agriculture in Borno State (PROSAB) project report. 125 pp.
- Yayock JY, Rossel HW and Harkness C. 1976. A review of the 1975 groundnut rosette epidemic in Nigeria. Samaru Conference Paper 9. Institute for Agricultural Research (Samaru). Ahmadu Bello University, Zaria, Nigeria. 12 pp.
- Yenish JP. 2007. Weed Management in Chickpea. Pages 233-245 in *Chickpea Breeding and Management* (Yadav SS, Redden RJ, Chen W and Sharma B. eds.). CAB International, Oxfordshire, UK. ISBN 1-84593-213-7.
- Zaman-Allah M, Jenkinson D and Vadez V. 2011. A conservative pattern of water use, rather than deep or profuse rooting, is critical for the terminal drought tolerance of chickpea. *Journal of Experimental Botany* doi: 10.1093/jxb/err139.

- Zaman-Allah M, Jenkinson D and Vadez V. 2011. Chickpea genotypes contrasting for seed yield under terminal drought stress in the field differ for traits related to the control of water use. *Functional Plant Biology* 38: 270-281.
- Zengeni R and Giller KE. 2007. Effectiveness of indigenous soybean rhizobial isolates to fix nitrogen under field conditions of Zimbabwe. *Symbiosis* 43: 129-135.

Appendix 1. CRP 3.5 GRAIN LEGUMES Initial Partners: Capacities and Priorities

CIAT: The International Center for Tropical Agriculture, Colombia

CIAT, headquartered in Cali, Colombia holds a mandate for research on *Phaseolus* beans. The *Phaseolus* genus is of neotropical origin and CIAT is located in the center of diversity of the crop. Five cultivated species of *Phaseolus* are conserved in the Genetic Resources Unit (almost 40,000 accessions), although most research is directed towards *Phaseolus vulgaris*, the common bean.

The ecologies in which *Phaseolus* species evolved range from arid to tropical rainforests, so the genus offers a unique perspective on adaptations across extremes of environmental conditions – especially relevant to looming climate change. The species with which the common bean may be hybridized cover most of this range, and represent a unique reservoir of genetic diversity.

CIAT's historical strength has been in genetic improvement. More than 300 varieties have been released by countries in Latin America and more than 170 in Africa. On both continents disease-resistant varieties have been the primary product. In Latin America varieties with resistance to Gemini viruses have been the hallmark, while in Africa root rot resistant varieties have sustained bean production in western Kenya and neighboring countries. The most dramatic impact has resulted from the introduction of improved climbing bean varieties in central and eastern Africa, first in Rwanda where they tripled yields, and subsequently spreading to Kenya, Uganda and Tanzania. Thirty years ago Rwanda was a net importer of beans; today that country exports beans to its neighbors.

CIAT has long emphasized participatory research and farmer involvement in the selection of new varieties. CIAT also pioneered the establishment of functional regional research networks, first in Central America, followed by East-Central Africa and the Andean zone. Today the Pan-African Bean Research Alliance (PABRA) is a model for partnership and has served to jump start the Wider Impact Program – a platform for interaction among actors along the research-to-development continuum that nurtures impact pathways by facilitating communication between those who supply and those who demand new technology.

To CRP 3.5, CIAT contributes a headquarters team of two breeders, a molecular biologist, a pathologist, an entomologist and a plant nutritionist is supported by shared-time contributions from agricultural geographers, a human nutritionist, a biometrician and statisticians. In Africa (Uganda and Malawi) CIAT contributes breeders, a pathologist, an agricultural economist, a geographer, a marketing specialist, and a seed systems specialist.

Looking ahead, climate change will bring particular challenges to bean cultivation. Central America and Mexico have always suffered periodic droughts, and meteorologists predict that the region will become progressively drier. However, beans are even more sensitive to excess moisture, and eastern Africa and the Andean zone may suffer greater average rainfall with accompanying disease pressure of root rots and other fungi. Soil fertility continues to be the biggest single constraint on bean yields, and climate change will likely accelerate the mineralization of organic matter, making such constraints even more acute. Adapting beans to problem soils will be the biggest challenge of all for increasing bean yields, and forms a major activity in CIAT's current research agenda.

EIAR: Ethiopian Institute of Agricultural Research, Ethiopia

Ethiopian Institute of Agricultural Research (EIAR), formerly known as the Ethiopian Agricultural Research Organization (EARO), is part of Ethiopian Agricultural Research System (EARS), and is the largest NARS institution which is responsible for the running of federal agriculture research centers. It is head quartered at Addis Ababa and is run under the aegis of Ministry of Agriculture and Rural Development. In addition to conducting research at its federal centers, EIAR is charged with the

responsibility for providing the overall coordination of agricultural research countrywide, and advising Government on agricultural research policy formulation. Currently, the EARS comprise 55 research centers and sites located across various agro-ecological zones. The research centers vary in their experience, human, facility, and other resources capacities. Some of the research centers and sites have one or more sub-centers and testing sites.

EIAR's mission is to conduct research that will provide market competitive agricultural technologies that will contribute to increased agricultural productivity and nutrition quality, sustainable food security, economic development, and conservation of the integrity of natural resources and the environment. As an apex body, EIAR provides strong leadership in coordinating research within the EARS, by taking a leading role in influencing agricultural policy development.

Core Mandates of EIAR include:

- Supply of improved agricultural technologies
- Popularization of improved technologies
- Coordination the national agricultural Researches
- Capacity building of Researchers

The grain legume priorities of EIAR's research include chickpea, lentil, pea, horse bean, mung bean and haricot bean.

EMBRAPA: The Brazilian Agricultural Research Corporation, Brazil

The Brazilian Agricultural Research Corporation (EMBRAPA) located in Distrito Federal, serves Brazilian society through the 38 Research Centers, 3 Service Centers and 13 Central Divisions distributed in different states of Brazil. There are 8,275 employees of which 2,113 are researchers. EMBRAPA coordinates the National Agricultural Research System, which includes most public and private entities involved in agricultural research in the country. EMBRAPA maintains projects in international cooperation in order to perfect knowledge of technical and scientific activities or to share knowledge and technology with other countries.

EMBRAPA has generated and recommended more than 9000 technologies for Brazilian agriculture, reduced production costs and helped Brazil to increase the offer of food while, at the same time, conserving natural resources and the environment and diminishing external dependence on technologies, basic products and genetic materials.

EMBRAPA's current major research areas include: (i) Genetic improvement of soybean, wheat and sunflower cultivars; (ii) Soybean pest control techniques; (iii) Techniques in reduction of soybean harvest loss; (iv) Soil-plant management for soybean production stability; (v) Socio-economic studies of soybean production. Hence soybean, bean and groundnut are EMBRAPA's grain legume priority crops; CRP 3.5 GRAIN LEGUMES outcomes would certainly add strengths to EMBRAPA's program and vice versa.

Products that EMBRAPA can share with CRP 3.5 GRAIN LEGUMES include: (i) Specialized publications and video-tapes; (ii) Biological insecticides and parasiticides for soybean pests; and (iii) Improved Soybean cultivars.

GCP: The Generation Challenge Programme

The **Generation Challenge Programme (GCP)** was created by the CGIAR in 2003 as a time-bound 10-year program. Its mission is to use genetic diversity and advanced plant science to improve crops by adding value to breeding for drought-prone and harsh environments. This is achieved through a network of more than 200 partners (as of 2009) drawn from CGIAR Centers, academia, regional and national research programs, and capacity enhancement to assist developing world researchers to tap into a broader and richer pool of plant genetic diversity.

GCP's network advances the frontiers of knowledge and develops practical tools such as molecular

markers for desirable genes, for efficient field selection in plant breeding. Through its network of partners in the CGIAR, ARIs, NARS and private sector, GCP implements programs that bring together plant scientists from different disciplines to improve crops for the ultimate benefit of resource-poor farmers. GCP works with cutting-edge plant biology research partners, and augments the efforts of the CGIAR and the broader agricultural research-for-development community. In the context of this CRP, GCP's efforts to develop an Integrated Breeding Platform and associated innovative breeding projects on various crops will be of tremendous value. This platform will comprise a one-stop-shop providing access to genetic stocks, pre-breeding materials, high throughput services for marker and trait evaluation, informatics tools, support services, capacity development and community support for conducting genomics research and integrated breeding projects. (www.generationcp.org)

GDAR: General Directorate of Agricultural Research, Turkey

Agricultural Research in Turkey is considered essentially a public duty which is mainly covered by the Ministry of Agriculture and Rural Affairs (MARA). Other functionaries which also took part in agricultural development are the Ministry of Environment and Forestry, Universities and TUBITAK (Turkish Scientific and Technological Council).

General Directorate of Agricultural Research (GDAR) is the apex body to administer agricultural research in Republic of Turkey, and is part of MARA. Under the administration of GDAR, there are 7 Central, 9 Regional, 32 subject-specific (14 Horticulture and Field Crops, 3 Plant Health, 4 Animal Husbandry, 3 Aquaculture and 8 Animal Health) and 12 Soil and Water Research Institutes are in operation throughout the country. Human Resources at GDAR include 1608 staff of which men are 1102 (69%) and women are 506 (31%).

Current Research Activities of GDAR: Biodiversity/Genetic Resources and Plant Improvement; Integrated Growing/Production Systems/ICM; Post-harvest Technologies; Agricultural Economy/Marketing; Food and Feed Technologies; Soil and Water Resources Management; Organic Agriculture; and Biosafety.

ICAR: Indian Council of Agricultural Research, India

The Indian Council of Agricultural Research (ICAR) is an autonomous organization under the Department of Agricultural Research and Education (DARE), Ministry of Agriculture, Government of India. ICAR is headquartered in New Delhi. With 97 ICAR institutes and 47 agricultural universities across the country, ICAR is one of the largest national agricultural systems in the world. As the apex body for coordinating, guiding and managing research and education in agriculture in the country, ICAR provides advice that informs government policies and programs on grain legume food security issues.

More than 250 scientists work on legumes in ICAR programs. ICAR institutes that work on grain legumes include the Indian Institute for Pulses Research (IIPR, Kanpur), the Indian Agricultural Research Institute (IARI, New Delhi), the Central Research Institute of Dryland Agriculture (CRIDA; Hyderabad), the Directorate of Groundnut Research (Junagadh), and the Directorate of Soybean Research (Indore). Under the All India Coordinated Research Project (AICRP) 58 research institutes (including state agricultural universities) work on chickpea, and 22 research institutes each work on pigeonpea and groundnut. Collectively these institutions address a wide range of grain legumes including chickpea (*Cicer arietinum*), pigeonpea (*Cajanus cajan*), mung bean (*Vigna radiata*), urdbean (black gram; *Vigna mungo*), lentil (*Lens culinaris*), lathyrus (*Lathyrus sativus*), common bean (*Phaseolus vulgaris*), pea (*Pisum sativum*), groundnut (*Arachis hypogaea*) and soybean (*Glycine max*). They address plant breeding, biotechnology, genetic resources (collection, evaluation and conservation), cropping systems research, integrated pest and disease management, on-farm research and informatics and postharvest technology.

The main issues that the ICAR institutes are currently addressing include increasing and stabilizing the production of legumes, in order to address national production shortfalls and to reduce the prices of these commodities, insect pest resistance (particularly against *Helicoverpa*) and expanding legume

cultivation in rice fallows and other niches.

ICAR works collaboratively with many CGIAR centers. Some of the strengths that the ICAR institutes that will contribute to CRP 3.5 include: (i) a large network of testing sites/locations for multi-location evaluation; (ii) capacity development for other NARS, especially from South Asia; (iii) leadership in farm machinery, mechanization, postharvest technologies, and development of novel food products; and (iv) possible coordination of activities in crops for centers not having offices in India

ICARDA: International Center for Agricultural Research in Dry Areas, Syria

ICARDA conducts breeding improvement R4D on kabuli chickpea, lentil, faba bean and grasspea in the temperate zone of the developing world, and is exploring expansion into field pea (*Pisum sativum*). ICARDA holds large genetic resource collections of all these crops and carries out collection, conservation and utilization studies to enhance their utility for crop improvement. A few major accomplishments to date include the development of winter planted chickpea technology for West Asia and North Africa that more than doubles yields; improved short-duration lentil varieties that triggered an increase in production from 600,000 tons to 1.27 million tons in the last 30 years in South Asia; new faba bean varieties that have contributed to poverty alleviation in Ethiopia, Sudan and Egypt; and the release of low-neurotoxin grasspea variety in Ethiopia.

Drought, cold, heat and salinity tolerance are major abiotic challenges being addressed through breeding, while soil-borne and foliar pathogens and parasitic weeds are leading biotic constraints receiving attention. This includes resistance breeding/screening and integrated pest management of leaf miner, aphids, Sitona weevils and against important viruses of grain legumes along with seed health testing, diagnostic kits for viruses, and village-level seed systems support. Conventional and molecular breeding approaches are utilized. For pests not endemic/epidemic in Syria, ICARDA relies on partnership with NARS to screen target crosses and other genetic materials. Agronomic research addresses tillage effects (till vs. no-till, irrigation vs. rainfed) on disease resistance and yield.

Major current activities focus on:

- Developing pre-breeding programs to introgress useful allele(s)/genes particularly from wild relatives;
- Increasing R4D on climate variability and development of heat, cold, and drought resistant germplasm using modern biotech approaches such as QTL and association mapping of these traits in lentil and chickpea;
- Developing disease and pest resistant varieties and IPM packages for existing and new biotic emerging threats in response to climate variability and change;
- Addressing pest problems in South Asia especially botrytis grey mold, wilt/root rot resistance and Stemphylium blight in partnership with NARS;
- A new effort to introduce pulses such as lentil into rice-fallow systems;
- Developing kabuli chickpea for East Africa (e.g. Ethiopia) to enter in the international kabuli commodity market;
- Developing different market classes of lentil and faba bean;
- Biofortification of lentil with iron and zinc and extending the work to chickpea, faba bean and pea;

Strengths that ICARDA will contribute to CRP 3.5 include a bio-pesticide laboratory; a large collection of bio-control agents; a strong seed technology section also focusing on seed delivery systems; screening facilities for *Fusarium* wilt, *Ascochyta* blight, cold tolerance and water supply variability; a well-organized plant virology laboratory providing training and support of NARS in virus identification and diagnosis; geospatial sciences capacity that improves understanding of germplasm and targeting of breeding efforts to fit climatic and soil environments; food-feed and crop residue research including a small ruminant research unit (sheep and goats); a biotechnology laboratory that routinely transforms

chickpea and lentil; a large collection of Rhizobium (1400 accessions) for BNF R4D; a legume food quality lab addressing nutritional (iron, zinc); and a strong international germplasm testing network with NARS.

ICRISAT: International Crops Research Institute for the Semi-Arid Tropics, India

ICRISAT improves chickpea, groundnut and pigeonpea crops and systems that are widespread across the tropical drylands and beyond. These crops are among the hardiest of the grain legumes against drought and heat, having evolved under conditions of high variability in rainfall, temperature and soil quality. ICRISAT holds in trust for humanity one of the world's largest collections of grain legume genetic resources. This includes 20,140 accessions of chickpea, 15,419 of groundnut, and 13,632 of pigeonpea.

ICRISAT conducts R4D on the characterization and use of this germplasm for plant breeding, including drought and heat physiology, pathology and entomology studies supported by a strong biotechnology effort. Cropping systems R4D addresses soil, water and nutrient management, while markets, institutions and policies are also studied to enhance market-access and profits for poor farmers. All these directions are accompanied by capacity-building activities to strengthen partner institutions across the dryland tropics of Africa and Asia.

Impacts to date have been large. Fifty-four countries have released improved cultivars of groundnut (135), chickpea (116) and pigeonpea (65) using germplasm accessions and breeding materials supplied by ICRISAT, resulting in impacts estimated at over US\$150 million annually in increased production. A few of these impacts are highlighted in Chapter 3. With their partners, biotechnologists in ICRISAT have constructed reference genetic maps in chickpea, groundnut and pigeonpea, and are in the process of sequencing the genomes of chickpea and pigeonpea.

In the partnership arena, ICRISAT has played a catalytic and coordinating role in the Cereals Legumes Asia Network (CLAN) since its inception. In recent years ICRISAT pioneered an important public-private partnership known as the Hybrid Parents Research Consortium (HPRC) with private-sector seed companies to which all partners contribute to advance hybrid varieties and seed supply chains. Another private-public partnership achievement is the Agri-business Innovation Platform (AIP) that fosters entrepreneurship to increase the availability of modern technology to poor dryland tropical farming communities. ICRISAT will contribute the experiences, partnerships and capacities gained in all the above areas to CRP 3.5.

IITA: International Institute for Tropical Agriculture, Nigeria

IITA improves cowpea and soybean for the sub-humid and semi-arid areas of sub-Saharan Africa. Research on the important but neglected bambara groundnut crop has recently been re-initiated. IITA aims to improve integrated farming systems, varieties, seed systems, plant health management and natural resource management. IITA also addresses postharvest value-chain activities in order to stimulate commercial demand through improved processing and marketing of grain legume products.

In view of the integrated and multiple objectives of small-scale farmers in Africa, IITA develops multiple-purpose varieties that provided grains for human food, feed for livestock and improve soil fertility. These targets include the development of efficient and effective rhizobial inoculants to enhance BNF, and integrated plant health management options. The IITA genebank holds the world's largest and most diverse collection of cowpeas, with 15,122 accessions from 88 countries representing 70% of African cultivars and nearly half of the crop's global diversity. The gene bank also holds 1742 soybean and 1815 bambara groundnut.

In cowpea the development and dissemination of a wide range of cultivars has led to increases in production and incomes of small-scale farmers. Improved varieties have been released by 68 countries around the world. Varieties tolerant to the parasitic weeds *Striga* and *Alectra* have reduced production losses. Other technologies that have increased cowpea production include the establishment of a novel

parasitoid against flower thrips in West Africa, and the development of cheap delivery systems for natural enemies of the legume pod borer.

In view of the commercial importance of soybean around the world, IITA approached the crop from a value chain perspective in Nigeria, generating major impact with partners. Keys to this success were the development and dissemination of promiscuously-nodulating varieties in concert with improved processing and utilization technologies and activities to raise public awareness of home preparation methods. Ensuring that all value chain bottlenecks were alleviated led to the emergence of a number of medium and large-scale soybean processors that added further value to the chain. IITA will contribute this learning to CRP 3.5 to assist its application to other grain legumes.

Current priorities include:

- Disease-resistant varieties targeted to a range of uses
- Improved resistance to drought and low phosphorus
- Resistance to *Maruca* pod borer
- Reducing the excessive use of synthetic insecticides
- Partnering with NGOs and private sector for the production of bio-pesticides
- Development of efficient rhizobial inoculants to increase BNF
- Improved nutritional quality, particularly for micronutrients
- Improved processing and utilization
- Crop management practices to increase productivity
- Dissemination and impact analysis

Pulse CRSP: The Dry Grain Pulse Collaborative Research Support Program, USA

The Dry Grain Pulses Collaborative Research Support Program (Pulse CRSP), funded by the Bureau of Food Security, USAID-Washington, seeks to contribute to economic growth and food and nutrition security through knowledge and technology generation that strengthens edible grain legume (e.g., bean, cowpea, pigeonpea, chickpea etc.) value chains and enhances the capacity and sustainability of agriculture research institutions which serve these sectors in developing countries in Sub-Saharan Africa and Latin America. Under the technical and administrative leadership of Michigan State University, U.S. university scientists collaborate in multi-disciplinary research and technology dissemination projects with National Agriculture Research Systems, agriculture universities, NGOs, International Agriculture Research Centers (CIAT, IITA, ICRISAT), and private sector organizations in approximately 20 countries. The Pulse CRSP seeks to contribute to USAID's Feed the Future global research objectives by focusing on the following themes:

- To reduce bean, cowpea and related dry grain pulses production costs and risks for enhanced profitability and competitiveness,
- To increase the utilization of bean, cowpea and other dry grain, food products, and ingredients so as to expand market opportunities and improve community health and nutrition,
- To improve the performance and sustainability of dry grain pulse value chains, especially for the benefit of women, and
- To increase the capacity, effectiveness and sustainability of agriculture research institutions which serve the dry grain pulse sectors and developing country agricultural industries.

Appendix 2. Brief Profiles of CRP 3.5 Target Crops

Chickpea (*Cicer arietinum* L.) is the world's second-largest cultivated food legume. Developing countries account for over 95% of its production and consumption (Gaur et al. 2008). Chickpea grain is an excellent source of high-quality protein, with a wide range of essential amino acids (Wood and Grusak 2007) and high ability to fix atmospheric nitrogen. Since major consumers such as India do not produce sufficient chickpeas domestically, there are opportunities especially for East African countries to sell into this important market; indeed, sown area in ESA doubled over the past 30 years and exports accounted for about 30% of total production, indicating that these poor farmers are using chickpea for both food and to earn extra income. The area under chickpea in West Asia has also increased dramatically in the past 30 years (from 378,000 ha to 1,526,000 ha) leading to the exportation of chickpea from countries such as Turkey, Syria, and Iran. Drought stress commonly affects chickpea because it is largely grown under rainfed conditions during the post-rainy season on residual soil moisture (Gaur et al. 2008). R4D on drought tolerance has paid dividends in recent years with the improved drought tolerant chickpea cultivars. Collar rot, *Fusarium* wilt, dry root rot and *Ascochyta* blight are some of the important diseases of chickpea in the Indian subcontinent, whereas *Ascochyta* blight and *Fusarium* wilt are the most important worldwide (Chen et al. 2011). Chickpea in CWANA is traditionally grown during spring to avoid ascochyta blight and cold/frost but then encounters drought conditions, reducing potential yields (Malhotra et al. 2009).

Common bean (*Phaseolus vulgaris* L.) is the most important grain legume for direct human consumption with 23 m ha grown worldwide (Broughton et al. 2003). Approximately 12 million metric tons are produced annually, of which about 8 million tons are from Latin America and Africa (FAO, 2005). Over 200 million people in SSA depend on the crop as a primary staple, with beans contributing to diet and incomes in over 24 countries in this region alone (Wortmann et al. 1998). In the developing world bean is a small farmer crop, and in Africa is cultivated largely by women. Consumption is as high as 66 kg/year/person, and in many areas, common bean is the second most important source of calories after maize. Typical bean yields, however, represent only 20 to 30% of the genetic potential of improved varieties due to major production risks such as insect pests, diseases and drought, which – due to climate change – is increasing in severity and frequency in the region (Funk et al. 2008). Drought affects production of common beans in most of Eastern Africa, but is especially severe in the mid-altitudes of Ethiopia, Kenya, Tanzania, Malawi and Zimbabwe, as well as in Southern Africa as a whole.

Cowpea (*Vigna unguiculata*) is the most important grain legume crop in sub-Saharan Africa (Timko et al. 2007), grown by tens of millions of smallholders. It is estimated that 200 million children, women, and men in West Africa rely on cowpea, consuming the grain daily whenever available. It is mostly grown in the hot drought-prone savannas and very arid Sahelian agro-ecologies, where it is often intercropped with pearl millet and sorghum (Hall, 2004). Cowpea is a protein-rich grain that complements staple cereal and starchy tuber crops, but also provides fodder for livestock, soil improvement benefits through nitrogen fixation, and households benefits in the form of cash and income diversity. Cowpea is highly drought-tolerant with deep roots that help stabilize the soil and dense foliage that shades the soil surface preserving moisture. Cowpea 'on-farm' grain yields in SSA reach only 10–30% of their biological yield potential, due primarily to insect and disease attacks and drought (Ehlers and Hall, 1997). Improved varieties are urgently needed that will help to reduce this yield gap (Hall et al. 1997).

Faba bean (*Vicia faba* L.) Faba bean (*Vicia faba* L.) also called fava bean, broad bean, field bean, horse bean and bell bean is an erect leafy winter or summer annual. It is one of the oldest crops domesticated in the Fertile Crescent of the Near East. It expanded around the world during Neolithic period: from Antalya (Turkey) towards Europe (Germany, Greece, France, Italy and Spain); from Egypt across North Africa and eastwards to Afghanistan and onwards to China, India and in more recent times to Latin America and North America (Canada and USA) (Cubero, 1974). In WANA faba bean is cultivated in coastal Mediterranean areas with 300 mm and above annual rainfall. In China there are two major production

areas, one sown in winter (mainly in the southern province of Yunnan) and the other sown in spring (in highlands stretching from Mongolia to Tibet). Faba bean is grown in northern India (Bihar, Uttar Pradesh, Madhya Pradesh, Chhattisgarh, Jharkhand, Orissa, West Bengal). In Latin America it is mainly grown in Argentina and Chile. Cultivated faba bean is used as human food in developing countries, and as animal feed (mainly for pigs, horses, poultry and pigeons) in developed countries and in North Africa. In addition to boiled grains, it is consumed as vegetable green seeds/pods, dried or canned. It is a staple breakfast food in the Middle East, Mediterranean region, China and Ethiopia (Bond et al. 1985). Faba bean has a protein content of 24-30 percent. Although the global average grain yield of faba bean has almost doubled during the past 50 years, the total area sown to the crop has declined by 56% over the same period due to the cheap availability of fertilizers (devaluing some of the short-term economic benefits of BNF) and competition with policy-favored cereal and high-value urban cash crops. The most important diseases of faba bean are chocolate spot (*Botrytis fabae* and *B. cinerea*), rust (*Uromyces viciae fabae*), Ascochyta blight (*Ascochyta fabae*), black root rot (*Thielaviopsis basicola*), stem rots (*Sclerotinia trifoliorum*, *S. sclerotiorum*), root rots/damping-off (*Rhizoctonia* spp.), pre-emergence damping-off (*Pythium* spp.), bean yellow mosaic virus, bean true mosaic virus, bean leaf roll virus and bean yellow necrotic virus (van Emden et al. 1988). Among the insect pests, bruchids and aphids are important.

Groundnut (*Arachis hypogaea*), is known by many local names including peanut, earthnut, monkey nut and poor man's nut. Though groundnut is native to South America, it is successfully grown in other parts of the world and became an important oil seed and food crop. From a nutritional point of view, groundnuts are very important in the lives of poor as they are very rich source of protein (26%) and monounsaturated fat. In addition to protein, groundnuts are a good source of calcium, phosphorus, iron, zinc and boron. While China and India are the leading producers worldwide, millions of small-holder farmers in sub-Saharan Africa (SSA) grow groundnut as a food and cash crop, which accounts for 9m ha of cultivated farmland (2007 datum). While this area is 40% of the world total, this percentage represents only 25% of the total production due to low yield (950 kg/ha, versus 1.8 t/ha in Asia). The main constraints hampering higher yields and quality in Africa are intermittent drought due to erratic rainfall patterns and terminal drought during maturation. Yield losses from drought run to millions of dollars each year (Sharma and Lavanya 2002). A drought-related quality issue is pre-harvest contamination of seeds with aflatoxin, a carcinogenic mycotoxin produced primarily by the fungus *Aspergillus flavus*, which consequently shuts out SSA groundnuts from export markets. In addition, major foliar fungus diseases like early leaf spots (ELS) and late leaf spots (LLS) and Rust; and virus diseases like Rosette, Peanut Clump and Bud Necrosis causes devastating yield losses (50-60% yield losses by ELS--LLS, Waliyar et al. 1991; Grichar et al. 1998) and as much as 100% by rosette in epidemic years, Yayock et al. 1976., Olorunju et al. 1992).

Lentil (*Lens culinaris* Medikus), one of the world's oldest cultivated plants, originating in the Middle East and spreading east through Western Asia to the Indian subcontinent. Lentil is currently grown in South America, Europe, Australia and Asia (Bangladesh, India, Jordan, Lebanon, Syria and Turkey). Lentil has a variety of different names in different countries and languages including *Masoor* (India), *Adas* (Arabic), *Mercimek* (Turkey), *Messer* (Ethiopia) and *Heramame* (Japanese) giving some indication of the breadth of its importance (Erskine et al. 2009). It is a short-statured, annual, self-pollinated, high valued crop species. The crop has great significance in cereal-based cropping systems because of its nitrogen fixing ability, its high protein seeds for human diet and its straw for animal feed. Protein content ranges from 22 to 35% and like other grain legumes its amino acid profile is complementary to that of cereals. Lentil is currently grown on 3.8 M ha worldwide (though much of this is in developed countries) with production of over 3.5 M metric tons (FAOSTAT, 2008). The major reason for its low productivity in developing countries is because the crop produced on marginal lands in semi-arid environments without irrigation, weeding or pest control. The major producers of lentil are the countries in Southern and Western Asia, Northern Africa, Canada, Australia and USA (Chen et al. 2011). The most economically important fungal diseases of lentil worldwide are *Ascochyta* blight and *Fusarium* wilt; however other diseases such as anthracnose, *Stemphylium* blight and *Botrytis* blight are also

economically significant. Major pests include aphids, bud weevils, cutworms, leaf weevils, pod borer, stink bugs and thrips (Chen et al. 2011).

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is a staple grain legume in South Asian diets and is also widely grown and consumed in household gardens in Africa – and rapidly expanding as an export crop from Eastern/Southern Africa to South Asia. Household artisanal production is not well documented in the FAO database, which indicates total global area of 4.79 M ha (FAO, 2008) in 22 countries. India is by far the largest producer with 3.58 M ha although this is insufficient to meet all its consumption needs; it imports from neighbor Myanmar (560,000 ha) and other countries, notably in ESA. In Africa smallholders are most intensified for dual consumption and export in Kenya (196,000 ha), Malawi (123,000 ha), Uganda (86,000 ha), Mozambique (85,000 ha), and Tanzania (68,000 ha) (Saxena et al. 2010). With protein content totaling more than 20%, almost three times that of cereals, pigeonpea plays an important role in nutrient-balancing the cereal-heavy diets of the poor. Pigeonpea is also important in some Caribbean islands and some areas of South America associated where populations of Asian and African heritage have settled (Saxena et al. 2010). In addition to being an important source of human food and animal feed, pigeonpea also plays an important role in sustaining soil fertility by improving physical properties of soil and fixing atmospheric nitrogen. Traditional long-duration pigeonpea expresses a perennial tall bush like growth habit that conveys additional soil protection and deep-rooted nutrient recycling ability. Shorter-duration varieties will naturally have less time to provide such services. Pigeonpea is generally relay or intercropped with sorghum, cotton, maize and groundnut and thus has to compete with that associated crop for water, nutrients, sunlight and other resources. Recently, ICRISAT has developed hybrid pigeonpea cultivars that produce 35% higher yields and are currently being multiplied through the private sector for dissemination to farmers. Major biotic stresses include diseases especially sterility mosaic, *Fusarium* wilt, and *Phytophthora* blight in the Indian subcontinent; wilt and *Cercospora* leaf spot in eastern Africa; and witches' broom in the Caribbean and Central America (Reddy et al. 1990). The major insect pests are pod fly (*Melanagromyza* sp), pod borers (*Helicoverpa armigera* and *Maruca vitrata*), and pod sucker (*Clavigralla* sp) (Joshi et al. 2001). Major abiotic constraints are drought and in some areas intermittent waterlogging.

Soybean (*Glycine max* L. Merr.) cultivation originated in China around 1700-1100 B.C. Soybean is now cultivated throughout East and Southeast Asia, North America, Brazil and Africa where people depend on it for food, animal feed and medicine. It is highly industrialized in developed countries, providing more than a quarter of world's food and animal feed requirement in addition to protein (Graham and Vance, 2003). It grows well in tropical, subtropical, and temperate climates during warm, moist periods. Postharvest technologies such as oil processing have led to many new applications of this useful plant. Soybean has great potential as an exceptionally nutritive and rich protein food. It contains more than 40 per cent protein of superior quality and all the essential amino acids, particularly glycine, tryptophan and lysine, similar to cow's milk and meat protein. Soybean also contains about 20 per cent oil including healthy fatty acids, lecithin and vitamins A and D. Soybean also contains secondary metabolites such as isoflavones (Sakai and Kogiso, 2008), saponins, phytic acid, oligosaccharides, goitrogens and phytoestrogens (Liener, 1994; Ososki and Kennelly, 2003). Soybean oil is also used as a source of biodiesel (Pimentel and Patzek, 2008). Some of the major biotic constraints include asian soybean rust, frogeye leaf spot, bacterial pustule, bacterial blight and soybean mosaic virus. Nematodes and insects such as pod feeders (stink bugs), foliage feeders, and bean flies feed on soybean plants. These wounds provide entry points for pathogens, and the plant frequently becomes susceptible to pathogenic organisms. Breeders at IITA are currently developing dual-purpose varieties that are tolerant to phosphorus-deficient soils and have enhanced capacity to kill seeds of the parasitic weed *Striga hermonthica* that attacks cereals.

Appendix 3. CRP 3.5 GRAIN LEGUMES Focus Regions: Brief Profiles

Central and West Asia and North Africa (CWANA)

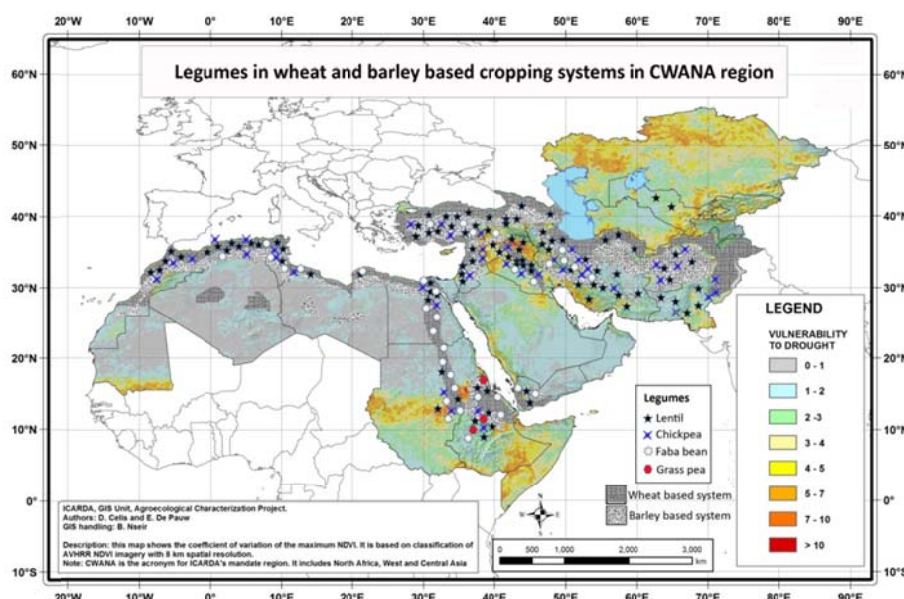
Faba bean, chickpea and lentil are the most important grain legumes in CWANA. In general faba bean is grown in the low coastal areas, chickpea in the continental areas and lentil in the high altitude areas. Faba bean and lentil are grown during the cool rainy winters and chickpea in the late winter/early spring as the rains end and temperatures rise. These crops are usually rotated with wheat or barley.

Over the past 30 years, the chickpea and lentil area has been increasing in West Asia while faba bean and other grain legumes are declining in other parts of CWANA. Although yields are low in West Asia (0.5-1 t/ha) the sown area quadrupled from 1976 to 2008 (from 378,000 ha to 1,526,000 ha - FAO 2008). The increase in West Asia is mainly due to growing awareness of the benefits of food legumes in cereal-dominated cropping systems. It is also partly due to the adoption of new cultivars suitable for machine harvesting, and winter-chickpea technology (*Ascochyta* blight-resistant, cold-tolerant cultivars of kabuli chickpea).

The biotic stresses of major importance for chickpea are *Ascochyta* blight and *Fusarium* wilt while abiotic stresses are drought, cold and heat. For high-altitude areas R4D emphasizes *Fusarium* wilt and plant type for lentil. R4D on faba-bean is focused on yield potential, combining early maturity with heat tolerance, and resistance to biotic stresses such as chocolate spot and rust, and to parasitic weeds especially Orobanche.

Livestock are very important components of CWANA farming systems, and lentil is well integrated as an important legume for food and feed. Lentil straw has good feed value and sometimes is as valuable as the grain per unit weight. Thus high biomass productivity is an important consideration for lentil.

There have been many reasons for the decline in grain legumes in North Africa including Orobanche infestation, non-availability of improved seed, lack of suitable varieties for mechanical harvesting, low prices, high production costs and climatic stress, especially severe droughts. Losses of human capacity to conduct R4D has also taken a toll. Morocco and Tunisia were formerly exporters of food legumes but have now become importers. Faba bean in North Africa is grown on 274,000 ha, mainly in Morocco. A large component of the faba bean production is in the form of green pods, but FAO production data do not report this form of the crop. Egypt (78,000 ha) and Sudan (68,000 ha) are the other large faba bean producers (FAO 2008).



During the Soviet era food legumes were important components of farming systems in Central Asia and the Caucasus, but have since become forgotten crops. Among the CRP 3.5 GRAIN LEGUMES, chickpea is still grown on a modest area of about 100,000 ha followed by lentil on about 10,000 ha. Chickpea is mainly grown in Uzbekistan and Azerbaijan, and lentil in Azerbaijan, Tajikistan, Armenia, and Uzbekistan. An organized marketing chain for these crops is lacking in this sub-region, so observations of grain legume trade within the region may give a false impression of production estimates. The main R4D effort on grain legumes takes place in Azerbaijan and Uzbekistan where few cultivars had been developed during the Soviet era.

Crop	Focus Countries	
	Primary	Secondary
Chickpea	Iran, Morocco, Syria, Turkey	Algeria, Tunisia, Uzbekistan
Faba bean	Egypt, Morocco, Syria	Algeria, Tunisia
Lentil	Iran, Syria, Turkey	Algeria, Morocco

Eastern and Southern Africa (ESA)

Bean, groundnut, cowpea, pigeonpea and soybean are the most important legumes in the ESA region, with lesser amounts of bambara groundnut, chickpea, lentil and faba bean. Largely grown as subsistence foodstuffs, these crops are especially cultivated by women for feeding the household. Annual per capita consumption is approximately 9 kg. A limited number of commercial farmers grow soybean in South Africa, Zimbabwe and Zambia.

Continuous maize cultivation is widespread in ESA. This monoculture has led to the mining of soil nutrients and soil degradation. Drought and low soil fertility are the main constraints. Where landholdings are small, grain legumes (primarily bean, cowpea, and pigeonpea) are intercropped or rotated with maize to diversify food supplies, hedge against drought risk, generate income and combat declining soil fertility. Sole crops of groundnut and soybean are grown in rotation with maize where sufficient land and labor or machinery are available.

The area devoted to chickpea and soybean production, though small has been steadily increasing over the years in the region. Chickpea doubled in sown area over the past 30 years (from 210,000 to 420,000 ha between 1979 and 2008) to meet increasing demand in domestic and international markets.

Crop	Focus Countries	
	Primary	Secondary
Common bean	Ethiopia, Kenya, Tanzania, Uganda, Zambia	Burundi, Malawi, Rwanda
Chickpea	Ethiopia, Malawi, Tanzania	Eritrea, Kenya, Mozambique
Cowpea	Mozambique, Tanzania	Malawi
Faba bean	Ethiopia, Sudan	-
Groundnut	Malawi, Tanzania, Uganda	Mozambique, Zambia, Zimbabwe
Lentil	Ethiopia	
Pigeonpea	Kenya, Malawi, Mozambique, Tanzania, Uganda	Zambia
Soybean	Kenya, Malawi, Mozambique	Rwanda

West and Central Africa (WCA)

The main legumes grown in WCA are: groundnut, cowpea, soybean, common bean and bambara nut. Pigeonpea and African yam bean are also grown as home garden intercrops. According to FAO data, average annual production and areas under the main legume crops in WCA are: groundnut (6.4 million tons on 5.3 million ha), cowpea (4.5 million tons on 10.1 million ha), soybean (610,000 tons on 660,000 ha), common bean (230,000 tons on 390,000 ha) and bambara nuts (58,300 tons on 71,000 ha).

Across WCA, both the production and land area under legumes has been increasing by 2- 6% per year over the past five years. This trend is expected to continue. Grain yield in these crops have remained static and low when compared with world averages.

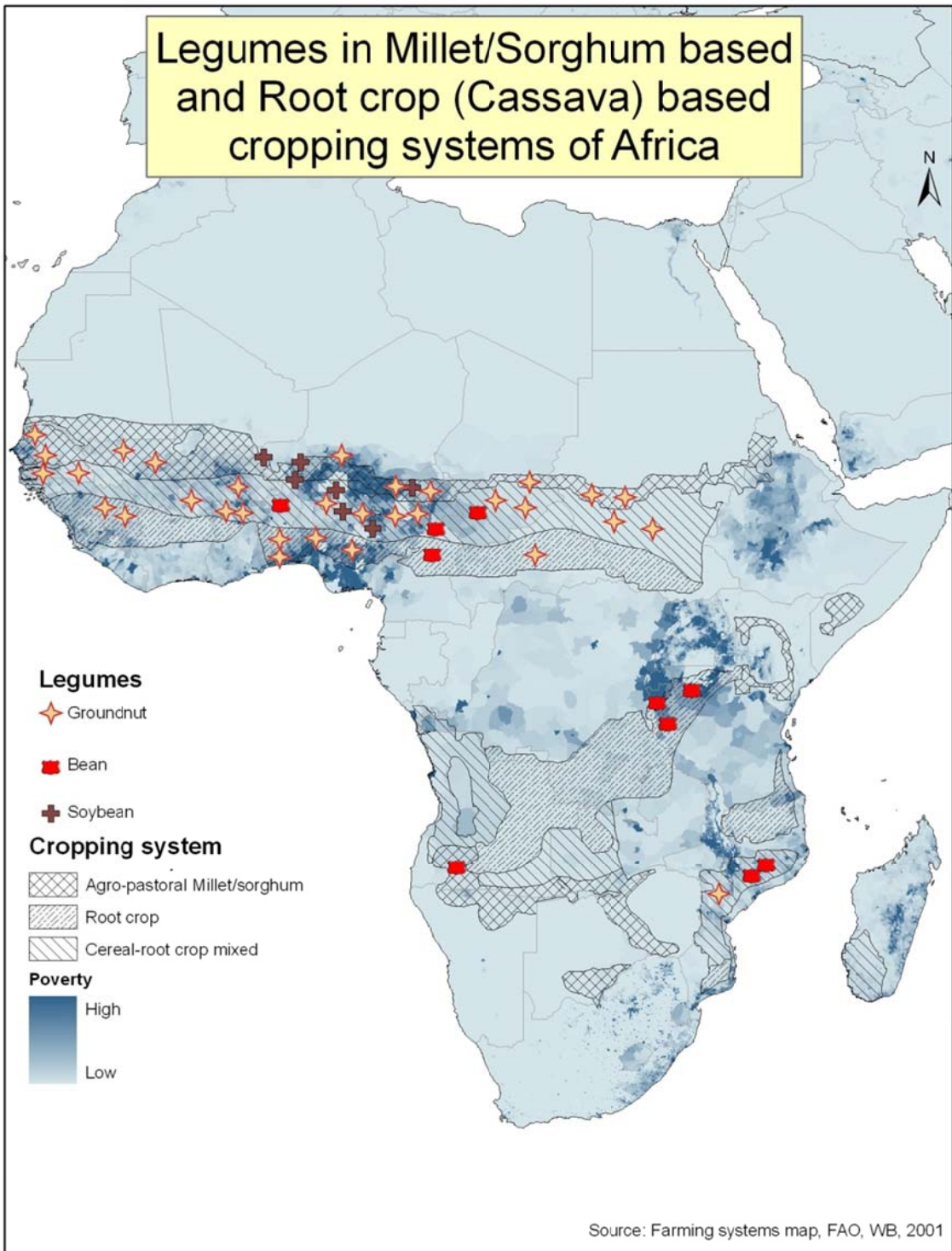
Apart from soybean and groundnut to lesser extent, the other legumes are grown in mixed cropping including intercropping and relay cropping with cereals (sorghum, millet, maize), other legumes and root crops such as cassava, yam and sweet potato, cotton (cowpea mainly), sugarcane, and plantation tree crops. With their increased role as cash crops, mono-cropping of the legumes is expanding in the different countries.

Women are the main producers of homestead legumes in mixed and intercrops. Where legumes are grown as field cash crops, men are more likely to be involved. Few large scale commercial farmers growing these crops in this region. Grain legume processing and retailing are carried out almost exclusively by women.

Cowpea and bambara nut are cultivated mainly in the drier Sudan savanna and the Sahel regions, while groundnut is better adapted to the less harsh northern guinea savanna zone. Soybean is grown in the still moister savanna regions (southern guinea) and extending to the forest/savanna transition agro-ecology. The legume crops often occupy marginal poor farmlands. Farmers use no or little fertilizer on them and do not inoculate with rhizobium. The only input that is often used is insecticide on cowpeas in some situations in Nigeria where such inputs could be obtained, often through cotton input supply systems. Most crop management activities are done by hand in this region, although animal traction is used in some areas.

Crop	Focus Countries	
	Primary	Secondary
Cowpea	Mali, Niger, Nigeria	Burkina Faso, Ghana, Senegal
Groundnut	Ghana, Mali, Nigeria, Senegal	Burkina Faso, Niger
Soybean	Nigeria	-

Legumes in Millet/Sorghum based and Root crop (Cassava) based cropping systems of Africa



Latin America and the Caribbean (LAC)

In Latin America and the Caribbean two grain legumes are of major importance: common bean (*Phaseolus vulgaris*) and soybean (*Glycine max*). Other legume species including another four species of cultivated *Phaseolus* as well as groundnut are also cultivated but on relatively small areas in niches of extreme heat, drought or high rainfall, rendering some of them as interesting potential components to help adapt farming systems to climate change. Several introduced legume species are important locally: cowpea in northeast Brazil, the northern coast of South America and eastern Cuba; pigeonpea in Haiti; chickpea in the Pacific coast of Mexico; and faba bean in the high Andes. For human consumption common bean is by far the most important in area and tonnage.

In general the grain legumes are cultivated by small farmers for home consumption and for sale through local and regional markets. Traditionally a large proportion of common bean area was planted with climbing or semi-climbing types in association or relay with maize; in highland areas of southern Mexico, Guatemala, Ecuador, and Peru some association with maize persists. However rising labor costs have led farmers to prefer upright bush habits that facilitate harvest. In Central America the small-seeded types of the Mesoamerican gene pool predominate, with most production in the range of 400 to 1200 m above sea level. Yields typically average around 700 kg/ha, although El Salvador now registers a national yield average of about 1000 kg/ha. In the low to mid-altitude regions Gemini viruses became the primary production limitation in the decade of the 1970s, and now are effectively controlled through genetic means. While vegetable production offers significant income for farmers with good market access, among field crops beans continue to be the best income option for small farmers.

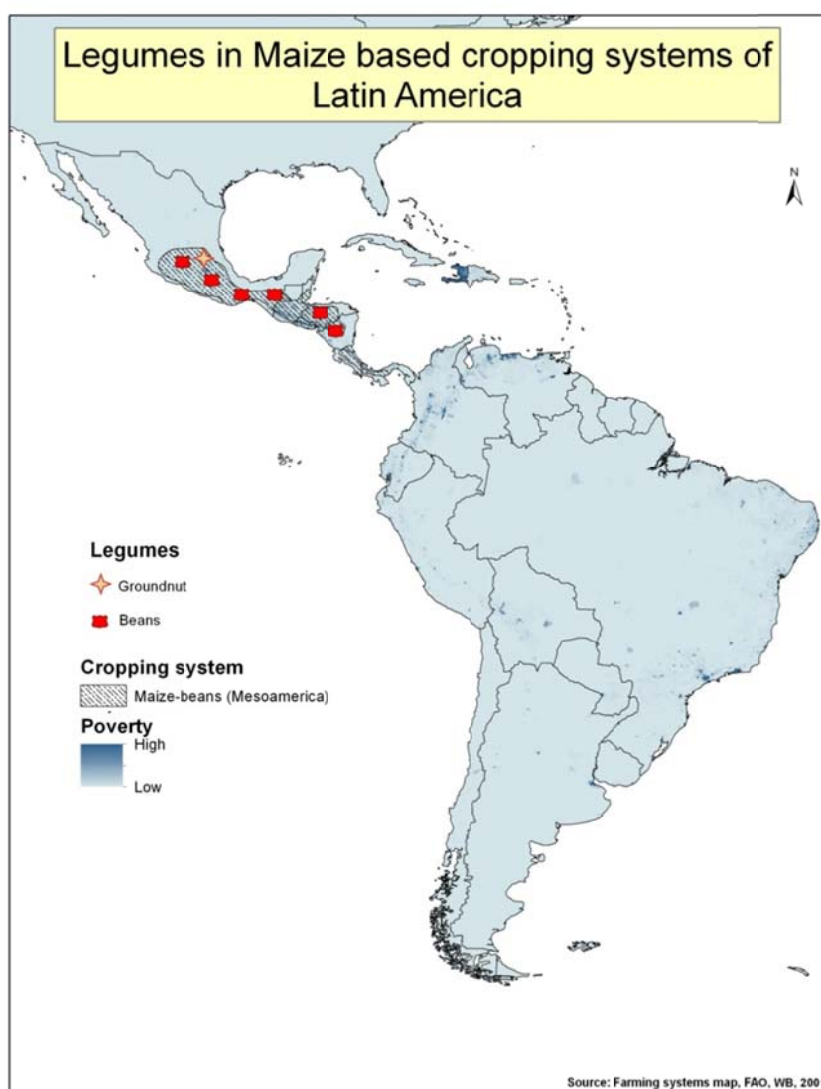
In the Caribbean, Cuba, the Dominican Republic and Haiti are the most important producers and consumers of legumes. Here the altitudinal gradient, soil and climate determine which legumes are produced, although common bean is the legume of preference. In the Caribbean and in the Andean zone, as well as in parts of Brazil the large-seeded types that originated in the Andes are preferred.

Mexico and Brazil present extremes of production systems. In Brazil the irrigated winter planting represents about 5% of total area, while the northeast of Brazil remains one of the strongholds of poverty in the western hemisphere with more than a million hectares of bean and cowpea, out of more than 4 million ha nationwide. Mexico presents even wider variability in production, from irrigated high input agriculture on the Pacific coast, to mechanized dryland agriculture in the central plateau, to totally traditional systems in the south.

In Latin America urbanization has led to lower per capita consumption and in some cases more diet-related illnesses such as cardio-vascular disease and diabetes. Common bean area has been steady or has declined slightly, but production has increased due to gradually improving yields. However, erratic weather in Central America in recent years has led to serious production shortages, with grain buyers looking far afield to meet local demand.

Soybean production is concentrated in Brazil and Argentina and is principally in the hands of large mechanized farmers, although some technology (for example, BNF) could be of utility to other regions of the world.

Crop	Focus Countries	
	Primary	Secondary
Common bean	Honduras, Guatemala, Nicaragua, Haiti	Northeast Brazil, El Salvador, Mexico



South and Southeast Asia (SEA)

South and Southeast Asia contains more than half of the world's population living on less than one-third of its arable land while producing more than half of the developing world's grain legume crop. Population pressures on land are particularly high in SEA, where grain legumes have traditionally provided a major source of food and nutritional security.

Asia is the center of origin of many important grain legumes. Asia dominates world production of several grain legumes including pigeonpea (95%), mung bean (90%) and chickpea (85%). India alone accounts for around 80% of SEA chickpea and pigeonpea production, about half of its lentils and about one third of its soybeans, groundnuts, dry peas and dry beans (mainly mung bean and urn bean). A ban on the trade of grasspea in India and Nepal due to neurotoxin concerns has been the main reason behind the drastic decline in this crop's cultivation. In Bangladesh, grasspea still occupies first position among the pulse crops.

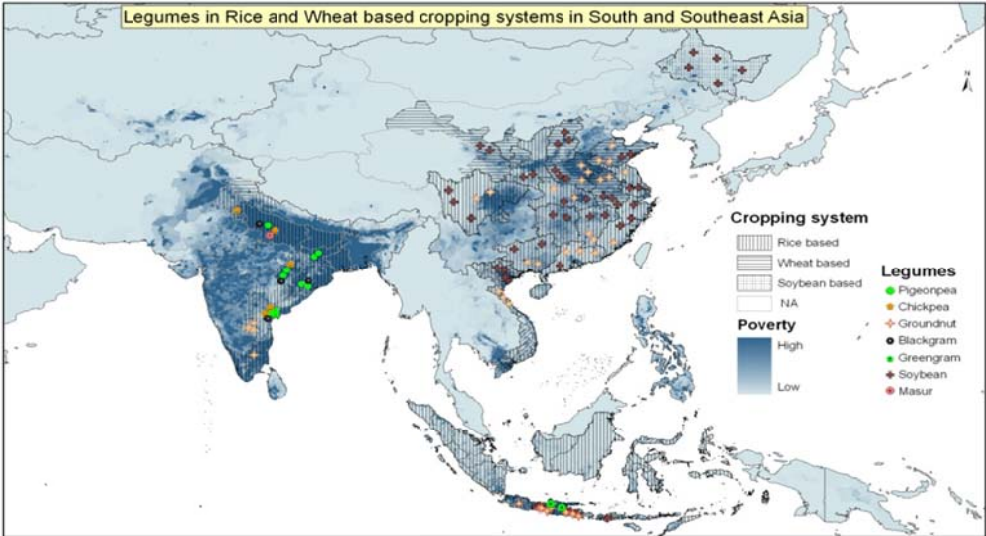
The sustainable legume-cereal system began to break down with the Green Revolution in the 1960s that heavily promoted increasing cereal production, as well as the rise of other cash crops responding to industrial development. Traditional legume components in crop rotations were relegated to marginal land areas. For example wheat, rapeseed, and mustard have largely replaced chickpea and lentil in the

middle and northern temperate regions of India, forcing those crops southward into hotter, drier areas. Competition from maize and cotton has contributed to declines in the area of groundnut in the Philippines, Thailand and India.

The deleterious consequences of policy bias against grain legumes on national economies as well as on farming systems are being increasingly recognized in the region. India, Pakistan and Sri Lanka have become major legume importers from China, Myanmar, Thailand, Australia and Canada, creating an outflow of hard currency from the region. Efforts to cope have resulted in the breeding of high-yielding short-duration grain legume varieties tolerant to heat and drought, so that these crops could better fit into the marginal niches available in cereal rotations, often maturing on residual moisture. But this progress has not been sufficient to meet growing food demand for legumes.

Rising prosperity is also changing the legume market in economically-emergent parts of Asia. Increasing

urbanization and changing food habits including growing demand for healthy convenience foods however is creating new kinds of demand that could benefit poor farmers. There is a need to diversify food products made from legumes to satisfy growing demands for such foods.



Crop	Focus Countries	
	Primary	Secondary
Chickpea	India, Myanmar, Pakistan	Bangladesh, Nepal
Groundnut	India, Indonesia, Myanmar, Vietnam	Bangladesh, Nepal, Philippines, Thailand
Lentil	India	Bangladesh, Nepal, Pakistan
Pigeonpea	India, Myanmar	Nepal

Appendix 4. Grain legume distribution by farming systems and region

Farming System	Bean	Cowpea	Soybean	Groundnut	Faba bean	Chickpea	Pigeonpea	Lentil	Total	Pov Pop <\$2
Latin America & Caribbean (LAC)										
Irrigated	885,266		11,783	18,089	7,146	70,886	0	1,583	994,752	5,524,925
Forest based	8,474		216,858	3,257	7,821	0	0	442	236,853	1,585,576
Coastal plantation mixed	633,403	37,099	110,754	78,079	21,957	1,498	38,715	801	922,306	24,287,080
Cereal-livestock (Campos)	62,627		2,947,538	24,850	14,484				3,049,499	1,626,798
Maize-beans (Mesoamerica)	762,647		14,779	40,816	33,153	20,120	926	6,282	878,724	10,885,814
Extensive mixed (Cerrados_Llanos)	59,868		369,820	4,441	4,204		1,933	0	440,266	3,528,738
Intensive highland mixed (N. Andes)	117,944		14,061	10,298	5,492	0	0	6,066	153,861	12,571,301
High altitude mixed (Central Andes)	82,339		62,221	5,880	44,876	0		2,345	197,660	4,581,291
Mediterranean mixed	16,229					1,790		955	18,974	787,312
Temperate mixed (Pampas)	4,148		164,462	2,494					171,104	108,862
Extensive dryland mixed (Gran Chaco)	12,766		444,506	4,991	4,623				466,886	553,381
Dryland mixed	6,673		1,141	52	0	0		0	7,866	272,863
Pastoral	0					0		0	0	1,332
Sparse (forest)	472					90		0	562	148,115
Total	2,652,856	37,099	4,357,923	193,247	143,755	94,382	41,575	18,474		66,463,388
Argentina & Brazil (ARGBRA)										
Forest based	143,952		905,704	0	398				1,050,053	4,359,130
Coastal plantation mixed	286,128		2,833	4,912	21,514				315,387	10,359,180
Intensive mixed	1,257,656		4,741,114	67,199	0				6,065,969	14,696,680
Cereal-livestock (Campos)	291,928		8,713,868	12,876	686	0			9,019,358	2,792,733
Extensive mixed (Cerrados_Llanos)	423,050		8,335,152	15,610	192				8,774,003	3,576,010
High altitude mixed (Central Andes)	119,150		111,556	0		845			231,552	268,856
Mediterranean mixed	102		40	0		0			142	68,422
Temperate mixed (Pampas)	10,442		13,476,625	256,360		0			13,743,427	3,325,325

Farming System	Bean	Cowpea	Soybean	Groundnut	Faba bean	Chickpea	Pigeonpea	Lentil	Total	Pov Pop <\$2
Extensive dryland mixed (Gran Chaco)	133,125		1,540,616	667		4,451			1,678,859	404,931
Dryland mixed	1,710,446		690,453	10,799	22,487				2,434,185	9,943,185
Pastoral	0		0	0		0			0	78,851
Sparse (forest)	680		40	0		0			720	87,333
Total	4,376,660	0	38,518,000	368,423	45,276	5,296	0	0		49,960,636
Central & West Asia & North Africa (CWANA)										
Irrigated	36,113	2,369	7,117	47,726	85,281	15,189		19,327	213,122	13,235,256
Highland mixed	64,522		54,675	574	34,389	492,200		150,101	796,461	13,074,907
Rainfed mixed	9,513		790	24,005	185,932	100,180		49,812	370,232	7,437,407
Dryland mixed	15,062		6,995	13,423	62,917	83,387		78,626	260,410	5,094,121
Pastoral	20,351	52	16,471	15,069	11,628	53,723		34,719	152,012	5,290,718
Sparse (arid)	8,669	0	7,241	1,457	1,622	12,918		5,596	37,503	5,133,242
Irrigated	3,063		50	2,550	2,494	0		400	8,557	12,191,311
Horticulture mixed	44,038		9,935	24,127	4,919	209,427		170,416	462,861	6,523,708
Large scale cereal-vegetable	0		0		0	0			0	3,431
Small scale cereal-livestock	56,613		577	1,208	4,740	245,501		39,871	348,511	2,551,641
Extensive cereal-livestock	0		28,200		0	14,300			42,500	1,650,042
Pastoral	0		47,050	2,975	1,052	0		1,700	52,776	16,772,842
Sparse (cold)	0		0		0	0			0	176
Sparse (arid)	0		0	775	578	0		0	1,354	4,474,164
Total	257,944	2,421	179,101	133,889	395,553	1,226,824	0	550,567		93,432,966
West & Central Africa (WCA)										
Irrigated	649	167,262	4,323	306,764					478,998	7,315,277
Tree crop	202,012	174,591	82,378	289,833	0		0		748,814	42,801,078
Forest based	74,738	15,806	53,234	399,223			0		543,000	42,143,874
Highland perennial	113,289	2,908	2,556	26,802			4,614		150,168	6,938,507
Highland temperate mixed	41,323	35,569	3,535	42,170					122,598	2,289,700

Farming System	Bean	Cowpea	Soybean	Groundnut	Faba bean	Chickpea	Pigeonpea	Lentil	Total	Pov Pop <\$2
Root crop	425,166	558,047	404,993	1,241,758	689		0		2,630,653	57,577,519
Cereal-root crop mixed	447,358	2,060,345	147,165	2,701,935			0		5,356,803	69,586,022
Maize mixed	27,382	4,587	16	30,186			2,692		64,863	3,740,063
Agro-pastoral millet/sorghum	74,911	3,043,625	24,699	2,448,939					5,592,175	44,925,840
Pastoral	107,048	2,813,152	3,454	458,067					3,381,723	11,072,801
Sparse (arid)	83	635	0	40					758	1,035,870
Coastal artisanal fishing	9,378	285,976	22,460	63,081	53				380,948	21,166,931
Total	1,523,336	9,162,506	748,814	8,008,798	742	0	7,306	0		310,593,482
Eastern & Southern Africa (ESA)										
Irrigated	18,775	0	70	77,691	5,403	702	0	138	102,779	147,034
Tree crop	28,082	4,347	700	11,555		1,781	2,053	0	48,518	1,188,714
Forest based	7,825	1,773		5,761					15,359	1,910,330
Rice-Tree crop	79,497	1,900		33,465					114,861	13,594,323
Highland perennial	1,231,549	43,168	78,769	119,452	18,279	25,755	43,358	3,858	1,564,187	35,213,221
Highland temperate mixed	154,988	677	12,259	50,173	284,774	115,686	227	61,978	680,762	38,366,291
Root crop	781,928	56,015	1,446	405,434	9,621	28,951	19,829	0	1,303,225	18,575,148
Cereal-root crop mixed	98,850	14,524	137	423,839	23,746	18,839	30,045	991	610,971	16,327,075
Maize mixed	1,696,418	269,129	336,192	1,129,386	109,623	176,458	289,618	21,591	4,028,415	76,644,405
Large commercial	48,594	7,437	204,645	64,265					324,940	17,035,657
Agro-pastoral millet/sorghum	154,821	18,035	23,410	292,793	20,913	10,371	15,983	1,492	537,817	2,809,050
Pastoral	414,138	45,009	58	263,076	106,430	68,115	41,499	20,529	958,854	13,533,960
Sparse (arid)	501	0	403	10,546	586	13	0	0	12,048	1,291,197
Coastal artisanal fishing	35,089	3,793	0	32,829		1,335	1,158	0	74,205	10,400,823
Total	4,751,054	465,807	658,089	2,920,265	579,375	448,006	443,770	110,576		247,037,228
South & Southeast Asia (SSEA)										
Lowland rice	823,180	48,744	890,308	627,592	0	85,478	182,983	26	2,658,311	127,494,776
Tree crop mixed	76,793	3,171	54,128	250,988	0	5,098	10,904	0	401,082	24,453,562

Farming System	Bean	Cowpea	Soybean	Groundnut	Faba bean	Chickpea	Pigeonpea	Lentil	Total	Pov Pop <\$2
Root-tuber	2,227		0	15,768					17,995	1,170,400
Upland intensive mixed	820,337	75,554	467,390	620,162	0	132,680	282,290	0	2,398,413	66,189,666
Highland extensive mixed	254,592	23,973	145,377	144,952	0	43,033	95,167	1,921	709,014	3,618,578
Temperate mixed	9,459		12,240	0		0			21,699	67,022
Pastoral	570	0	195	125	0	0	85	0	975	777,072
Sparse (forest)	113,575	8,559	52,266	189,232	0	15,722	33,603	0	412,958	9,107,635
Sparse (arid)	0		0	0		0	0	0	0	238,000
Rice	22,057	4,374	40,177	27,168		5,154	323	45,332	144,586	100,074,203
Coastal artisanal fishing	1,390	624	415	2,255		294	0	2,541	7,519	7,138,334
Rice-wheat	115,180	0	12,108	73,622		733,382	11,184	135,989	1,081,465	122,564,585
Highland mixed	32,612	3,810	13,021	11,659		98,912	9,992	90,681	260,687	32,967,319
Rainfed mixed	1,856	5,592	0	3,526					10,973	2,556,295
Pastoral	7,480		0	388		65,636	0	1,680	75,184	3,506,167
Sparse (arid)	21,750		3	10,062		188,538	0	5,044	225,397	22,035,235
Sparse (mountain)	1,128		316	69		5,331	260	4,359	11,462	5,887,963
Total	2,304,186	174,400	1,687,945	1,977,570	0	1,379,256	626,791	287,571		529,846,812
India										
Upland intensive mixed	0	0	0	0		0	0	0	0	65,819
Highland extensive mixed	0	0	0	0		0	0	0	0	27,626
Pastoral	96	0	22	0		0	0	68	187	2,713
Sparse (forest)	0	0	0	0		0	0	0	0	11,957
Rice	83,960	24,487	267	412,316		73,029	112,838	53,502	760,399	128,908,283
Coastal artisanal fishing	10,345	1,376	41	113,560		7,556	23,365	6,071	162,313	22,281,962
Rice-wheat	1,960,813	0	564,300	215,787		1,438,429	164,415	859,913	5,203,657	393,560,192
Highland mixed	39,467	9,369	9,887	17,668		4,651	6,530	18,350	105,921	31,867,564
Rainfed mixed	692,476	222,524	10,363,007	5,165,370		5,719,534	2,659,660	696,887	25,519,458	332,222,682
Dry rainfed	144,834	13,249	294,480	1,341,007		1,247,052	1,041,191	0	4,081,814	38,507,397

Farming System	Bean	Cowpea	Soybean	Groundnut	Faba bean	Chickpea	Pigeonpea	Lentil	Total	Pov Pop <\$2
Pastoral	15,192	0	4	299,470		709,942	5,565	2	1,030,175	8,697,638
Sparse (arid)	0	0	0	71,889		286,378	12	2	358,280	2,393,149
Sparse (mountain)	13,067	0	1,690	0		11	141	5,282	20,191	2,092,441
Total	2,960,249	271,005	11,233,698	7,637,067	0	9,486,582	4,013,717	1,640,076		960,639,423
China										
Extensive cereal-livestock	3	0	6,062	0	5	0	0	0	6,070	20,982
Pastoral	0	0	0	0	0	0	0	0	0	10,032
Sparse (cold)	0	0	978	0	0	0	0	0	978	1,512
Lowland rice	86,725	0	1,951,428	2,165,107	139,968	0	0	9,468	4,352,697	180,187,309
Upland intensive mixed	119,617	0	2,592,412	1,049,920	193,026	0	0	13,419	3,968,394	161,126,680
Highland extensive mixed	24,443	0	455,465	38,820	39,038	2,188	0	1,184	561,137	41,716,894
Temperate mixed	174,790	0	3,199,323	1,069,230	282,128	0	0	21,566	4,747,037	96,699,611
Pastoral	126,928	0	891,037	73,325	205,016	0	0	15,974	1,312,280	41,784,612
Sparse (forest)	2,495	0	36,234	2,029	3,835	313	0	6	44,912	2,213,717
Sparse (arid)	7,482	0	57,184	0	11,984	0	0	382	77,032	19,282,079
Total	542,484	0	9,190,123	4,398,431	875,000	2,500	0	62,000		543,043,428
Eastern Europe & Central Asia (EECA)										
Irrigated	551		51,730			0			52,282	180,535
Mixed	55,018	2,410	343,456	6,214	17,414	1,605		2,274	428,391	1,646,348
Forest based livestock	63,710		35,221			33			98,964	630,455
Horticulture mixed	48,307	6,863	107,305	3,786	0	1,934		46	168,241	2,341,605
Large scale cereal-vegetable	38,370		714,736	0	0	0		0	753,106	1,358,537
Extensive cereal-livestock	3,803		570,488			13,967			588,259	1,652,088
Sparse (cold)	0		90,771			0			90,771	328,151
Total	209,760	9,273	1,913,708	10,000	17,414	17,539	0	2,320		8,137,719

Appendix 5. The ex-ante economic, nutritional, and environmental impacts of legume R4D

Methods and Data

An economic surplus model (Alston et al. 1995) was used to derive summary measures of the potential impacts of legumes improvement under certain reasonable assumptions for research starting in 2011 and benefits accruing from 2014 (beginning of adoption of improved technologies) to 2020. The benefits were measured based on a parallel downward shift in the (linear) supply curve following research. The annual flows of gross economic benefits from crop improvement were estimated for each of the countries and aggregated, with the aggregate benefits finally discounted to derive the present value (in 2011) of total net benefits from the intervention. The key parameters that determine the magnitude of the economic benefits are: (1) the expected technology adoption in terms of area under improved technologies; (2) expected yield gains following adoption; and (3) pre-research levels of production and prices.

Specifically, the economic surplus empirical model for an open economy was used to calculate the economic benefits for each country from a downward shift in the supply curve. In an open economy, economic surplus measures can be derived using formulas presented in Alston et al. (1995)—i.e. change in economic Surplus (ΔES) = $P_0 Q_0 K_t (1 + 0.5 K_t \epsilon)$; where K_t is the supply shift representing cost reduction per ton of output as a proportion of product price (P); P_0 represents pre-research price for 2006–2008 (US\$/ton); Q_0 is pre-research level of production for 2006–2008; and ϵ is the price elasticity of supply. The research-induced supply shift parameter, K , is the single most important parameter influencing total economic surplus results from unit cost reductions and was derived as $K_t = A_t (\Delta Y/Y)/\epsilon$ where $\Delta Y/Y$ is the average proportional yield increase per hectare, with the elasticity of supply (ϵ) used to convert the gross production effect of research-induced yield changes to a gross unit production cost effect.

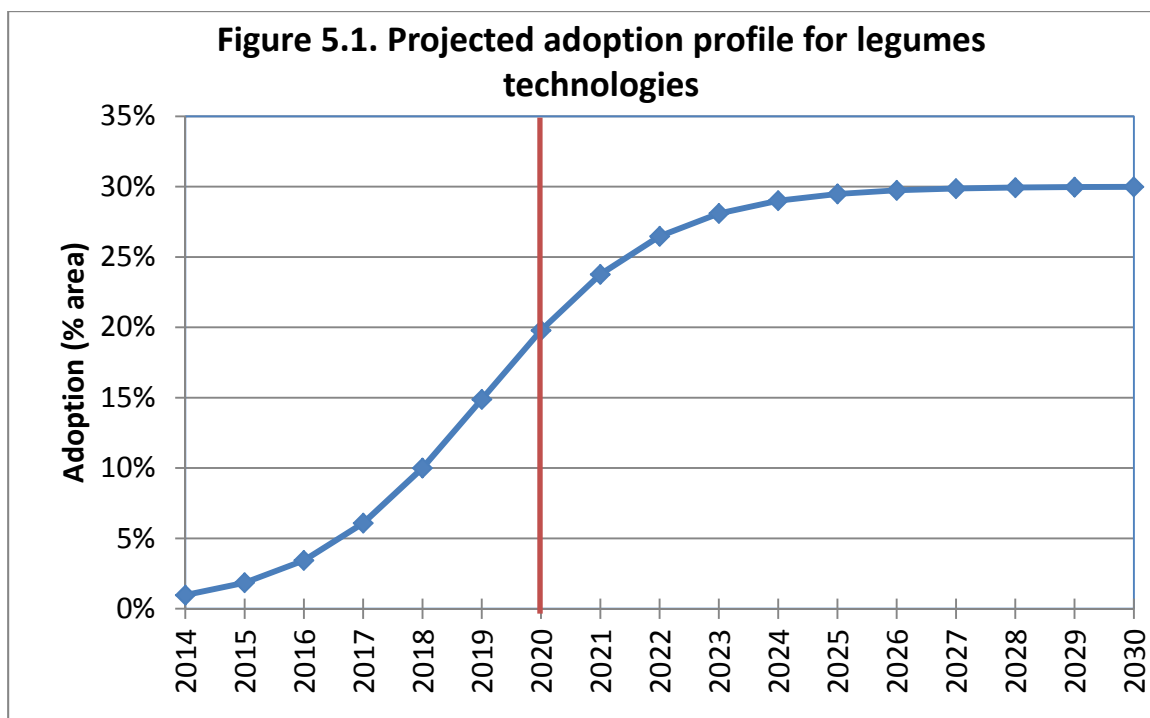
Annual supply shifts were then projected based on projected adoption profile for improved technologies (A_t) for the period from 2014 to 2020 for research starting in 2012. Adoption (A_t) is assumed to follow the logistic diffusion curve starting in 2014 with less than 1% of the area put under improved technologies in 2014. In view of the already available pool of improved technologies some of which would only need investments in seed production and distribution, a research lag of only three years was assumed from the year of initial research investment in 2011 to the beginning of adoption of technologies in 2014. Table 5.1 presents the values of some of the key project-, technology-, and market-related parameters used in the projection of impacts of legumes research and extension. The values of these parameters and others were assembled from several sources—such as project proposal, past empirical work (e.g. Alston et al. 1995; Alene et al. 2009), and others (e.g. FAOSTAT). Figure 5.1 presents the projected technology adoption profiles for legumes implied by the expected values of the technology parameters.

The food security and nutritional impacts of legume research and extension were calculated as the incremental per capita grain and protein availability associated with the incremental production attributable to research.

Table 5.1. Values of key parameters used in the projections of impacts of legume R4D

Parameter	Bean	Chickpea	Cowpea	Faba bean	Groundnut	Lentil	Pigeonpea	Soybean
Productivity change (%)	20	20	20	20	20	20	20	20
Maximum adoption (%)	20	20	20	20	20	20	20	20
Maximum adoption beyond 2020 (%)	30	30	30	30	30	30	30	30
Gestation lag (years until start of adoption)	3	3	3	3	3	3	3	3
Adoption lag (years until maximum adoption)	10	10	10	10	10	10	10	10
Elasticity of supply	1	0	1	1	0	0	0	1
Elasticity of demand	Perfectly elastic	Perfectly elastic	Perfectly elastic	Perfectly elastic	Perfectly elastic	Perfectly elastic	Perfectly elastic	Perfectly elastic
Discount rate (%)	5	5	5	5	5	5	5	5
Project duration	2011-2020	2011-2020	2011-2020	2011-2020	2011-2020	2011-2020	2011-2020	2011-2020
Time path of benefits from investments	2014-2020	2014-2020	2014-2020	2014-2020	2014-2020	2014-2020	2014-2020	2014-2020
Protein content (g protein/kg of grain)	220 ¹	171 ³	240	300	401 ³	251 ³	223 ³	400 ³
Biological Nitrogen Fixation (kg N/ton of grain)	50 kg/ha/yr ⁴	62 ⁵	50	86	55 ⁵	62 ⁵	50 ⁵	76 ⁵

¹ For South and South East Asia, the maximum adoption considered is 20%
² Assumption: 22g of protein/100 g of bean (Litzenberger SC. 1973).
³ Calculated using figures from Gopalan et al. 2004.
⁴ Common bean fixes 50 kg/ha/yr (Adrian Montanez, 2000).
⁵ Calculated using Herridge et al. 2008.



Biological nitrogen fixation (BNF) benefits were estimated as the replacement cost of an equivalent value of N from urea fertilizer based on FAOSTAT regional average urea producer prices, e.g. US\$420 per metric ton in sub-Saharan Africa vs. \$375/ton in SSEA region. The quantity of BNF was estimated following Herridge et al. (2008). The calculation is [aboveground biomass estimated from grain production/crop harvest index] x [crop-specific average shoot % N content] x [crop-specific average % of plant N that is atmospheric in origin] x [crop-specific multiplier to include belowground BNF]. For protein content, published values were used, e.g. Litzenger (1973) demonstrated that bean contains 22 g of protein per 100 gr of beans.

Results

The summary measures of the ex-ante economic, nutritional, and environmental impacts of grain legume research and extension are presented in Table 5.2. Given the long lag between research investments and reaping the full benefits, the projections of benefits and returns under any short-term scenario represent more conservative estimates of the social profitability of research investments. Although subsequent benefits will not flow without further research and extension investments beyond 2020, the analysis that links project investments (2011–2013) to a finite stream of benefits (2014–2020) is bound to understate the true benefits.

The present value of gross benefits of grain legume research and extension is estimated at US\$2,755 million, equivalent to US\$ 505 million per year. Over the period 2014–2020, legume research is also projected to contribute to: (1) food security through increased availability of food (7,071,000 tons); (2) nutrition security through increased availability of protein (2,123,000 tons); and (3) environmental benefits through biological nitrogen fixation (402,000 tons) that also translates to a fertilizer cost saving of US\$271 million. Legume research and extension will have the greatest economic impacts in South and South-East Asia and SSA where most of the poor are located accounting for over 50% of the projected economic benefits.

Table 5.2. Summary measures of potential impacts of investment in legume research and extension activities, 2011–2020

Region	Bean	Chickpea	Cowpea	Faba bean	Groundnut	Lentil	Pigeonpea	Soybean	Total
Present value of gross benefits (US\$ million)									
Sub-Saharan Africa (SSA)	286	34	197	36	437	6	26	47	1069
West & Central Africa (WCA)	81		186		316			27	610
East & Southern Africa (ESA)	205	19	11		121		26	20	402
Central & West Asia & North Africa (CWANA)		94		31		50			175
Latin America & Caribbean (LAC)	262								262
South and Southeast Asia (SSEA)		305			759	51	191		1306
Total	548	418	197	31	1196	101	217	47	2755
Annual gross benefits (US\$ million)									
Sub-Saharan Africa (SSA)	36	4	28	5	69	1	5	7	155
West & Central Africa (WCA)	10		27		47			4	88
East & Southern Africa (ESA)	26	2	2		22		5	3	59
Central & West Asia & North Africa (CWANA)		13		4		7			24
Latin America & Caribbean (LAC)	33								33
South and Southeast Asia (SSEA)		69			174	15	44		301
Total	69	84	28	4	243	22	48	7	505
Incremental food availability ('000 tons)									
Sub-Saharan Africa (SSA)	677	96	618	112	1197	15	61	159	2937
West & Central Africa (WCA)	148		581		993			77	1799
East & Southern Africa (ESA)	529	52	38		204		61	82	967
Central & West Asia & North Africa (CWANA)		136		82		84			302
Latin America & Caribbean (LAC)	347								347
South and Southeast Asia (SSEA)		1030			1928	168	530		3656
Total	1024	1218	618	82	3125	252	591	159	7071
Incremental protein availability ('000 tons)									
Sub-Saharan Africa (SSA)	149	16	148	33	479	4	14	64	907
West & Central Africa (WCA)	33		139		397			31	600
East & Southern Africa (ESA)	116	9	9		82		14	33	262

Region	Bean	Chickpea	Cowpea	Faba bean	Groundnut	Lentil	Pigeonpea	Soybean	Total
Central & West Asia & North Africa (CWANA)		23		25		18			66
Latin America & Caribbean (LAC)	76								76
South and Southeast Asia (SSEA)		185			773	42	118		1118
Total	226	217	148	25	1252	60	132	64	2123
Incremental nitrogen fixation ('000 tons)									
Sub-Saharan Africa (SSA)	34	7	31	8	66	1	3	12	161
West & Central Africa (WCA)	8		29		54			6	97
East & Southern Africa (ESA)	26	4	2		11		3	6	52
Central & West Asia & North Africa (CWANA)		10		6		4			20
Latin America & Caribbean (LAC)	19								19
South and Southeast Asia (SSEA)		72			107	9	27		214
Total	53	86	31	6	172	13	30	12	402
Fertilizer cost savings due to N fixation (US\$ million)									
Sub-Saharan Africa (SSA)	40	4	22	5	35	1	2	9	117
West & Central Africa (WCA)	8		20		28			4	61
East & Southern Africa (ESA)	32	2	1		7		2	4	49
Central & West Asia & North Africa (CWANA)		6		4		2			12
Latin America & Caribbean (LAC)	14								14
South and Southeast Asia (SSEA)		46			68	5	17		136
Total	54	54	22	4	102	7	19	9	271

Table 5.3. Area, poverty and benefits breakdown of CRP 3.5 GRAIN LEGUMES focus crops in the five target regions (priority crop/regions shaded)

	CHICKPEA						COMMON BEAN					
	SSEA	WCA	ESA	LAC	CWANA	Total	SSEA	WCA	ESA	LAC	CWANA	Total
Area (million ha) ¹	10.9		0.5	0.1	1.2	12.7	0.3	1.5	4.8	2.7	0.3	9.6
Number of poor (<US\$ 1 per day, millions) ²	119		4.0		21.2	144		9.4	38.5	39.2		87
Number of beneficiaries in farm households (million) ³	40		1.8		6.0	48		6.3	17.2	19.2		43
Present value of gross benefits (US\$ million) ⁴	305		19		94	418		81	205	262		548
Incremental food availability ('000 tons)	1,030		52		136	1,218		148	529	347		1,024
Incremental protein availability ('000 tons)	185		9		23	217		33	116	76		225
Fertilizer cost savings due to N fixation (US\$ million)	46		2		6	54		8	32	14		54

	COWPEA						FABA BEAN					
	SSEA	WCA	ESA	LAC	CWANA	Total	SSEA	WCA	ESA	LAC	CWANA	Total
Area (million ha) ¹	0.4	9.2	0.5			10.1			0.6	0.1	0.4	1.1
Number of poor (<US\$ 1 per day, millions) ²		57	4.0			61			4.8		7.1	12
Number of beneficiaries in farm households (million) ³		38.9	1.8			41			2.1		2.0	4.1
Present value of gross benefits (US\$ million) ⁴		186	11			197					31	31
Incremental food availability ('000 tons)		581	38			619					82	82
Incremental protein availability ('000 tons)		139	9			148					25	25
Fertilizer cost savings due to N fixation (US\$ million)		20	1			21					4	4

	LENTIL						GROUNDNUT					
	SSEA	WCA	ESA	LAC	CWANA	Total	SSEA	WCA	ESA	LAC	CWANA	Total
Area (million ha) ¹	1.9		0.1		0.6	2.6	9.6	8	2.9	0.2	0.1	21
Number of poor (<US\$ 1 per day, millions) ²	21				10	31	105	50	23			178
Number of beneficiaries in farm households (million) ³	7.0				3.0	10.0	35	34	10			80
Present value of gross benefits (US\$ million) ⁴	51				50	101	759	316	121			1,196
Incremental food availability ('000 tons)	168				84	252	1,928	993	204			3,125
Incremental protein availability ('000 tons)	42				18	60	773	397	82			1,252
Fertilizer cost savings due to N fixation (US\$ million)	5				2	7	68	28	7			103

	PIGEONPEA						SOYBEAN					
	SSEA	WCA	ESA	LAC	CWANA	Total	SSEA	WCA	ESA	LAC	CWANA	Total
Area (million ha) ¹	4.6		0.5			5.1	12.9	0.7	0.7			14.3
Number of poor (<US\$ 1 per day, millions) ²	50		4.0			54		4.4	5.6			10
Number of beneficiaries in farm households (million) ³	17		1.8			19		3.0	2.5			5.5
Present value of gross benefits (US\$ million) ⁴	191		26			217		27	20			47
Incremental food availability ('000 tons)	530		61			591		77	82			159
Incremental protein availability ('000 tons)	118		14			132		31	33			64
Fertilizer cost savings due to N fixation (US\$ million)	17		2			19		4	4			8

	TOTALS					
	SSEA	WCA	ESA	LAC	CWANA	Total
Area (million ha)¹	40.6	19.4	10.6	3.1	2.6	76.3
Target area (shaded, million ha)	27.0	19.4	10.5	2.7	2.2	61.8
Number of poor (<US\$ 1 per day, millions)²	443	121	85	45	46	740
Number of beneficiaries in farm households (million)³	149	82	38	22	13	304
Present value of gross benefits (US\$ million)⁴	1,306	610	402	262	175	2,755
Incremental food availability ('000 tons)	3,656	1,799	966	347	302	7,070
Incremental protein availability ('000 tons)	1,118	600	263	76	66	2123
Fertilizer cost savings due to N fixation (US\$ million)	136	60	48	14	12	270

¹ Source: FAOSTAT 2008 data. Large-scale commercial soybean and common bean areas in Argentina, Brazil, Chile, China, Mexico and USA (all non-LIFDCs) is excluded. FAOSTAT bean area in SSEA adjusted by ICRISAT in consultation with the Indian Institute for Pulse Research to delineate the area of *Phaseolus vulgaris*, the common bean.

² Number of poor growing a crop in a region was estimated as proportional to the area of that crop relative to total legume area in that region.

³ Number of beneficiaries of a crop in a region was estimated as: the total beneficiaries in that crop/region (taken from Table 3.2) multiplied by the analogous crop area fraction (area of that crop/region relative to total legume area in that region).

⁴ Net present value of a 20% yield increase on 20% of the crop/region grain legume area during 2014-2020.

Appendix 6. Relative importance and yield losses (%) due to biotic/abiotic constraints in grain legumes in different regions

Crop/constraint	Asia	ESA	WCA	CWANA	LA
Chickpea					
Abiotic:	34.0	30.0		40.0	
Drought stress	25.0	25.0	-	25.0	-
Heat/cold tolerance	9.0	5.0		15.0	
Diseases:	24.0	27.0		35.0	
Fusarium wilt/root rot*	16.0	15.0	-	15.0	-
Ascochyta/Botrytis*	8.0	12.0		20.0	
Insect pests:	26.0	20.0		22.0	
Helicoverpa*	18.0	15.0	-	12.0	-
Leaf miner/aphids/cut worm	8.0	5.0		10.0	
Soil Fertility/BNF:	16.0	23.0	-	3.0	-
Common bean					
Abiotic:	20.0	30.0	30.0		22.0
Drought/heat stress	20.0	30.0	30.0	-	22.0
Diseases:	30.0	30.0	30.0		30.0
Mosaics - Viruses	15.0	14.0	20.0		15.0
Angular leaf spot/Anthracnose	7.0	6.0	5.0	-	8.0
Root rots	8.0	10.0	5.0		7.0
Insect pests:	25.0	20.0	20.0		28.0
Bean fly/Apion	15.0	15.0	10.0	-	16.0
Leaf hoppers/aphids	10.0	5.0	10.0		12.0
Soil Fertility/BNF:	25.0	20.0	20.0		20.0
Cowpea					
Abiotic:	20.0	25.0	28.0		24.0
Drought/heat stress	20.0	25.0	28.0	-	24.0
Diseases:	30.0	25.0	30.0		30.0
Mosaics - Viruses	15.0	10.0	15.0		15.0
Bacterium blight	10.0	8.0	5.0	-	10.0
Rust	5.0	7.0	10.0		5.0
Insect pests:	25.0	25.0	22.0		26.0
Flower thrips	5.0	5.0	8.0		7.0
Pod bugs	5.0	5.0	5.0	-	6.0
Maruca	10.0	10.0	4.0		9.0
Aphids	5.0	5.0	5.0		4.0
Soil Fertility/BNF:	25.0	25.0	20.0	-	20.0
Faba bean					
Abiotic:	30.0	30.0		30.0	
Drought stress	10.0	15.0		15.0	
Heat/cold stress	10.0	10.0	-	10.0	-
Salinity	10.0	5.0		5.0	
Diseases:	30.0	30.0	-	40.0	-

Crop/constraint	Asia	ESA	WCA	CWANA	LA
Ascochyta blight*	20.0	15.0		15.0	
Chocolate spot/rust	10.0	15.0		15.0	
Viruses	-	-	-	10.0	-
Insect pests: Aphids	15.0	15.0	-	5.0	-
Parasitic weeds:	-	-	-	15.0	
Soil Fertility/BNF:	25.0	25.0	-	10.0	
Groundnut					
Abiotic:	23.0	17.0	17.0		
Drought/heat stress	23.0	17.0	17.0	-	-
Diseases:	36.0	50.0	50.0		
Aflatoxin	10.0	12.0	15.0	-	-
Foliar diseases	15.0	20.0	20.0		
Rosette/bud necrosis*	11.0	18.0	15.0		
Insect pests:	18.0	18.0	15.0		
Defoliators/leaf miners	10.0	8.0	5.0	-	-
White grubs/termites	8.0	10.0	10.0		
Soil Fertility/BNF:	23.0	15.0	18.0	-	-
Lentil					
Abiotic:	28.0	28.0		28.0	
Drought stress	15.0	20.0	-	15.0	-
Heat stress/low temperature	13.0	8.0		13.0	
Diseases	40.0	27.0		22.0	
Wilt/root rots*	20.0	12.0	-	10.0	-
Rust	10.0	8.0		7.0	
Ascochyta/Stemphylium/Botrytis	10.0	7.0		5.0	
Insect pests:	12.0	15.0		20.0	
Sitona weevil	5.0	10.0	-	15.0	-
Aphids	7.0	5.0		5.0	
Parasitic weeds:	0.0	0.0	-	10.0	
Soil Fertility/BNF:	20.0	30.0	-	20.0	
Pigeonpea					
Abiotic:	15.0	20.0			
Drought stress	15.0	20.0	-	-	-
Diseases:	32.0	25.0			
Fusarium wilt*	15.0	15.0	-	-	-
Sterility mosaic*	9.0	0.0			
Phytophthora*	8.0	10.0			
Insect pests:	33.0	35.0			
Helicoverpa/Maruca	20.0	20.0	-	-	-
Pod fly	13.0	15.0			
Soil Fertility/BNF:	20.0	20.0	-	-	-
Soybean					
Abiotic:	23.0	20.0	20.0		23.0
Drought/heat stress	23.0	20.0	20.0	-	23.0
Diseases:	40.0	35.0	40.0		37.0
Bacterial blight*	10.0	5.0	5.0	-	7.0
Mosaic virus*	10.0	10.0	10.0		10.0

Crop/constraint	Asia	ESA	WCA	CWANA	LA
Soybean rust	15.0	15.0	10.0		15.0
Frogeye leaf rust	5.0	5.0	15.0		5.0
Insect pests:	20.0	15.0	25.0		20.0
Pod sucking bugs	5.0	5.0	5.0		5.0
Bean fly	8.0	5.0	8.0	-	10.0
Leaf defoliators	7.0	5.0	12.0		5.0
Soil Fertility/BNF:	17.0	30.0	15.0	-	20.0

*Have the potential to cause complete loss during outbreaks, which are quite frequent in the tropics. Weeds and bruchids cause 10–15% loss across crops/regions.

Notes: Based on inputs received on percentage yield loss in different regions due to various biotic and abiotic production constraints, and the published information on various crops / constraints. Total yield loss due to various constraints in a region has been computed as a percentage of total loss.

Appendix 7. Grain Legume Regional R4D Networks: Brief Profiles

A number of important regional networks that are important to CRP3.5 success are described here in more detail.

Sub-Saharan Africa

PABRA: CIAT facilitates the Pan- Africa Bean Research Alliance (PABRA). PABRA was founded in 1996 and now is a consortium of regional bean networks consisting of about 350 direct and indirect partners, mainly NARS in 28 countries in sub-Saharan Africa, an international research organization (CIAT), and a number of donor organizations, Government and Non-Governmental Organizations (NGOs), sub-regional organization (SROs) such as ASARECA, SADC-FANR and CORAF, community-based Organizations (CBOs), selected rural communities, farmers (seed producers and on-farm researchers), traders and the commercial private sector. The sub-regional bean networks linked by PABRA are the Eastern and Central Africa Bean Research Network (ECABREN) with eight countries (Kenya, Ethiopia, Uganda, Rwanda, Burundi, Sudan, Eastern and west DRC, Madagascar and Northern Tanzania), the Southern Africa Bean Research Network (SABRN) consisting of 10 countries (Southern Tanzania, Mozambique, Zambia, Malawi, Lesotho, Mauritius, South Africa, Angola, southern DRC, Swazi land) and the relatively new West and Central Africa Bean Network (WECABREN) consisting of Burkina Faso, Cameroon, Central African Republic, Congo Brazzaville, Guinea Conakry, Senegal, Sierra Leone and Togo, Ghana and Mali. The regional networks are managed by regional coordinators and respond to issues and priorities of respective sub-regional organization (SROs). A network Steering Committee (SC) is made of leaders of the National Bean Programs of countries in the network who by and large are also leaders of the Legume Program. Annual work plans and budgets are proposed by the SC of each network based on regional network partnership activities. The network workplans are integrated and harmonized to into PABRA workplans.

PABRA facilitates collaborative research within and between the bean networks in Africa by providing a forum for building and maintaining linkages to multiple partners and between research and development. PABRA's five-year framework (developed by partners, based on shared vision and objectives, and a long term mutual agreement to collaborate, sharing of knowledge, resources and capabilities) has well defined performance indicators and is collaboratively implemented by NARS partners in 28 countries belonging to three regional bean networks through complementarity which PABRA harnesses through a process facilitated by the three Regional Networks and PABRA Steering Committees. The successes in beans in Africa are largely attributed to the partnership: release of several bean varieties and the reach of over 7 million households with improved bean varieties within a period of five years.

PRONAF and NGICA on cowpea in Western and Central Africa: Several networks were established mainly in West Africa for cowpea. The main objectives of these networks are to allow interactions among cowpea scientists in the region and to exchange improved cowpea breeding lines and crop management knowledge. RENACO (Réseau de Recherche sur le Niébé pour l'Afrique de l'Ouest et du Centre) [West and Central African Cowpea Research Network] created in covered the following **Countries:** Benin, Cameroon, Ghana, Nigeria, Niger, Mali, Senegal and Burkina Faso. Another project PEDUNE (Protection écologiquement durable du niébé) was set up in 1997 to increase cowpea production and productivity in the Sahel and African savannas by devising ecologically and economically sustainable cowpea pest control for subsistence farmers. PEDUNE covered Benin, Burkina Faso, Mozambique, Niger and Nigeria in the pilot phase and was expanded later to include Cameroon, Ghana, Mali and Senegal. From 2000, RENACO and PEDUNE were merged to form PRONAF (Projet Niebe pour l'Afrique) with IFAD funding which serves nine **Countries:** Benin, Burkina

Faso, Cameroon, Ghana, Mali, Mozambique, Niger, Nigeria and Senegal. The goal of this project is to enhance livelihoods of rural poor through empowerment and gender equitable access to cowpea value chain opportunities via improved institutional arrangements, capacity building and strong linkages with NARES, countries' IFAD investment projects, farmer's organizations and the private sector. The current phase of the project involves the following **Countries:** Benin, Burkina Faso, Ghana, Malawi and Nigeria.

IITA scientists are also involved in the Network for the **Genetic Improvement of Cowpea for Africa – NGICA**. This is a voluntary association of scientists and other stakeholders in cowpea. NGICA take a novel approach to maximizing the benefits of this crop in Africa – NGICA seeks to address the entire spectrum of the cowpea production and utilization system. NGICA is an informal organization made up of volunteers dedicated to the genetic improvement of cowpea worldwide. The main geographic focus is sub-Saharan Africa. The central goal is to benefit the millions of cowpea producers and tens of millions of cowpea consumers in Africa, but if the benefits can be extended further, so much the better. Because the NGICA community is international, it involves participants from North America, South America, Europe and Australia in addition to Africa. It represents disciplines ranging from plant breeding to molecular biology, from agricultural economics to public policy. We believe that traditional institutions and approaches have often become less and less relevant, and that bold, unconventional institutions and approaches are needed – particularly to take advantage of the information and biotechnology revolutions of the past decade.

South and Southeast Asia (SSEA)

All India Coordinated Research Programs (AICRP): AICRP is multi-disciplinary multi-location research network spearheaded by ICAR to monitor, guide, and coordinate research on pulses in India. Many CGIAR centers participate including ICARDA and ICRISAT for the evaluation of lentil, chickpea, pigeonpea, groundnut, and grasspea. This network has identified appropriate varieties and production technologies of these crops in India.

Cereals and Legumes Asia Network (CLAN): The Cereals and Legumes Asia Network (CLAN) was established in 1992, after merging the erstwhile Cooperative Cereals Research Network (CCRN) and the Asian Grain Legumes Network (AGLN). CLAN currently includes scientists and policymakers from 12 member countries (Bangladesh, China, India, Indonesia, Iran, Myanmar, Nepal, Pakistan, Philippines, Thailand, Sri Lanka, and Vietnam). It also includes interested regional and international research institutions in Asia. The Asia-Pacific Association of Agriculture Research Institutions (APAARI) has endorsed and supported the network activities over the past two decades. CLAN is co-facilitated by three CRP 3.5 partners, ICRISAT, ICARDA and AVRDC. CLAN aims to enhance production and productivity of grain legumes (as well as cereals) in Asia. Major network activities include: i) research collaboration to generate smallholder-appropriate technologies, ii) strengthening crop improvement and natural resource management research in NARS, iii) information and knowledge sharing among member countries and iv) capacity building of NARS research and development programs.

Central and West Asia and North Africa (CWANA)

In collaboration with national scientists across CWANA, ICARDA is leading multi-location, multi-year testing of advanced lines to identify improved germplasm through an international nursery system. Lines are evaluated against stresses such as drought, heat, cold, salinity, disease, and insects at many key sites. The information received includes performance data, meteorological data, and agronomic information, providing valuable information on the performance and adaptation of the test genotypes. Every year, ICARDA's food legume program distributes improved germplasm to 50 countries. Thus, ICARDA's international testing network complements national efforts for fast-tracking the release of improved germplasm for general cultivation and facilitating the design of appropriate breeding strategies for specific regions.

Regional Seed Network: The national seed sectors in the West Asia and North Africa (WANA) region are at different stages of development in terms of policy, regulation, technology, and institutions, which affects the progress of seed sector in each country and its integration both at national and regional levels. Networking between national seed programs can assist regional cooperation through the exchange of information and sharing of experiences. Since 1992, the Network is operational as the regional seed organization and the scope of its activities has increased. It is now the major 'outreach vehicle' of the ICARDA Seed Unit and complements other main regional activities such as training.

Nile Valley Regional Food legume Network: Three networks are being established at the regional level in Nile valley and Red Sea region. Ethiopia coordinates one network for the management of wilt and root-rot diseases of cool-season food legumes. Breeding lines and varieties from the four countries, Egypt, Sudan, Ethiopia and Eritrea and ICARDA are screened in Ethiopia (hot spot areas) and shared among countries. Egypt coordinates the network on integrated control of aphids and major virus diseases in cool-season food legumes and cereals and similar IPM options are being tested and demonstrated across participating NARS. Egypt also coordinates the network on socioeconomic studies to see the adoption and impact studies of regional projects on the livelihoods of small-holder farmers.

Maghreb Food Legumes Network: The Maghreb Food Legumes Network [Roseau Maghreb in de Recherche et Developpement des Legumineuse Alimentaires (REMALA)] was created in Tunis targeting North African countries especially Morocco, Algeria and Tunisia for setting up research and development priorities for food legumes in the region. The network comprises a steering committee and the representative members from each country, ICARDA, and European network on protein pea (link to European researchers). The network is dormant now and needs to be revitalized as the demand for food legumes in the region is increasing.

Latin America and the Caribbean

Bean networks were initiated in Central America with the PROFRIJOL network, and a second network was subsequently formed in the Andean zone as well. These networks are no long funded but the collegial relationships established in the past are still carried forward. These include the exchange of information and joint planning, either under projects that span the region such as the AgroSalud project on crop biofortification, or through the regional agronomy meetings known as the PCCMCA (Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos y Animales). Bean programs of Costa Rica, Cuba, El Salvador, Guatemala, Honduras, and Nicaragua routinely participate in the PCCMCA.

Appendix 8. Global Partners in CRP 3.5 GRAIN LEGUMES

National Agricultural Research Systems (NARS)

1. Agricultural Research Council (ARC), Egypt
2. Agricultural Research Council (ARC), South Africa
3. Agricultural Research Council (ARC), Sudan
4. Agricultural Research Council of Nigeria (ARCN)
5. Agricultural Research Division (ARD), Swaziland
6. Agricultural Research Institute, Naliendele (ARI-TANZANIA)
7. Agriculture Research Division (ARD), Lesotho
8. Agricultural Rural Extension Services, Zimbabwe (AREX)
9. All India Coordinated Research Programs (AICRPs), India
10. Bangladesh Agricultural Research Council (BARC), Bangladesh
11. Bangladesh Agricultural Research Institute (BARI)
12. Bayero University Kano (BUK), Nigeria
13. Bureau of Agricultural Research (BAR) and Philippine Council for Agriculture, Forestry and Natural
14. Resources Research and Development (PCARRD), Philippines
15. Central Food Technological Research Institute (CFTRI), Mysore, India
16. Central Institute of Agricultural Engineering (CIAE), Bhopal, India
17. Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, India
18. Central Research Institute for Field Crops (CRIFC), Turkey
19. Centre de Recherches Agronomiques de Loudima (CRAL), Congo Brazzaville
20. Centre National de la Recherche Appliquée au Développement Rural (FOFIFA), Madagascar
21. Centro Nacional de Tecnificación Agrícola (CENTA), El Salvador
22. Chinese Academy of Agricultural Sciences (CAAS), China
23. Comisión Para la Promoción de Exportaciones (PROMPEX), Peru
24. Crops Research Institute, (CRI), Ghana
25. Department of Agricultural Extension Services (DAES)
26. Department of Agricultural Research (DAR), Myanmar
27. Department of Agriculture & Cooperation (DAC), India
28. Department of Agriculture Research and Technical Services (DARTS)
29. Department of Research and Training, Tanzania (DART)
30. Department of Research & Specialist Services (DR&SS), Zimbabwe
31. Department of Science & Technology, India
32. Department of. Agricultural Research Services (DARS), Malawi
33. Direccion de Ciencia Y Tecnologia Agropecuaria (DICTA) and Escuela Agrícola Panamericana (EAP), Honduras
34. Directorate of Groundnut Research (DGR), Junagadh, India
35. Directorate of Soybean Research (DSR), Indore, India
36. Diocese Of Central Tanganyika (DCT), Tanzania
37. Dry-land Agricultural Research Institute (DARI), Iran
38. Ethiopian Institute of Agricultural Research (EIAR), Ethiopia
39. Ethiopian Seed Enterprise (ESE), Ethiopia
40. General Commission for Agricultural Scientific Research (GCSAR), Syria
41. General Directorate of Agricultural Research (GDAR), Turkey
42. Indian Agricultural Research Institute (IARI), New Delhi, India
43. Indian Council for Agricultural Research (ICAR), India
44. Indian Institute of Chemical Technology (IICT), Hyderabad, India
45. Indian Institute of Pulses Research (IIPR), Kanpur, India

46. Institute of Agricultural Research, Nigeria (IAR)
47. Institut Centrafricain de Recherche Agronomique (ICRA), Republic of Central Africa
48. Institut d' Economie Rurale. Mali (IER), Mali
49. Institut de l'Environnement et de Recherches Agricoles (INERA), Burkina Faso
50. Institut de Recherche Agricole Pour Le Developpement (IRAD), Cameroun
51. Institut de Recherche Agronomique de la Guinée (IRAG), Guinée
52. Institut d'Economie Rurale (IER), Mali
53. Institut Des Sciences Agronomiques Du Burundi (ISABU), Burundi
54. Institut des Sciences Agronomiques du Rwanda (ISAR), Rwanda
55. Institut National De La Recherche Agronomique (INRA), Rabat, Morocco
56. Institut National de Recherche Agronomique de Tunis (INRAT), Tunisia
57. Institut National de Recherches Agronomiques du Niger (INRAN), Niger
58. Institut National des Recherches Agricoles du Benin (INRAB), Benin
59. Institut National pour l'Etude et la Recherche Agronomique (INERA), DR Congo
60. Institut Senegalais de Recherches Agricoles (ISRA), Senegal
61. Institut Togolais de Recherche Agronomique (ITRA), Togo
62. Institute for Agricultural Research (IAR), Nigeria
63. Instituto de Ciencia y Tecnología Agrícolas (ICTA), Guatemala
64. Instituto de Investigacao Agraria de Mocambique (IIAM), Mozambique
65. Instituto de Investigaçao Agronómica (IIA), Angola
66. Instituto Nacional Autonomo de Investigaciones Agropecuarias (INIAP), Ecuador
67. Instituto Nacional de Investigaciones Forestales y Agropecuarias (INIFAP), Mexico
68. Instituto Nicaraguense de Tecnología Agropecuaria (INTA), Nicaragua
69. Kenya Agricultural Research Institute (KARI), Kenya
70. La Estación Experimental Agroindustrial Obispo Colombres (EEAOC), Argentina
71. Lake Zone Agricultural Research and Development Institute (LZARDI), Tanzania
72. Mauritius Sugar Industry Research Institute (MSIRI), Mauritius
73. Ministry of Agriculture and Food Security, Malawi
74. Msekera Research Station (ZARI) and Provincial Department of Agriculture, Zambia
75. Naliendele Agricultural Research Station (NARS), Tanzania
76. National Agricultural Research Organization (NARO), Uganda
77. National Bureau of Agriculturally Important Microorganisms (NBAIM), Mau, UP, India
78. National Bureau of Plant Genetic Resources (NBPGR), New Delhi, India
79. National Cereal Research Institute (NCRI), Nigeria
80. National Institute of Nutrition (NIN), Hyderabad, India
81. National Smallholder Farmer's Association of Malawi (NASFAM), Malawi
82. Nepal Agricultural Research Council (NARC), Nepal
83. Pakistan Agricultural Research Council (PARC), Pakistan
84. Plant Protection Research Institute (PPRI), Hanoi, Vietnam
85. Projet de Developpement Rural Integree (PDRI)
86. Selian Agricultural Research Institute (SARI), Tanzania
87. Soil Research Institute (SRI), Bhopal, India
88. Vietnam Academy of Agricultural Sciences (VAAS), Hanoi, Vietnam
89. Zambian Agricultural Research Institute (ZARI), Zambia

International Agricultural Research Centers (IARCs)

1. Bioersity International, Rome, Italy
2. Centro Internacional de Agricultura Tropical (CIAT), Columbia
3. Generation Challenge Program (GCP), Mexico
4. HarvestPlus Challenge Program of CGIAR
5. International Center for Agricultural Research in the Dry Areas (ICARDA), Syria

6. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India/Africa
7. International Food Policy Research Institute (IFPRI), USA
8. International Institute of Tropical Agriculture (IITA), Nigeria
9. International Livestock Research Institute (ILRI), Kenya/Ethiopia
10. International Maize and Wheat Improvement Center (CIMMYT), Mexico
11. International Rice Research Institute (IRRI), Philippines
12. International Water Management Institute (IWMI), Sri Lanka

Advanced Research Institutes (ARIs)/Universities

1. Acharya N G Ranga Agricultural University (ANGRAU), Hyderabad, India
2. Aleppo University, Syria
3. Assam Agriculture University, Jorhat, India
4. Australian Centre for International Agricultural Research (ACIAR), Australia
5. Bayero University of Kano (BUK), Nigeria
6. Beijing Genomics Institute (BGI), China
7. Birsa Agricultural University (BAU), Jharkhand, India
8. Botswana College of Agriculture (BCA), Botswana
9. Bunda College of Agriculture (BCA), Malawi
10. Catholic University of Leuven, Belgium
11. Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), France
12. Centre for Legumes in Mediterranean Agriculture (CLIMA), Australia
13. Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), Haryana, India
14. Colorado State University (CSU), USA
15. Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia
16. Consejo Superior de Investigaciones Científicas (CSIC), Spain
17. Cornell University, United States of America
18. CSK Himachal Pradesh Krishi Vishva Vidyalaya (CSKHPKVV) Dhaulakuan, India
19. Department of Employment, Economic Development and Innovation (DEEDI), Queensland, Australia
20. Donald Danforth Center, St Louis, USA
21. Dry Grain Pulses Collaborative Research Program, USA
22. Egerton University, Kenya
23. Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Brazil
24. Estação Nacional de Melhoramento de Elvas (ENMP), Portugal
25. GB Pant University of Agriculture and Technology, Pantnagar, India
26. Ghent University, Belgium
27. Halemaya University, Ethiopia
28. Indian Agriculture Research Institute (IARI), New Delhi, India
29. Indira Gandhi Agricultural University (IGAU), Raipur, Chhattisgarh, India
30. Institut National De La Recherche Agronomique (INRA), France
31. Instituto de Investigacion y Formacion Agraria y Pesquera de Andalucia (IIFAPA), Spain
32. Instituto Nacional de Salud Publica (INASP), Mexico
33. Iowa State University, United States of America
34. Japan International Research Centre for Agricultural Sciences (JIRCAS), Tsukuba, Japan
35. Jawaharlal Nehru Krishi Vishva Vidyalaya (JNKVV), Jabalpur, Madhya Pradesh, India
36. Kaduna State Agricultural Development Project (KADP), Nigeria
37. Kano State Agricultural and Rural Development Authority (KNARDA), Nigeria
38. Kansas State University (KSU), USA
39. Kenyatta University, Kenya
40. Kwame Nkrumah University of Science and Technology (KNUST), Ghana

41. Lanzhou University, China
42. Laval University, Canada
43. Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, India
44. Makerere University, Kampala, Uganda
45. Michigan State University, USA
46. Moi University, Kenya
47. Murdoch University, Australia
48. Narendra Deva University of Agriculture & Technology (NDUA&T), Faizabad, India
49. National Centre for Genome Resources (NCGR), New Mexico, USA
50. National Research Centre on Plant Biotechnology (NRCPB), New Delhi, India
51. National University of Ireland, Galway, Ireland
52. Njala University, Sierra Leone
53. North Carolina State University (NCSU), USA
54. North Dakota State University, USA
55. Nottingham University, UK
56. Odisha University of Agriculture & Technology, Odisha, India
57. Osmania University (OU), Hyderabad, India
58. Panjabrao Deshmukh Krishi Vidyapeeth (PDKV), Akola, India
59. Peanut Collaborative Research Support Program, (Peanut CRSP), USA
60. Dry Grain Pulses Collaborative Research Support Program, (Pulse CRSP), USA
61. United States of America Penn State University, USA
62. Pulse Breeding Australia (PBA), Australia
63. Punjab Agricultural University (PAU), Ludhiana, India
64. Purdue University, USA
65. Rajmata Scindia Krishi Vishwavidyalaya (RSKV), Gwalior, India
66. Savanna Agricultural Research Institute (SARI), Ghana
67. Sokoine University of Agriculture, Tanzania
68. Tamil Nadu Agricultural University (TNAU), Coimbatore, India
69. Tamworth Agricultural Institute, NSW, Australia
70. Techreen University, Syria
71. Tuskegee University, USA
72. Université Nationale de Rwanda, Rwanda
73. University of Agricultural Sciences, Raichur, India
74. University of Agricultural Sciences, Bangalore, India
75. University of Agricultural Sciences, Dharwad, India
76. University of Agriculture, Makurdi (UAM), Nigeria
77. University of California, Davis, USA
78. University of California, Riverside, USA
79. University of Cordoba, Spain
80. University of Frankfurt, Germany
81. University of Georgia, United States of America
82. University of Ibadan, Nigeria
83. University of Illinois, USA
84. University of KwaZulu Natal, South Africa
85. University of Maiduguri, Nigeria
86. University of Makurdi, Nigeria
87. University of Nairobi, Kenya
88. University of Pretoria, South Africa
89. University of Queensland, Australia
90. University of Saskatoon, Canada
91. University of West Virginia, USA

92. University of Western Australia, Australia
93. University of Wisconsin, Madison, USA
94. University of Zambia, Zambia
95. University of Zimbabwe, Zimbabwe
96. USDA-ARS, Soybean Genomics Lab, BARC, United States of America
97. Victorian Agri-Biosciences Centre (VABC), Australia
98. Washington State University, USA

Non-Government Organizations (NGOs)

1. African Seed Trade Association (AFSTA), Kenya
2. Africare, Washington DC, United States of America
3. Alliance for a Green Revolution in Africa (AGRA), Kenya
4. Agriculture Man Ecology (AME) Foundation, Bangalore, India
5. Association of Church Development Projects (ACDEP), Ghana
6. Association marocaine des multiplicateurs de semences (AMMS), Morocco
7. Bharatiya Agro Industries Foundation (BAIF) Institute for Rural Development, Pune, India
8. CARE International, Switzerland
9. Catholic Dioceses Development, Kenya
10. Catholic Relief Services (CRS), USA
11. Catholic Relief Services, Kenya (CRS)
12. Centre for World Solidarity (CWS), Hyderabad, India
13. Centre Régionale pour la Production Agricole (CERPA), Nigeria
14. Concern Universal, Malawi
15. Foundation for Participatory Research in Honduras (FIPAH), Honduras
16. Organization for the Rehabilitation of the Environment (ORE), Haiti:
17. Consortium of Non-Governmental Organizations of Central Asia and the Caucasus (CNGO-CAC)
18. Fédération Interprofessionnelle des Activités Céréalières (FIAC), Morocco
19. Initiative for the Promotion of Green Resources (PROGREEN)
20. Kirkhouse Trust, United Kingdom
21. One Acre Fund/Tubura Rwanda, Burundi and Kenya
22. Radio Communautaire FM Alaketu (ALAKETU FM), Benin
23. Radio Gbetin (Radio Gbetin), Senegal
24. Radio Horizon (Radio Horizon), Sofia, Bulgaria.
25. Rural Development Trust (RDT), Anantapur, India
26. Sasakawa Global 2000 (SG2000), Ethiopia
27. Seed Trade Association of Malawi, Malawi
28. Sustainable intensification of maize-legume cropping systems for food security in eastern and southern Africa (SIMLESA), Africa
29. Techno Serve, Washington DC, USA
30. The Cooperative League of USA (CLUSA), USA
31. Women Organizing for Change in Agriculture and Natural Resource Management (WOCAN), Africa
- 32.** World Vision International, USA

Private Sector

1. Agricultural Commodity Supplies (ACOS), Ethiopia
2. Agri-Inputs Suppliers Association of Malawi, Malawi
3. Agricultural Seed Agency, Tanzania
4. Alheri Seeds, Niger
5. Asia & Pacific Seed Association (APSA)

6. Association of Smallholder Seed Growers (ASSMAG), Malawi
7. Demeter Agriculture, Malawi
8. Dry Bean Producers Organization South Africa
9. Dry Land Seed Co, Kenya
10. East African Seeds Co Ltd, Tanzania
11. Elfora Agro-industry Ltd, Ethiopia
12. FAMCO Seed Ltd, Tanzania
13. Farm Input Care (FICA) Seed, Uganda
14. Farmers' Link, Zambia
15. Funwe Farm, Malawi
16. Highland Seed Company Ltd, Tanzania
17. International Seed Testing Association (ISTA), Switzerland
18. Kamano Seeds, Zambia
19. Kenya Seeds, Kenya
20. Krishidhan Seeds Ltd., India
21. Krishna Seeds, Tanzania
22. Leldet Seeds, Kenya
23. Mahyco Seeds, India
24. Masoumin Grain Trader, Madagascar
25. Nalweya Seed Company (NASECO), Uganda
26. National Smallholder Farmers' Association of Malawi (NASFAM), Malawi
27. Nimbkar Seeds Private Ltd., India
28. PANNAR Seed (PTY) Ltd, South Africa
30. Premier Seeds Nigeria Limited
31. Pristine Seeds, Zimbabwe
32. Progeny Seeds, Zimbabwe
33. Rwanda Seed Company (RWASECO) Private Seed Co, Rwanda
34. Simlaw Seeds Company Ltd, Kenya
35. Transeed International Ltd, Tanzania
36. Victoria Seeds Limited, Uganda
37. Zenobia Seed Co, Tanzania

Regional/sub-regional organizations

1. Asia-Pacific Association of Agriculture Research Institutions (APAARI), Thailand
2. Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), Uganda
3. Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA), Jordan
4. Central Asia and the Caucasus Association of Agricultural Research Institutions (CACAARI), Uzbekistan
5. Coordination Centre for Agricultural Research and Development for Southern Africa (CCARDESA), Botswana
6. Conseil Ouest et Centre Africain pour la Recherche et le Développement Agricoles (CORAF), Senegal
7. Forum for Agricultural Research in Africa (FARA), Ghana

Regional Networks

1. Cereals Legumes Asia Network (CLAN)

2. East and Central Africa Bean Research Network (ECABREN)
3. Foundation for Participatory Research in Honduras (FIPAH)
4. Network for the Genetic Improvement of Cowpea for Africa (NGICA)
5. Pan Africa Bean Research Alliance (PABRA)
6. ProjectNiebe pour l'Afrique, West Africa (PRONAF)
7. Sistema de Integracion Centroamericano de Tecnologia Agricole (SICTA)
8. Southern African Bean Research Network (SABRN)
9. El Programa Cooperativo Regional de Frijol para Centro América, México y El Caribe (PROFRIJOL)
10. West and Central Africa Bean Research Network (WECABREN)

Farmer organizations

1. Association des Organizations des Paysans Professionels (AOPP), Mali
2. Consortium of Farmer Organizations of Central Asia and the Caucasus (CFO-CAC), Central Asia
3. Democratic Republic of Congo (DRC): UMAMABU Farmers associations, DR Congo
4. FUMA Gaskiya, Niger
5. Indian Farmers Fertilizer Co-operative (IFFCO), India
6. Krishak Bharati Co-operative Ltd., (KRIBHCO), India
7. L'Association Féminine des Transformatrices Anoura Da Dounia, Gaya, Niger
8. L'Association des Producteurs WADACHE, Gaya, Niger
9. L'Association des Producteurs GANI YAKORJI, Gaya, Niger
10. Mozambican Farmers Co-operative- for agri-trading, processing and exporting (IKURU), Mozambique
11. Myanmar Central Co-operative Society Ltd. (CCS), Myanmar
12. Mtandao wa Vikundi vya Wakulima Tanzania (MVIWATA), Tanzania
13. National Smallholder Farmers' Association of Malawi (NASFAM), Malawi
14. National Co-operative Council of Sri Lanka (NCC), Sri Lanka
15. Philippine Federation of Credit Cooperatives (PFCCO), Philippines
16. Vietnam Cooperative Alliance (VCA), Vietnam
17. Water Users Association, Malawi

Appendix 9. CRP 3.5 GRAIN LEGUMES: Current bilateral funded R4D projects

CIAT

Project Title: Biofortified crops for improved human nutrition - Harvest Plus Challenge Program

Donor: Bill & Melinda Gates Foundation, Canadian CIDA, World Bank

Countries: Rwanda and D.R. Congo, Honduras, Nicaragua, Guatemala

Crops: Common bean

Partners: ISAR, INERA, PABRA- ECABREN –SABRN, EAP, INTA, FUNDIT

Summary: This is an annual project carried out as part of the CGIAR HarvestPlus Challenge Program, which is bringing together scientific and research resources of the CGIAR to combat malnutrition in the developing world. Using phenotypic and marker-assisted selection, this project aims to biofortify varieties of beans to create lines with higher mineral content, especially iron, and superior agronomic traits. Bioefficacy trials are also conducted to demonstrate the value of high-iron beans.

Project Title: Improving tropical legume productivity for marginal environments in sub-Saharan Africa (TL-I) Phase 2

Donor: Bill & Melinda Gates Foundation through the Generation Challenge Program

Countries: Ethiopia, Kenya, Malawi, Tanzania, Zimbabwe

Crops: Common bean

Partners: SARI-Awassa, KARI, DARTS, SARI-Selian, Zimbabwe

Summary: This project aims to contribute to the development of improved legume varieties in sub-Saharan Africa by developing genomic resources and molecular markers for traits of importance, and by implementing modern breeding in sub-Saharan Africa. Being a collaborative project, CIAT's specific role is to improve common bean productivity for marginal environments in sub-Saharan Africa. This project will address this issue along with additional important biotic stress resistance traits through five activities.

Project Title: Improving the livelihoods of farmers in drought-prone areas of sub-Saharan Africa and South Asia through enhanced grain legume production and productivity (TL-II) – Phase 1: Aug 1997 to Aug 2011; Phase 2: Sep 2011 to Aug 2014

Donor: Bill & Melinda Gates Foundation through ICRISAT

Countries: Ethiopia, Kenya, Malawi, Tanzania, Zimbabwe

Crops: Chickpea, common bean, cowpea, groundnut, pigeonpea and soybean

Partners: EIAR, KARI, DARTS, SARI-Selian, Zimbabwe

Summary: This project aims to increase the productivity and production of six grain legumes – groundnut, cowpea, bean, chickpea, pigeonpea and soybean. Project activities involve developing cultivars tolerant to drought and the major pests and diseases using modern plant-breeding techniques such as marker-aided selection (which will be developed under the Tropical Legumes I Project supported by the Bill & Melinda Gates Foundation). A major thrust will be to develop sustainable seed production and delivery systems in project countries that enhance access to improved legume varieties by resource-poor farmers. Social science research will be used to analyze and provide advice concerning the social and cultural environments that influence the sustainable adoption and spread of promising varieties, technologies and innovations, and the scaling-up and scaling-out work done amongst farm communities. Capacity building and infrastructure development among national program partners involved in breeding and seed delivery systems is a major activity, in order to ensure the sustainability of legume breeding efforts in the project countries.

Project Title: Dry bean improvement and marker assisted selection for diseases and abiotic stresses in Central America and the Caribbean

Donor: Generation Challenge Program

Countries: Haiti, Mexico, Nicaragua

Crops: Common bean

Partners: ORE, INIFAP, INTA

Summary: This project will be one of the first to apply molecular breeding on a large scale to common bean

improvement for the region of Central America and the Caribbean, and will focus on tolerance to drought stress and diseases that occur under drought and low soil-fertility conditions. The project combines the strengths of the INIFAP, the Mexican national agriculture research institution, with CIAT. Studies on gene expression have revealed several differences between drought resistant red seeded beans and less resistant black seeded beans. Lines selected in CIAT have performed well at the mid-altitude site in the Bajío, Guanajuato.

Project Title: Basal root architecture and drought tolerance in common bean

Donor: Generation Challenge Program

Countries: Mozambique, USA

Crops: Common bean

Partners: Penn State University

Summary: Beans have many different classes of roots. Basal roots are those which originate at the crown, and can vary widely in number. The project is designed to test if basal roots give plasticity to the plant to explore shallow soil strata for plant nutrients, and simultaneously to explore lower strata for moisture. The outcome will assist in the development of germplasm that is tolerant to low levels of soil phosphorus as well as to drought.

Project Title: The Pan Africa Beans Research Alliance (PABRA) Phase IV 31/12/2013

Donor: CIDA- Canadian International Development Agency

Countries: 28 countries in East, southern and West Africa

Crops: Common bean

Partners: National programs in 28 countries; international and local NGOs; private seed companies

Summary: PABRA (Pan-Africa Bean Research Alliance) is a consortium of sub-regional bean networks: ECABREN (Eastern and Central Africa), SABRN (Southern Africa) and WECABREN (West and Central Africa). PABRA is quite large, with 350 direct and indirect partners from NARS, IARCs, donors, NGOs, sub-regional organizations (ASARECA, SADC-FANR, CORAF), community-based organizations, seed producers, traders and the commercial private sector. PABRA works under a programmatic framework with seven broad objectives: improved and more resilient bean varieties; improved nutrition through consumption of biofortified beans and bean based foods; improved crop management; strengthened market linkages; wider impact through partnerships; enhanced research and institutional capacity; gender equity. Under the BMGF-funded Tropical Legumes II project, in addition to supporting the bean component, PABRA also led the seed systems component, opening new options for decentralized seed production, and links to the private sector.

Project Title: Supporting nutrition and health, food security, environmental stresses and market challenges that contribute to improve livelihood and create income resource poor small holder families in sub-Saharan Africa

Donor: SDC-Swiss Agency for Development and Cooperation

Countries: 28 countries in East, southern and West Africa

Crops: Common bean

Partners: National programs in 28 countries; international and local NGOs; private seed companies

Summary: This project is part of PABRA which is co-funded by SDC and Canadian CIDA.

ICARDA

Project Title: Improving the livelihoods of resource-poor farmers through the use of biodiversity of food legumes to increase productivity, nutritional security and establish sustainable farming system in the non-tropical dry areas

Donor: World Bank, EU, USAID

Countries: Afghanistan; Algeria; Armenia; Azerbaijan; Bangladesh; Eritrea; Ethiopia; Egypt; Georgia; Iran; India; Iraq; Jordan; Lebanon; Morocco; Nepal; Pakistan; Sudan; Syria; Tunisia; Turkey; Uzbekistan and Yemen.

Crops: Chickpea, lentil, faba bean and grasspea

Partners: ICARDA and National Programs in the target region

Summary: Food legume crops (lentil, Kabuli chickpea, faba bean and grasspea) play an important role in food, feed and farming systems of dry areas. A vast majority of people in dry areas of South Asia, West Asia,

Central Asia, China, North and East Africa and Latin America are dependent on these crops for their nutritional requirement and food security. The residues of food legumes are valuable animal feed. These legumes when grown in rotation with cereals provide sustainable cropping systems. The productivity of food legumes in developing countries remains stagnant and per capita availability is far below the WHO recommended 45g/person/day. Therefore, improvement in the production of these crops through germplasm enhancement and crop management will therefore contribute substantially to improved human nutrition in the developing world. This project aims to develop methodologies and technologies, improved genetic stocks and associated knowledge to improve crop productivity and eventually contributes to better livelihoods of people in the developing world. Food legume improvement links components of basic and strategic research with appropriate field evaluation across a diverse range of environments. The creation and application of linkages among gene identification, plant breeding, crop management practices, and livelihood outcomes across multiple sites and cropping systems are the guiding principles of this project. The genetic enhancement research represent genetically enhanced, seed-embedded technologies developed by multidisciplinary teams (germplasm enhancement, integrated pest management, biotechnology, genetic resources, seed systems) charged with the generation of products reflecting integrated solutions for target end-users. The exciting portfolio under development through consultation with and analysis of the needs of National programs are stress tolerant (diseases, pests, drought and cold) cool-season legumes for food security, and crop intensification and diversification, bio-fortified lentils, integrated pest management (IPM) options for the control of diseases, insect pests, strengthening seed delivery systems, and capacity building in NARS programs.

Project Title: Genetic enhancement in breaking yield barriers in Kabuli chickpea and lentil through pre-breeding for the development of high yielding cultivars

Donor: Department of Agriculture & Cooperation (DAC), Government of India

Countries: India and Syria

Partners: DAC, ICAR and ICARDA

Summary Lentil and chickpea have an intrinsically narrow genetic base in India. This limits breeder's progress today. The existing variability among indigenous germplasm has been exploited to reach to a desirable level of productivity today. However, to attain further breakthrough in increasing yield and improving stability in future cultivars, new variability needs to be tapped and incorporated into Indian germplasm. There is a striking difference between germplasm available in South Asia including India and the centers of origin/diversity of these crops. For example, lentil germplasm from India is among the least variable among lentil producing countries, despite India being the largest lentil producing country in the world. Similar striking difference was recorded in other crops between germplasm from South Asia and the rest of the world. This project aims to widen the genetic base of chickpea, and lead to the development of new lines which may be used in ongoing breeding program for improvement of cultivated chickpea as well their release directly as varieties. Similarly in lentil the project envisages genetic enhancement through pre-breeding for increasing the extent of useful diversity to breeders through introgression of desirable characteristics from exotic cultivated and wild species. Varieties with better yield potential, enhanced quality and wider genetic base will lead to increased productivity and better adaptability.

Project Title: Breeding chickpea for drought tolerance and disease resistance

Donor: Australia

Countries: Australia and WANA Region

Crops: Chickpea

Partners: Australia and regional NARS

Summary: This project aims to enhance production, productivity and yield stability of chickpea under Mediterranean and similar Australian environments through genetic improvement and agronomic options. Most chickpea cultivars grown by farmers in Mediterranean and Australian environments are susceptible to Ascochyta blight, affected by terminal drought, susceptible to vegetative and flowering stage cold. An additional threat from Fusarium wilt, a soil borne disease present in most of the chickpea growing countries is increasing under the changing climates, which requires pre-emptive action. This project will use genetic and agronomic manipulation to enhance production and productivity of chickpea. It will attempt to develop efficient and reliable field and laboratory screening techniques for the evaluation of germplasm and breeding materials for biotic and abiotic stresses, understand their genetic bases, and develop efficient and high yielding cultivars with combined resistances to these stresses through conventional and molecular breeding approaches. The results of this project will be shared with

NARS in the West Asia and North Asia (WANA) institutions and in areas with similar environments in Australia.

Project Title: Development of large-seeded lentil varieties with high biomass, multiple disease resistance and tolerance to terminal drought and heat

Donor: ICAR, New Delhi, India

Countries: India

Crops: Lentil

Partners: IIPR (Kanpur); GBPUA&T (Pantnagar); CSKHPKV (Dhaukuan); RMVRSKV (Sehore); JNKVV (Jabalpur); NDUA&T (Faizabad); IARI (New Delhi)

Summary: Lentils of Indian-subcontinent have marked lack of variability with respect to important morphological, agronomic, and phenological and stress resistance traits. Seed size of local cultivars and landraces are generally <2.5 g per 100-seeds. This requires infusion of new germplasm in the Indian breeding program to make a significant improvement in lentil crop. ICARDA has >11,000 germplasm and breeding lines with enormous variability for various traits, and is running a strong international breeding program. Through rigorous screening and multi-location evaluation, ICARDA has identified accessions with various maturity groups, different seed traits, rust, wilt and Stemphylium blight resistance, etc. Recently, ICARDA has developed early maturing lines in large-seeded group by involving early material from South Asian origin in its breeding program. The genetically fixed materials and segregating populations having large-seed trait (up to 7.00 g per 100-seed weight), and other desirable traits can be tested by collaborating institutions in various edapho-climatic conditions. The project aims at development of bold-seeded cultivars (>3.0 g per 100-seeds) using local and ICARDA-supplied genetic materials (germplasm, breeding lines, segregating populations) with resistance to rust, vascular wilt and root rot, and tolerant to drought and heat, and identification and use of wild relatives having desirable genes, and tagging of rust resistant genes to use in MAS.

Project Title: Development of lentil cultivar with high concentration of iron and zinc

Donor: HarvestPlus Challenge Program of CGIAR

Countries: Bangladesh, Nepal, India, and Syria

Crops: Lentil

Partners: ICAR, BARI, NARC, GCSAR

Summary: Over 2 billion people in the developing world are affected by micronutrient malnutrition, the “Hidden Hunger”, and many times it is ignored/unnoticed by us. Of them, Iron deficiency alone affects >47% of women and preschool children, often leading to anemia, impaired physical and mental growth, and also affect learning capacity. Like Iron deficiency, Zinc deficiency also prevails to a great extent in the developing world and thought to affect billions of people. Among various options, “Biofortification” of staple crops and their intake in daily diet has been proved to be a key strategy to address micronutrient malnutrition and thereby nutritional security. Lentil, which is a staple pulse crop and is a key component of daily dish of the people of South & West Asia and North & East Africa and where micronutrient deficiency is prevailing, is being researched for the development of Iron- and Zinc-rich cultivars under the HarvestPlus Challenge Program of CGIAR.

ICRISAT

Project Title: Improving the livelihoods of farmers in drought-prone areas of sub-Saharan Africa and South Asia through enhanced grain legume production and productivity (TL-II)

Phase 1: Aug 1997 to Aug 2011; Phase 2: Sep 2011 to Aug 2014

Donor: Bill & Melinda Gates Foundation

Countries: Ethiopia, Kenya, Malawi, Mozambique, Tanzania, Zimbabwe, Mali, Niger, Nigeria, India

Crops: Chickpea, common bean, cowpea, groundnut, pigeonpea and soybean

Partners: ICRISAT, CIAT, IITA, AGRA/PASS, N2Africa, WFP/P4P

Summary: This project aims to increase the productivity (yield per unit area) and production (total availability) of six grain legumes – groundnut, cowpea, bean, chickpea, pigeonpea and soybean. These are important sources of protein for more than 2.1 billion people living in sub-Saharan Africa and South Asia. The project proposes to develop, test and promote improved crop cultivars (and associated crop management practices) which can enhance legume productivity and production in the drought-prone areas of target regions and countries. Project activities will involve developing cultivars tolerant to drought and the major

pests and diseases using modern plant-breeding techniques such as marker-aided selection (which will be developed under the Tropical Legumes I Project supported by the Bill & Melinda Gates Foundation). A major thrust will be to develop sustainable seed production and delivery systems in project countries that enhance access to improved legume varieties by resource-poor farmers. Social science research will be used to analyze and provide advice concerning the social and cultural environments that influence the sustainable adoption and spread of promising varieties, technologies and innovations, and the scaling-up and scaling-out work done amongst farm communities. Social science inputs will also support research developments in breeding through a feedback process, policy dialogue, and by identifying lessons learnt for technology dissemination. Ensuring capacity building and infrastructure development among national program partners involved in breeding and seed delivery systems will be a major activity, in order to ensure the sustainability of legume breeding efforts in the project countries.

Project Title: Improving tropical legume productivity for marginal environments in sub-Saharan Africa and South Asia (TL I-Phase 2) (Objectives 1, 4 and 5)

Donor: Bill and Melinda Gates Foundation thru Generation Challenge Program/CIMMYT

Countries: Senegal, Niger, India, Malawi, Mali, Tanzania

ARIs: University of California-Davis (UC-Davis), USA; University of Georgia, USA; North Carolina State University (NCSU), USA; University of Frankfurt, Germany; Agropolis, CIRAD, France; UCB, Brazil; EMBRAPA Genetic Resources and Biotechnology, Brazil

Crops: Groundnut, cowpea, common bean and chickpea

Summary: This project aims to contribute to the development of improved legume varieties by developing genomic resources and molecular markers for traits of importance, and by implementing modern breeding in sub-Saharan Africa and South Asia. Being a collaborative project, ICRISAT's specific role is to improve groundnut and chickpea productivity for marginal environments in sub-Saharan Africa and South Asia. Its overall objective is to improve the productivity of groundnut, cowpea, common bean and chickpea for SSA through the application of modern breeding approaches using the genetic resources and genomic tools developed in the first phase of the project, in close partnership with SSA countries and regional research institutions. This project will apply modern breeding for the four legume crops, will conduct high-quality phenotyping and will improve human resources and local infrastructure.

Project Title: Sustainable Intensification of Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA)

Donor: Australian Centre for International Agricultural Research (ACIAR) thru CIMMYT

Countries: Ethiopia, Kenya, Tanzania, Malawi, Mozambique, Republic of South Africa, Uganda, Australia

ARIs: Queensland Department of Employment, Economic Development and Innovation (QDEEDI), Australia; Murdoch University, Australia

Crops: Chickpea, pigeonpea, groundnut, common bean, cowpea and soybean

Summary: The aim of the project is to increase food security and incomes at household and regional levels and economic development in eastern and southern Africa through improved productivity from more resilient and sustainable maize-based farming systems. The overall objective is to sustainably increase the productivity of selected maize-legume systems in eastern and southern Africa by 30% from the 2009 average for each target country by the year 2020 and at the same time reduce seasonal down-side risks by 30%.

Project Title: BREAD: Overcoming the Domestication Bottleneck for Symbiotic Nitrogen Fixation in Legumes

Donor: National Science Foundation, USA thru the University of California-Davis, USA

Countries: USA, India

Partners: University of California-Davis, USA; Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya (RVSKVV), India; Punjab Agricultural University (PAU), India

Crops: Chickpea

Summary: It is commonly asserted that domestication has reduced the efficiency of symbiotic nitrogen fixation in cultivated legume species, and that this situation continues to worsen as modern breeding further reduces genetic variation in elite varieties. Despite the important implications, we have essentially no understanding of the mechanisms that underlie efficient symbiosis, or how and to what extent breeding has reduced ancestral gains to symbiotic nitrogen fixation. The goal of the proposed research is to characterize the genetic mechanisms that underlie phenotypic plasticity for symbiosis in the agricultural context. We propose: (1) to elucidate the molecular genetic basis of phenotypic variation for symbiotic

nitrogen fixation efficiency in *Cicer* spp, including *C. ariteinum* (cultivated chickpea) and *C. reticulatum* (the wild progenitor), (2) to quantify the impact of domestication on the potential for symbiotic nitrogen fixation in chickpea, and (3) to initiate purpose-driven populations and association genetics to examine genetic potential for efficient nitrogen fixation in elite genotypes of chickpea.

Project Title: Zambia Groundnut Productivity – Improving Groundnut Farmers’ Incomes and Nutrition through Innovation and Technology Enhancement (I-FINITE)

Donor: USAID

Countries: Zambia

Crops: Groundnut

Partners: IITA-Nigeria; Msekera Research Station (ZARI) and Provincial Department of Agriculture, Zambia; University of Zambia, Zambia; Tuskegee University, USA; USDA-ARS-National Peanut Research Laboratory, Georgia, USA

Summary: This project aims to increase the incomes of smallholder groundnut farmers in four districts in the Eastern Province of Zambia (Chipata, Katete, Petauke and Lundazi). This will be achieved through innovative partnerships; developing crop management strategies and seed systems to enhance productivity and link farmers to markets; developing low-cost technologies to control and determine aflatoxin contamination; and setting up systems of grades and standards to enhance traceability.

Project Title: Malawi Seed Industry Development

Donor: Irish Aid

Countries: Malawi

Crops: Groundnuts, pigeonpea, chickpea, beans and rice

Partners: Bunda College of Agriculture, Malawi; National Smallholder Farmers Association of Malawi (NASFAM), Malawi; African Seed Trade Association (AFSTA), Kenya; Agri-Inputs Suppliers Association of Malawi, Malawi; Director of Agricultural Research Services (DARS), Ministry of Agriculture and Food Security, Malawi; Seed Trade Association of Malawi, Malawi, Water Users Association, Malawi

Summary: With the Malawi Seed Industry Project’s activities implementation having commenced towards the end of 2008, ICRISAT has since been working with various stakeholders to improve the livelihoods of smallholder farmers through the provision of high quality foundation and certified seeds. While legumes, particularly groundnuts, pigeonpeas, chickpea and beans have been the major target crops, rice – a cereal crop – has been added to the portfolio of crops targeted under the project. The decision to include rice, a non-legume crop, was demand driven to multiply certified seed of selected varieties in order to help rice producing smallholder farmers attain high yields. While taking cognizance of the successes of the past three years, ICRISAT will continue working to achieve its project goal of increasing smallholder farmer yields and incomes through provision of high quality seeds. Year-4 grant will be used to implement activities that will ultimately contribute to the attainment of three primary objectives: i) Develop capacity of existing and potential local seed companies; ii) Improve the policy environment for seed trade and quality assurance using novel technology such as genetic finger printing; iii) Strengthen the commercial distribution network for improved seed, complementary inputs, and resulting crop outputs.

Project Title: Groundnut improvement for poor smallholder farmers in Asia

Donor: OPEC Fund for International Development

Countries: Bangladesh, China, India, Indonesia, Myanmar, Nepal, Philippines, Sri Lanka, Timor Leste, Uzbekistan and Vietnam.

Crops: Groundnut

Partners: NARS in Asia

Summary: This project intends to help alleviate rural poverty by raising incomes and food and nutritional security of poor smallholder groundnut farmers in Asia by ensuring regular and sustainable increases in groundnut productivity and the profitability of groundnut cultivation through genetic enhancement in partnership with NARS in Asia.

Project Title: Securing chickpea productivity under contemporary abiotic stresses: improvement of podding and seed-filling under heat, drought and salinity (Approved in principle -- Awaiting sanction order)

Donor: Australia-India Strategic Research Fund (AISRF), Department of Science & Technology, Govt. of India

Countries: India, Australia

Crops: Chickpea

Partners: University of Western Australia, Australia; Punjab University, India

Summary: Chickpea is an important grain legume crop in Australia and India, but grain yields are often restricted by stresses of heat, drought and salinity. Drought and heat often co-occur in field situations and during terminal drought when soils dry in late spring salinity also increases; yet, virtually all studies of plant responses to these stresses have investigated each individual factor. The overall goal is to identify mechanisms contributing to stress tolerance in chickpea and the information on tolerance mechanisms can then be used in breeding programs in the development of stress tolerant cultivars for Australia and India. Thus, project aims are to: (i) elucidate the processes in the reproductive phase of chickpea most susceptible to heat, drought and salinity stress; (ii) identify sources of tolerance across stresses and the physiological mechanisms involved; (iii) further our understanding of salinity tolerance of reproduction and validate salinity tolerance quantitative trait loci (QTL); (iv) initiate breeding for multiple stress tolerance by developing multi-parental crosses involving stress-tolerant chickpea genotypes.

IITA

Project Title: Encouraging regional trade with hermetic storage for cowpea in West and Central Africa

Donor: Purdue University (PURDUE)

Countries: Nigeria, Cameroon, Togo, Benin

Crops: Cowpea

Partners: Initiative for the Promotion of Green Resources (PROGREEN), Centre Régionale pour la Production Agricole (CERPA) MONO-COUFFO (CERPA MONO-COUFFO), Institut de Conseil et d'Appui Technique (ICAT), Institut Togolais de Recherche Agronomique (ITRA), Centre Régionale pour la Production Agricole (CERPA) OUEME-PLATEAU (CERPA OUEME-PLATEAU), Centre Régionale pour la Production Agricole (CERPA) ZOU-COLLINES (CERPA ZOU-COLLINES), Centre Régionale pour la Production Agricole (CERPA) ATACORA-DONGA, (CERPA ATACORA-DONGA), Centre Régionale pour la Production Agricole (CERPA) BORGOU-ALIBORI (CERPA BORGOU-ALIBORI), Institute of Agricultural Research for Development (IRAD), La Nouvelle Tribune (La Nouvelle Tribune), Radio Communautaire FM Alaketu (ALAKETU FM), Radio Gbetin (Radio Gbetin), Radio Horizon (Radio Horizon), Department of Agriculture Research Services (DARS)

Summary: The IITA component of the project has two parts. Part one is about conducting village's demonstrations and collect data on technology performance. Part II is about conducting research to understand adoption patterns and household characteristics that affect adoption.

Project Title: Public-private partnership for innovation in soybean and cowpea value chains in Mozambique (Platform Mozambique)

Donor: USAID through Consultative Group on International Agricultural Research (CGIAR)

Countries: Mozambique

Crops: Cowpea, Soybean

Summary: The project proposes to use the public-private innovation partnership approach. Public-private sector partnerships in research have been used in many developed and developing countries to generate innovations and developmental impact in the education, health, community development and agriculture. The conceptual debate about increasing agricultural productivity through agricultural research and development has now shifted from agricultural knowledge and information systems to agricultural innovation systems. This project proposes to address the following research questions (a) Does the innovation partnership approach work and have impact on food security, productivity, and reduced poverty of rural households? (b) Under what context, when and for whom does the innovation partnership approach work? (c) How sustainable and usable is the approach outside the test environment? The multisite randomized trials research design will be used to test the causal effects of the innovation partnerships approach and compare to the counterfactuals of what would have happened without the interventions. Some geographical units (districts/administrative posts/localidades/villages) will be selected for implementation of the project while others are not chosen. The difference in the before-after change in outcomes between households in the project areas participating in the project and households in the non-project areas not participating will be used to evaluate the impact of innovation partnership approach. The innovation partnership interventions will be randomly allocated to district sites. Stratified randomization sampling will be used to select lower administrative levels within chosen areas (administrative posts/localidades/villages) and households that will be contacted and interviewed to collect baseline and end-of-project evaluation data. Hierarchical meta-modeling approaches will be used to assess the impact of the project at different sites, and predict impact of subsequent implementation of

the program in other sites and extrapolate results outside the current geographically targeted areas. The project areas will be in Nampula, Zambezia and Manica provinces. The provinces are high potential areas for soybean and cowpea production. IITA has ongoing activities, which will be complementary to the proposed activities

Project Title: Less loss, more profit, better health: reducing the losses caused by the pod borer *Maruca vitrata* on vegetable legumes in Southeast Asia and sub-Saharan Africa

Donor: The World Vegetable Center (AVRDC)

Countries: Benin, Kenya

Crops: Vegetable legumes

Summary: The overall project goal is to improve the livelihoods and income generation capacity of small-scale vegetable legume farmers in the target countries of Thailand and Vietnam in Southeast Asia, and Benin and Kenya in sub-Saharan Africa by developing a simple, economical, and environmentally sound integrated pest management (IPM) strategy for the control of the legume pod borer (LPB), *Maruca vitrata*. Existing IPM technologies based on sex pheromones, entomopathogens, and botanicals will be refined and combined with species-specific natural enemies of the LPB for introduction and release throughout Southeast Asia and sub-Saharan Africa.

Project Title: Enhancing grain legumes productivity, production and income of poor farmers in drought-prone areas of sub-Saharan Africa and South Asia (TL II)

Phase 1: Aug 1997 to Aug 2011; Phase 2: Sep 2011 to Aug 2014

Donor: Bill & Melinda Gates Foundation, through International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)

Countries: Kenya, Malawi, Mali, Mozambique, Niger, Nigeria, Tanzania

Crops: Bean, chickpea, cowpea, groundnut, pigeonpea and soybean

Partners: Kaduna State Agricultural a Development Project (KADP), The Borno State Agricultural Development Project (BOSADP), Agricultural Research Institute Naliendele (ARI-TANZANIA), Premier Seeds Nigeria Limited (PREMIER SEEDS), National Cereals Research Institute (NCRI), Institut d'Economie Rurale du Mali (IER-MALI), Sokoine University of Agriculture (SOKOINE UNIVERSITY), Instituto de Investigacao Agraria de Mocambique (IIAM), Department of Agriculture Research Services (DARS), Institute for Agricultural Research (IAR), Kano State Agricultural and Rural Development Authority (KNARDA), Institut National de la Recherches Agronomiques du Niger (INRAN), Empresa Comercial dos Produtores Associados (IKURU), Organisation Néerlandais de Développement (SNV), Jirkur Seed Cooperative Biu (JIRKUR SEED), University of Agriculture, Makurdi (UAM)

Summary: This project aims at increasing productivity (yield per unit area) and production (total availability) of five legumes (bean, chickpea, cowpea, groundnut, pigeonpea and soybean) that are important sources of protein to more than 206.8 million people living in sub-Saharan Africa and South Asia. The project proposes to develop, test and promote improved crop cultivars and crop management practices that can enhance legume productivity and production in the drought-prone areas of target countries. This will involve developing cultivars that have drought tolerance and resistance to major pests and diseases, using modern plant breeding techniques such as marker-aided selection (developed under Tropical Legumes I Project supported by the Foundation). A major thrust will be to develop and operationalize sustainable seed production and delivery systems in project countries to enhance access of farmers, especially resource poor, to improved cultivars. Social science research will analyze and advise on social and cultural environments that influence sustainable adoption and spread of promising varieties, technologies and innovations, scaling-up and scaling-out of amongst farmers. Social science inputs will also support research developments in breeding through a feedback process, policy dialogue, and lessons learnt for technology dissemination. Capacity building and infrastructure development of national program partners in modern breeding and seed delivery systems is a major activity to ensure sustainability of breeding research in project countries.

Project Title: Putting Nitrogen Fixation to Work for Smallholder Farmers in Africa (N2fixAfrica)

Donor: Bill and Melinda Gates Foundation (Gates Foundation) through Wageningen University

Countries: Kenya, Nigeria, Ghana, Rwanda, Democratic Republic of the Congo, Malawi, Mozambique, Zimbabwe

Crops: Groundnut, cowpea, soybean, common bean

Partners: Institute for Agricultural Research (IAR), International Institute of Tropical Agriculture (IITA), Kaduna

State Agricultural Development Project (KADP), Sasakawa Global 2000 (Sasakawa Global 2000), Bayero University Kano (BUK), Association of Church Development Projects (ACDEP), URBANET (URBANET), Savanna Agricultural Research Institute (SARI) (SARI- GHANA), Kwame Nkrumah University of Science and Technology (KNUST), Department of Agricultural Extension Services (DAES), Bunda College of Agriculture (BUNDA), Centro Internacional de Agricultura Tropical (CIAT), WORLD VISION (WORLD VISION), Women Organizing for Change in Agriculture and Natural Resource Management (WOCAN), Concern Universal Malawi (Concern Universal), Soil Research Institute (SRI)

Summary: Smallholder farmers operate under diverse socio-ecological constraints that limit the productivity of legumes and farmers' ability to scale up the integration of legumes into their farming systems. This project is a new initiative in which legumes are used as a basis for improving cropping systems and household well-being, increasing inputs from biological nitrogen fixation (BNF) that will link family protein supply and farm nitrogen inputs directly to the atmosphere, will improve soil health and will increase household incomes. An integrated assessment will be made of the biophysical and socio-economic factors that are likely to influence farmers' decisions to adopt legume and associated rhizobial inoculation technologies to improve BNF, allowing for identification of appropriate legume niches for different farmer resource endowments, farm typologies and agroecologies. The large body of research findings on BNF and nitrogen dynamics in smallholder farming systems in SSA will be used, together with the results from adaptive on-farm research to improve existing legume and inoculum-based technologies, develop new ones and support extension campaigns intended to increase BNF and its benefits under smallholder conditions. The project will explore the research-and-development continuum from laboratory testing to collaboration and dissemination with farmer groups in West, East and Southern Africa.

Appendix 10. Assessment of Production Constraints, Progress, Barriers to Adoption and Opportunities in Grain legumes

1. A critical analysis of prior research to alleviate constraints in grain legumes

The review below looks at the previous research efforts to alleviate production constraints, as it relates to the Strategic Objectives in the proposal.

Strategic Objectives 1, 2

Production and productivity of grain legumes are constrained by several biotic and abiotic factors, resulting in an average of 30–70% loss in crop productivity due to insects, diseases, drought, weeds, and poor biological nitrogen fixation/soil fertility. Mining genetic resources and genetic improvement are the cornerstones of efforts to overcome many production constraints, and have been reviewed for CRP 3.5 grain legumes.

Common bean: Breeding of common beans for biotic and abiotic constraints was extensively reviewed by Singh (2001) and again by Beebe (2012), reporting progress on most biotic limitations to production and for drought tolerance, but less in insect resistance and tolerance to edaphic constraints. Between 2003 and 2008, more than 146 bean varieties were tested/released in collaboration with farmers, resulting in higher adoption and use of bean varieties such as white pea bean in Ethiopia (Rubyogo et al. 2010, 2011), and climbing beans in Uganda and Rwanda (Buruchara et al. 2011), where adoption rates reached 90% within a few years. Farmers are now harvesting 2-4 tons per ha. Lines with drought tolerance (Beebe et al., 2008) have now been released in Nicaragua, Rwanda and Malawi through participatory approaches. Abiotic stresses, especially those associated with soil problems, are the biggest challenge for future breeding (Beebe, 2012). The wider implementation of existing molecular markers for disease resistance genes would permit selecting these with confidence and would facilitate dedicating more effort to abiotic stresses (Miklas et al., 2006). Marketability is a primary criterion of farmers, even in the most precarious of production areas (Katungi et al, 2011).

Chickpea: New sources for germplasm resistant to diseases (Pande et al., 2006); tolerant to salinity (Krishnamurthi et al., 2011c; Vadez et al., 2007), drought (Kashiwagi et al., 2005; 2007; Krishnamurthy et al., 2010), and high temperature (Upadhyaya et al., 2011a; Krishnamurthy et al., 2011a); and for agronomic traits such as early maturity (Upadhyaya et al., 2007b), large seeded type (Gowda et al., 2011), and high yield (Upadhyaya et al., 2007a) have been identified using core/mini core strategy at ICRISAT for use in breeding. Progress in chickpea improvement has been reviewed by Gaur et al. (2007). Fusarium wilt resistant cultivars have been developed (Pande et al. 2005) leading to the expansion of chickpea in southern India, Myanmar, and in rainfed rice fallow lands (Gowda and Gaur 2004, Than et al. 2007), with success extended to Nepal and Bangladesh (Pande et al. 2005). Considerable advances have also been made in developing transgenic plants with *cry2a* gene for resistance to *Helicoverpa*. ICARDA has developed improved chickpea lines that can tolerate temperatures as low as –12°C for 30 to 50 days during the vegetative stage and resistant to Ascochyta blight leading to expansion of winter sown area and productivity enhancement in West Asia and North Africa (Malhotra et al 2007). Early-maturing, heat tolerant high-value chickpea varieties have more than doubled yields, from 600 to 1400 kg/ha in Andhra Pradesh, India, stimulating a four-fold increase in area sown (ICRISAT 2010). Wild relatives with resistance/tolerance to different stresses have been identified, and are being used in chickpea improvement resulting in release of at least one variety BG1103 (Gaur et al 2007; Kumar et al 2010).

Drought tolerance is being pursued through the selection of QTL for deep rooting (Gaur et al. 2008; Tropical Legumes-I report <http://www.generationcp.org/gcptli/>). Drought tolerance has been deployed widely in Turkey (New Agriculturist: <http://www.new-ag.info/07/05/brief.php>; African Agriculture: http://www.africanagricultureblog.com/2007_09_01_archive.html)

Pigeonpea: New germplasm sources resistant/tolerant to water logging (Krishnamurthy et al., 2011b), salinity (Srivastava et al., 2006); and agronomic traits such as vegetable type, early maturity, stable and high seed yield (Upadhyaya et al., 2010, 2011c, 2012a) have been identified using core/mini core and composite collections for use in breeding programs. Progress made in genetic enhancement of pigeonpea was recently reviewed (Saxena 2008). Several pigeonpea varieties with resistance to Fusarium wilt and sterility mosaic disease have been developed (Reddy et al. 1998). Fusarium wilt-resistant, medium-long duration pigeonpea varieties have been adopted on 25,000 ha, which have tripled yields, and created a thriving export market, delivering US\$33 million in extra value to the farmers. Hybrid pigeonpea has yielded 33% more in on-farm trials, adding about US\$400 to net income per ha (Saxena and Nadarajan 2010).

Groundnut: New sources of resistance/ tolerance to diseases (Kusuma et al., 2007; Jiang et al., 2010), drought (Upadhyaya, 2005; Hamidou et al., 2012), salinity (Srivastava et al., 2010), low temperature at germination (Upadhyaya et al., 2001, 2009); and for early maturity (Upadhyaya et al., 2006), large-seeded, high-yielding with high shelling percentage (Upadhyaya et al., 2005), superior nutritional traits (Upadhyaya et al., 2012b) were identified for use in breeding. Groundnut varieties having resistance to diseases (such as rust and late leaf spot in Asia; and rust, late and early leaf spots and rosette in ESA and WCA) and drought tolerance or avoidance (early maturing) have been developed for cultivation in Asia and Africa. Varieties with reduced seed infection and contamination by *A. flavus* (the aflatoxin producing fungus) have been developed. This has been possible through use of sources of resistances from germplasm, including for components of aflatoxin contamination. However, there is still no single germplasm line that is completely resistant to aflatoxin production and is aflatoxin free. The short duration, drought tolerant variety ICGV 91114 is spreading rapidly in Anantapur (a district in Andhra Pradesh state of India), the largest groundnut growing district in the world (0.8 million ha). An estimated additional 42,000 t of groundnut is being produced annually, worth US\$3.7 million (Birthal et al. 2010).

Cowpea: Cowpea varieties resistant to diseases (such as brown blotch, *Sclerotium*, and *Septoria*), insect pests (viruses, aphids, and bruchids) and some races of *Striga gesnerioides* and *Alectra vogelli* have been developed (Ajeigbe et al., 2006). Dual purpose cowpea cultivars with tolerance to biotic and abiotic stresses (e.g. IT90K-277-2, IT97K-499-35, IT98K-131-2, and IT89KD-288) combined with improved crop management practices can increase productivity from 300 to 1500 kg/ha. Thirteen dual-purpose lines that have high grain and fodder yields have been released and adopted by farmers in Africa. However, there is no single line with resistance to the pod borer (*Maruca vitrata*), the bean flower thrips (*Megalurothrips sjostedti*), and newer races of *S. gesnerioides*. Most of the high yielding improved cultivars have determinate growth habit, and therefore are not very suitable for the widely practised relay-intercropping in the smallholder agricultural systems in Africa (PROSAB 2010).

Soybean: Soybean breeding in tropical Africa has identified and developed high yielding lines with tolerance to biotic and abiotic stresses (Tefera, 2011). A total of 27 IITA cultivars have been released by different NARS in Africa, with valuable traits such as high grain (1.5 to 3 t/ha) and fodder yields (up to 4 t/ha), different maturity groups in West Africa, ability to nodulate with a wide array of Rhizobium strains, tolerance to drought, resistance to pod shattering, longer seed viability, and resistance to common insect pests (caterpillars and pod sucking bug) and diseases (rust, bacterial blight and pasture, frog eye leaf spot and viruses). Three rust resistant varieties have been released in Nigeria and Uganda (Tefera et al. 2010). In Nigeria, two varieties (TGx 1448-2E and TGx 1904-6F) have been widely adopted by farmers. The value of benefits associated with soybean improvement is estimated at US\$880 million in Nigeria, Malawi, Mozambique, Kenya and Tanzania. Studies have

also established the positive beneficial effects (nitrogen contribution and suicidal germination of *Striga hermonthica*) of soybean to cereals (Kamara et al., 2008). Future efforts should focus on developing germplasm adapted to wide range of environments in southern and eastern Africa, tolerance to poor soil fertility especially low phosphorus, market preferred traits such as bigger seed size and high protein content as well as resistance to the Asian rust.

Lentil: ICARDA identified 51 new accessions resistant to Fusarium wilt, 12 tolerant to salinity and 6 tolerant to heat (Kumar et al 2010; Erskine et al 2011). Lentil genotypes resistant to Soybean dwarf virus, Bean leafroll virus and Faba bean necrotic yellows virus were identified (Makkouk et al., 2001). In addition, lentil genotypes with low seed transmissibility to Broad bean stain virus and Pea seed-borne mosaic virus were identified. Multiple disease-resistant varieties have been released by the NARS (Kimiya in Iran, Chakkouf in Morocco, Maheshwor Bharati and Sagun in Nepal, and Punjab Masoor and NARC-06-1 in Pakistan). Moitree (meaning friendship) has been released in India. In Ethiopia, adoption of improved lentil and chickpea production technologies resulted in additional income of \$451 and \$551 ha⁻¹, which was 17% more than the traditional farming practices. Over the last 30 years, South Asian lentil production has doubled, reaching 1.27 million tons due to adoption of short-duration, disease resistant varieties developed by ICARDA in partnership with India, Nepal, and Bangladesh. Impact is also reported in Ethiopia with a 150% increase in production and 73% increase in area under rust resistant varieties.

Faba bean: In Tunisia, “Najah” with high yield and resistance to *Orobanche* was released in 2009 (Kharrat et al 2010). TBIA kit for detection of Faba bean necrotic yellow virus (FBNYV) has been developed (Kumari et al 2006). Sources with resistance to BYMV have been identified. Some success has also been achieved in identifying hardy, drought- and salt tolerant genotypes (Khan et al. 2010). In Egypt, adoption of faba bean production technologies increased benefits by \$962 ha⁻¹, which was 173% more than the traditional practices.

Strategic Objective 3

Soil fertility: The introduction of legumes into a cropping system reduces soil erosion, enhances the use of nutrients and water, fixes atmospheric nitrogen, and increases access to nutrients such as phosphorus from deep soil horizons (Giller 2001; Shapiro and Sanders 2002; Adu-Gyamfi et al. 2007). Legume rotations also play an important role in weed control (DeGroot et al. 2010). Symbiotic fixation of nitrogen is sensitive to even modest soil water deficits (Sinclair et al. 2007). In the case of chickpea, the high nodulating variety ICC 4948 fixed more N and yielded 31% more than its low nodulating version

Sufficient numbers of compatible rhizobia are often not naturally occurring in most of the soils where grain legumes are cultivated (Marufu et al. 1995), and thus there is a need for rhizobia application to seeds (Catroux et al. 2001).

Integrated pest management: Major success has been achieved in Senegal with the introduction of ‘triple bag storage’, using several layers of thick plastic bags to minimize the damage by bruchids (Boys et al. 2007). The method is being promoted in several West African countries (Moussa et al. 2009). Examples of legume IPM programs include those for cowpea in Benin (Nathaniels 2005), groundnut and cowpea in Uganda (Bonabana-Wabbi 2002), pigeonpea and groundnut in India (Tripp and Ali 2001), and chickpea in Nepal (Pande et al. 2005). The deployment of natural enemies of *Maruca*, a major pest of cowpea in West Africa, is being planned (CRSP, 2010). In Sudan, adoption of improved chickpea production technologies resulted in additional income of \$496/ha, which was 73% more than the traditional farming practices. Growing winter chickpea varieties with improved farming practices increased net farm income by US\$220/ha. The main reasons for slow diffusion were the risk of *Ascochyta* blight, lack of knowledge on winter chickpea technology, insufficient farmer awareness of chemical spray options, and increased risk of crop failures.

Strategic Objective 4

Seed systems: Modern crop varieties and complementary technologies are indisputably the most critical output of investments in international and national agricultural research systems. Several studies show that improved bean varieties give yield increases of 30 to 50 percent above local varieties (Kalyebara and Andima 2006), up to 32% for chickpea in CWANA (Mazid, et al, 2009) and up to 68 % for early maturing pigeon pea in East Kenya (Jones et al 2001). However, lack of timely access and availability of quality seeds of improved bean varieties was the bottleneck to technology adoption and impact realization (Rubyogo *et al.*, 2010; Rubyogo et al 2011).

A well-functioning seed delivery system is expected to deliver these varieties by providing sufficient quantity of seed of adequate quality at the right place, at the right time and at reasonable price to benefit producers and to realize the impacts from investments in agricultural research (Potts and Nagujja 2007). The private seed industry has not found the grain legume seed business lucrative nor reliable like hybrid maize or vegetable seed, as farmers tend to re-sow from their own harvests for many seasons to come, instead of purchasing seed anew from the formal, certified sources (David and Sperling 1999). Cost-benefit analyses indicate that certified (formal sector) legume seed costs two to four times (especially packed in large amount) that of seed found in the local markets. The formal sector generally focuses multiplication on a few of the more popular varieties, usually those for medium to higher potential areas catering for well off farmers (Sperling et al. 1996). Major share of grain legume seeds comes from the informal sector (Materne and Reddy in Yadav *et al.*, 2007). In the absence of the formal seed delivery system, actors particularly NARS have been innovative to devise other approaches for increasing the adoption and diffusion of legume varieties. These include i) decentralized seed supply of locally identified genotypes through PVS in collaboration with participating farmer groups (Teshale et al. 2006); ii) Recent studies have shown that the use of small packets (100-2000 g) can greatly enhance access and utilization of improved bean varieties and complementary technologies because they are more affordable (Buruchara et al. 2011); and iii) more recently, there is increased interest in legume seed by medium and large scale seed companies in some countries (TL II, 2010).

Strategic Objective 5

Market participation: Legumes have created considerable impacts by opening new avenues in markets. Enhanced lentil production in Nepal created export markets to Bangladesh. Similarly, marketable surpluses of pigeonpea in Malawi, Tanzania, Mozambique, and Myanmar, and chickpea in Ethiopia, Tanzania, and Myanmar, increased exports of these legumes to India (Jones et al. 2002). Other examples include common bean export from Ethiopia (Ferris and Kaganzi 2008), and increased regional West African cowpea trade (Langyintuo 2003). However, the lack of adequate output markets is an important constraint in legume production, for example, in the rice-wheat based cropping system of the Indo-Gangetic plain of India (Ali et al. 2000). Markets for legumes are thin and fragmented in comparison to rice and wheat, which have assured markets (Byerlee and White 1997), and a large share of market margin goes to middlemen. Price spread (or the market margin) for legumes is much higher than that of rice and wheat due to higher post-harvest costs (Joshi 1998). ICRISAT has developed kits for detecting aflatoxins in groundnut, which has helped to improve the export of peanuts in Africa.

Gender related impacts: Adoption of climbing bean modern varieties in Rwanda indicated that women-headed households were as likely to adopt as male-headed households (Sperling and Muyaneza 1995). Extra yield contributed to women's ability to produce and market bean cakes and other cowpea preparations (Tipilda et al. 2008). In Mali, groundnuts are women's most important source of income (Diallo 2009).

2. Constraints to adoption of technologies to improve production of grain legumes

A fuller analysis of constraints to adoption and of lessons learned from successes is found in Chapter 4 of the main document on “Impact pathways.” A summary is offered here. The most frequently cited constraints to adoption of improved technologies include:

- Various social and economic factors such as farmers’ preferences, risk perceptions, and access to inputs and markets (Ndjeunga and Bantilan 2005);
- Risk aversion by farmers that lead them to adopt technologies in stages, one component at a time (ICARDA, 2008);
- Inability to make the initial investments to adopt the technology, due to inadequate access to financial services;
- Inadequate farmers’ knowledge of improved technology and modern varieties, as in the case of groundnut varieties in West Africa (Ndjeunga et al. 2008), pigeonpea varieties in Tanzania (Shiferaw et al. 2008), and cowpea varieties in Nigeria (Kristjanson et al. 2005);
- Poor availability of quality seed at prices that are accessible to small farmers (David et al. 2002), combined with reticence of seed suppliers to provide legumes seed, e.g. of the 70 seed companies in Kenya, only 4 supply bean seeds compared to 60 in maize (Rubyogo et al. 2010);
- High seeding rates (80-100 kg/ha in the case of groundnuts) and low seed multiplication rates; and
- Lack of domestic markets, and unreliable export markets (Shurtleff and Aoyagi 2007; van de Brand 2011), and lack of policy support to develop input/output markets.

On the positive side, lessons learned to overcome these barriers include:

- Participatory methods have now been widely deployed to improve relevance and adoption of technologies (Chamango 2001; Snapp et al. 2002);
- Adapting seed systems to the reality of legumes has been a key to improving dissemination of improved legumes (objective 4), including the testing and implementation of an array of models in the Tropical Legumes-II project involving both the public and private sectors in their respective and complementary roles;
- Creating markets for legumes has been one of the most potent forces in stimulating adoption of new cultivars and other technology options (Strategic Objective 5), for example, common beans and chickpeas in Ethiopia;
- Models of public information are being tested through several media including rural radio;
- In Egypt, farm size, education, availability of off-farm income, and exposure to the technology were positively associated with adoption;
- In Ethiopia, factors showing positive associations with adoption include availability of seed from a research organization, awareness of the role of faba bean in crop rotations and in household nutrition, access to market, farming experience, and participation in the project; and
- In Sudan, the main positive factor affective the adoption was participation in project activities and field days.

Adoption is thus the result of a complex interaction of multiple factors that must be evaluated in each circumstance. This implies the need for agility in the evaluation not only of constraints but also of opportunities, as opposed to a one-size-fits-all approach, to be able to generate adoption and

impact in the most efficient and effective manner. Chapter 4 in the proposal presents a more detailed discussion.

3. Constraints that remain to be addressed and the way forward

Most efforts in breeding have been directed toward pest and disease resistance that will stabilize yield but, in most cases, will not improve average or national yields dramatically. Yield stability is of critical importance to risk adverse farmers with little resilience to withstand crop failure. Breeding for resistance to many diseases proceeds as a mainstream, routine activity, although re-selection of resistance must be practiced as susceptible parents are introduced into the breeding program as sources of other traits. Further, it is important to enhance use of germplasm in breeding programs to develop cultivars with a broad genetic base. Streamlining of selection through molecular selection techniques would facilitate maintaining these resistance genes in breeding populations. Considerable progress has been made in addressing the diseases such as early and late leaf spot in groundnut, wilt and *Ascochyta* blight in chickpea and pigeonpea, rust in soybean, anthracnose in common bean, wilt in lentil, chocolate spot in Faba bean, and viral diseases in several legumes. The progress in developing germplasm with resistance to insect pests, particularly pod borers in chickpea, pigeonpea, and cowpea, and certain fungal problems including Aflatoxin contamination in groundnut, root rots in chickpea and common bean, and *Phytophthora* blight in pigeonpea has been slower. Soil constraints, both deficiencies and toxicities, are serious limitations that require solutions combining management and genetics. Land degradation and nutrient depletion are very severe in sub-Saharan Africa and Central America. The genetic component of edaphic adaptation in legumes has received relatively little attention to date and should be a major emphasis for CRP 3.5, while management practices must be developed in collaboration with CRP 1.1, CRP 1.2, and CRP 5. Meanwhile, legumes have proven to be mobile and have moved into “new” environments (e.g., chickpeas moving south in India; beans expanding in the dry highlands of Mexico) and climate change will create yet new combinations of environmental factors and stresses, both biotic and abiotic. Technologies to extend production of grain legumes in the Indo-Gangetic plains in the rice-wheat production systems, and introduction of chickpea and lentil in rice fallows have not made much progress. Thus, there is a need to:

- Identify trait-specific genetically diverse sources for important biotic and abiotic stresses and for agronomic traits for use in breeding programs to develop improved cultivars with a broad genetic base.
- Identify photoperiod insensitive gene(s) to develop grain legume cultivars with wider adaptation and/or early maturity, and model plant attributes to help determine trait arrays that are most useful for adaptation to different environments;
- Develop cultivars with broader resistance to biotic and abiotic stresses (such as pod borers, stem flies, aflatoxin contamination, parasitic weeds, bruchids and root rots) by introgressing resistance genes from the wild and cultivated relatives and develop transgenic plants with resistance to the target traits;
- Explore the potential consequences of deployment of transgenic plants and natural enemies of insect pests (parasitoids, predators, and entomopathogens) on native fauna and the beneficial organisms;
- Map resistance genes for drought, diseases and insect pests, and identify diverse sources/genes for gene pyramiding to develop cultivars with stable and multiple resistance to insects, diseases and drought;
- Develop doubled haploid technology in grain legumes to reduce the average length of the breeding cycle;
- Understand the climate change effects on production, productivity and pest–host–environment interaction in grain legumes;

- Utilize high-protein genes or protein morphotypes with high digestibility from wild species in tertiary gene pools for improving the cultigen; understand the functional roles of anti-nutritional factors of grain legumes, and understand their role in resistance/susceptibility to pests;
- Explore possibilities for inducing mutations for herbicide tolerance to reduce drudgery to women; and
- Develop robust crop management technologies to increase the sustainability and productivity of grain legumes.
- Strengthen capacities of public and private sector to ensure that farmers have better access to quality seed of improved legume varieties.

Appendix 11. Workplan for Strategic Objectives of CRP 3.5

GRAIN LEGUMES

Strategic Objective 1: Conserving and characterizing genetic resources and developing novel breeding methods/tools for improving efficiency of crop improvement

Output 1.1: Grain legumes genetic resources collected, conserved and made available to researchers globally.

Key Activities

- Identify gaps in CRP grain legumes germplasm available at ICARDA, ICRISAT, IITA and CIAT (2012-14)
- Collect/assemble new germplasm of cultivated and wild species of CRP grain legumes, e.g. exploration of *Phaseolus* species in Mexico and Brazil targeting specific traits (e.g., salinity tolerance in coastal Mexico); collection of *Phaseolus* species suitable for hot and humid conditions in West Africa; collection of FB and LN germplasm from Cyprus and Algeria; collection of PP germplasm from ESA (2012-14)
- Acquire new germplasm accessions from partners benefiting from the Trust regeneration grants (2012-14)
- Safely conserve the available and newly acquired genetic resources (2012-14)
- Distribute requested germplasm (including DNA) along with updated information to researchers globally (2012-14)
- Conduct training courses on genetic resources management for NARS partners (2013-14)

Key Partners:

- IARCs
- Genebanks and Institutes of Plant Genetic Resources (EMBRAPA, Brazil; NBPGR, India; GCDT, Germany; Peanut Collaborative Research Support Program, USA; USDA, USA; Agricultural Technology Transfer Center Lushnja, Albania; Institute of Genetic Resources, Azerbaijan; Institute of Plant Genetic Resources “K. Malkov”, Bulgaria; Research Centre for Agrobotany, Hungary; SINAREFI, Mexico; PRONAREG, Peru, WECABREN NARS; IAR, Nigeria; INRAN, Niger; INERA, Burkina Faso; ISRA, Senegal; SARI, Ghana; DRD, Tanzania; National Genebanks in Kenya, Cyprus, Algeria and other countries)
- Universities (State Agricultural Universities in India; Georgia State Agrarian University, Georgia; Birmingham University, UC-Riverside)
- Global Crop Diversity Trust

Key milestones

- Gaps in existing germplasm collections of at least three legumes identified (2012-14)
- Available and newly acquired genetic resources (at least 500 accessions) of grain legumes safely conserved (2014)
- Germplasm of cultivated and wild species of grain legumes collected/assembled from the geographic areas rapidly eroding and/or less represented in existing collections (2012-14)
- At least 5,000 accessions of grain legume germplasm supplied via SMTA to researchers globally on request (2014)
- At least two training courses for NARS partners on genetic resources management conducted (2013-14)

Output 1.2: Genetic resources characterized, evaluated and documented for unique traits/genes related to nutritional value and adaptation to current and future stressful environments.

Key Activities

- Conduct a workshop and establish a legume phenotyping networks for CRP3.5 target countries (2012)
- Identify and agree upon germplasm sets, priority traits, phenotyping methods, key sites and research partners for evaluation of grain legumes germplasm (2012)
- Develop algorithms for Focused Identification of Germplasm Strategy (FIGS) for various biotic and abiotic stresses using databases and geographic information system (GIS) (2012-13)
- Evaluate selected germplasm accessions/reference set/core and minicore collections/FIGS sets of grain legumes for key traits (e.g. resistance/tolerance to abiotic and biotic stresses, phenology, plant type, BNF, yield and yield components, quality traits) to identify trait-specific germplasm (2013-14)
- Evaluate neglected species (e.g., *Phaseolus coccineus*, *P. dumosus*, *P. acutifolius*) and wild species of CRP grain legumes for climate change related traits such as drought and heat tolerance (2012)
- Develop standard phenotyping protocols for tolerance to drought, temperature extremes and salinity and exploit promising traits for adaptation to existing and future climatic conditions across CRP grain legumes based on crop simulation modelling (2012-13)
- Establish standard phenotyping protocols for resistance to diseases across grain legumes (2013)
- Develop a web-based and open access resource on standard phenotyping protocols for resistance/tolerance to abiotic and biotic stresses and quality parameters of CRP grain legumes (2013-14)

Key Partners:

- IARCs
- NARS in target countries (e.g. ICAR institutes and SAUs in India; BARI, Bangladesh; EIAR, Ethiopia; DARI, Iran; CRIFEC, Turkey; IAR, Nigeria; INRAN, Niger; INERA, Burkina Faso; ISRA, Senegal; SARI, Ghana; DRD, Tanzania; KARI-Kenya; NARO-Uganda; EAP-Honduras; National Programs in Tunisia, Morocco, Malawi, Zimbabwe and other countries)
- ARIs (e.g. USDA, University of North Carolina, University of Nebraska, Colorado State University, UC-Riverside, the University of Western Australia, the University of Cambridge)
- EMBRAPA-Brazil; National bean program partners in ECABREN, WECABREN and SABRN; CRSP, GCP

Key milestones

- Global legume phenotyping networks formed, priority traits, methods, research partners, and germplasm accessions to be characterized agreed upon (2012)
- Phenotypic data available on targeted traits in structured and representative sets of germplasm of each CRP legume species (2013-14)
- Trait-specific germplasm identified using core/mini core, reference, and FIGS sets in at least five legumes (2013-14)
- Comparative performance of neglected species (e.g. *Phaseolus coccineus*, *P. dumosus*, and *P. acutifolius*) and wild relatives of CRP grain legumes assessed in different environments for climate change-related traits (2012)
- A web-based resource made available for open access on phenotyping protocols and

standard methods to evaluate stress resistance (2014)

Output 1.3: Novel and efficient breeding methods/tools for cultivar development established and shared.

Key Activities

- Develop RIL populations in grain legumes for molecular mapping of traits of interests (e.g. resistance/tolerance to drought, heat, cold, salinity, leaf-miner and nematodes in CP; resistance to viral diseases in CW; chocolate spot and ascochyta blight resistance and flowering time in FB; drought and salinity tolerance, oil content, protein content, Fe and Zn content, haulm traits, and foliar fungal disease resistance in GN; fusarium wilt and rust resistance, drought and cold tolerance, earliness, seed size, Fe and Zn contents and yield QTL in LN; and rust resistance and BNF in SB) (2012-14)
- Develop multiparent advanced generation inter-cross (MAGIC) populations in CB, CP, CW and LN for genetic studies and also to increase the genetic basis of the breeding pool (2012-13)
- Generate TILLING populations in CP, FB and LN (2012-14)
- Generate the entire genome sequences of CP and GN and exploit the available/to be available genome sequences for marker development and genome-wide selection in CB, CP, GN and PP (2012-14)
- Establish high throughput genotyping platforms for grain legumes through Integrated Breeding Platform (IBP) of the GCP (2012-13)
- Develop integrated high-density genome map with > 2000 marker for CB, CP, CW, GN, and PP (2012-13)
- Develop high throughput phenotypic platforms to assess critical traits for climate resilience across crop species (2012-13)
- Identify molecular markers linked to genes that confer resistance/tolerance to key abiotic and biotic stresses, yield and quality traits using association and linkage mapping (e.g. resistance genes for BCMNV, angular leaf spot, bruchids and CBB in CB; drought and heat tolerance, ascochyta blight and fusarium wilt resistance and protein content in CP; ascochyta blight and chocolate spot resistance and flowering time in FB; rust and fusarium wilt resistance and earliness in LN) (2013-14)
- Assess effectiveness of marker-assisted recurrent selection (MARS) for improvement of drought tolerance and yield in CB and CP (2012-14)
- Study components and genetics of tolerance to drought and heat stresses and interaction of drought and low phosphorus with BNF (2012-14)
- Identify key patterns of gene expression during the transition to reproductive growth under unstressed and drought stressed conditions in CB (and related *Phaseolus* species) using transcriptomics (2013-14)
- Develop and validate protocols for development of doubled-haploids in CP and PP (2013-14)
- Use plant breeding data management software and modern IT equipment to assist breeders in data collection, analysis and decision making (2012-14)

Key Partners:

- IARCs
- NARS in target countries (e.g. ICAR institutes and SAUs in India; IAR, Nigeria; University of Ibadan, Nigeria; INRAN, Niger; INERA, Burkina Faso; ISRA, Senegal; SARI, Ghana; DRD, Tanzania; national programs of Ethiopia, Kenya, Malawi and Zimbabwe)

- ARIs (University of Saskatchewan, Saskatoon, Canada; NRC-PBI, Saskatoon, Canada; DPI, Victoria and Victorian AgriBiosciences, Bundoora, Victoria, Australia; NIAB Institute UK; IFAPA, Cordoba Spain; CLIMA, Australia; USDA; USDA/ARC, Beltsville; Laval University, Qubec, Canada; UC-Riverside, USA),
- CRSP, Integrated Breeding Platform of GCP

Key milestones

- Mapping populations (RILs/AB-QTL, MAGIC lines), TILLING populations and other genetic stocks developed in CRP grain legumes for use in genetic studies and for practical use in breeding programs (2013)
- Whole genome sequence information available for at least one accession in CP and GN and strategies for genome-wide selection developed in CB, CP, GN and PP (2014)
- High throughput genotyping platforms such as SNP established for at least CB, CP, CW, PP and SB (2013)
- Integrated high-density genome map with >2000 markers developed for CP, CW, GN, PP, and CB (2013)
- Diagnostic markers linked to key traits identified in CB, CP, CW, LN, FB (2014)
- Cross-legume genomic studies of gene expression to identify genes involved in the transition from vegetative to reproductive phase completed (CB, CP) (2014)
- Better understanding of the mechanisms and genetics of resistance/tolerance to biotic and abiotic stresses (CB, CP,GN, LN) (2014)
- Genetic basis of interaction of drought and low P with BNF understood (2014)
- Key trait-linked markers validated and converted to cost-effective platforms for implementation in breeding programs of CB, CP, CW, LN, FB (2012-14)
- Protocols for development of double haploids validated in CP and PP (2013)
- Plant breeding software and IT equipment (private or public) integrated in CRP crop legumes breeding and genetics programs (2013)

Output 1.4: Novel genes/traits accessed/mobilized/incorporated through wide hybridization/genetic engineering to broaden the genetic base of grain legumes.

Key Activities

- Develop protocols for making interspecific crosses of cultivated species with species of secondary and tertiary gene pools in CP, LN and PP (2012-13)
- Utilize wild relatives of grain legumes for introgressing yield enhancing traits and resistance to various stresses (e.g. cyst nematode and BGM resistance in CP; pod borer resistance in CP and PP; Orobanche and Sitona weevil resistance in LN) and broadening the genetic base (2012-14).
- Evaluate interspecific derivatives for yield, yield components, resistance/tolerance to key abiotic and biotic stresses and nutritional quality traits (e.g. root traits, enhanced remobilization of photosynthate to grain, and heat tolerance in CB; aflatoxin resistance in GN; pod borer, cyst nematode, BGM and bruchid resistance in CP; pod borers, fusarium wilt, SMD and bruchid resistance in PP) (2013-14)
- Develop and use ABQTL populations in CB, CP and PP (2012-14)
- Exploit amphidiploids for broadening genetic base of GN (2012-13)
- Develop and characterize transgenic events for various traits [e.g. PBNV resistance (by using RNAi technology) and omega-3-fatty acid rich oil in GN; *Helicoverpa* resistance and drought

tolerance in CP; *Maruca* resistance in CW; drought tolerance and disease resistance in LN; *Helicoverpa* and *Maruca* resistance in PP] (2012-14)

- Evaluate already available and to be developed transgenic events for target traits under greenhouse and confined field conditions to identify promising events (e.g. tolerance to intermittent drought stress, resistance to PBNV and PSND, accumulation of pro vitamin A carotenoids, omega-3-fatty acid rich oil in GN; tolerance to terminal drought and resistance to *Helicoverpa* in CP; resistance to *Maruca* in CW; resistance to *Helicoverpa* and *Maruca* and accumulation of pro vitamin A carotenoids in PP) (2012-14)

Key Partners:

- IARCs
- NARS in target countries (e.g. ICAR institutes and SAUs in India; IAR, Nigeria; INRAN, Niger; INERA, Burkina Faso; ISRA, Senegal; SARI, Ghana; ARI-Ilonga, Tanzania; KARI-Kenya, EIAR and SARI, Ethiopia; INRA, Morocco; GCSAR, Syria; SPII, Iran)
- ARIs (JIRCAS, Japan; EMBRAPA, Brazil; CIRAD; Louisiana State University, USA; USDA; CLIMA, Australia; UC-Riverside, USA)

Key milestones

- Key traits not available in cultivated germplasm such as resistance/tolerance to pod borer/bruchid (CP, PP), leaf spots and aflatoxin (GN), sitona weevil and *Orobanche* (LN) introgressed from wild relatives (2013)
- Broaden the genetic base of legumes (GN, CP, PP, CB, LN) utilizing wild relatives from different gene pools (2013)
- Inter-specific derivatives with enhanced yield and improved yield related traits identified in CB, CP, GN, PP, and LN (2014)
- Transgenic events for biotic constraints including pod borer (CP, CW, and PP), viral diseases (GN) and fungal pathogens (GN) developed and characterized (2014)
- Transgenic events for tolerance to abiotic constraints including drought (GN and CP), developed and characterized (2013)
- Transgenic events developed for enhanced micronutrients (pro vitamin A) in GN and PP, and candidate genes/promoters for improved oil quality in groundnut (2014)
- Resistance associated genes/proteins for complex combinational traits (e.g., aflatoxin-resistance and drought tolerance) in GN identified (2014)

Strategic Objective 2: Accelerating the development of more productive and nutritious cultivars for resilient cropping systems of smallholder farmers

Output 2.1: Elite lines/cultivars with at least 25% higher yield potential than the best available cultivars developed for different production systems.

Key Activities

- Generate breeding materials specifically targeted for enhancing yield potential of CRP grain legumes by selecting parental lines and crossing them in appropriate single and multiple cross combinations (2012-14)
- Evaluate elite breeding lines of grain legumes for yield and yield stability in representative environments and production systems (2012-14)
- Test prototype of delayed flowering combined with accelerated grain filling in CB (2012-13)
- Identify yield enhancing traits and conceptualize high yielding plant ideotypes of CRP grain legumes for major growing environments and production systems and breed for major

ideotypes (2013-14)

- Study stability of male sterility in A lines and stability of fertility restoration in hybrids of PP in ESA (2013)
- Develop hybrid pigeonpea cultivars for different agro-ecological zones and cropping systems (2012-14)
- Identify traits associated with enhanced photosynthate remobilization in grain legumes including lines derived from *Phaseolus acutifolius* in CB (2012-13)

Key partners

- IARCs
- NARS in target countries (e.g. ICAR institutes and SAUs in India; IAR, Nigeria; INRAN, Niger; INERA, Burkina Faso; ISRA, Senegal; SARI, Ghana; DRD, Tanzania; KARI-Kenya, EIAR, Ethiopia; National bean program partners in ECABREN and SABRN; and National partners in Uganda, Rwanda, DRC, Malawi, Mozambique, Zambia and other countries)
- ARIs (e.g., UC-Riverside, USA)

Key milestones

- Ten elite lines with at least 25% higher yield than the best available cultivars developed across target legumes and shared with NARS partners (2013-14)
- At least five hybrids/ parental lines (A-, B-, R-lines) of PP made available to partners (2013)
- Prototype of ideal plant type for various production zones conceptualized and shared with national partners in targeted legumes (2014)
- Traits for enhanced photosynthetic remobilization to grain identified for at least one grain legume (2013)

Output 2.2: Elite lines/cultivars with enhanced resistance/tolerance to key biotic and abiotic stresses and resilience to climate change developed.

Key Activities

- Develop breeding lines with improved resistance to key soil borne diseases (e.g. fusarium wilt in CP, LN and PP; dry root rot in CP) and test these across locations (2012-14)
- Develop breeding lines with improved resistance to foliar fungal diseases (e.g. ascochyta blight in CP and LN; foliar fungal diseases in GN, rust in SB) and evaluate these at hot spots and/or artificial epiphytotic conditions (2012-14)
- Develop breeding lines with improved resistance to foliar viral diseases (e.g. *Beet western yellows virus*, *Chickpea chlorotic stunt virus*, *Alfalfa mosaic virus* and *Cucumber mosaic virus* in CP and LN; and *Faba bean necrotic yellows virus* and *Bean yellow mosaic virus* in FB; *groundnut rosette assistor virus* in GN) (2012-14)
- Develop breeding lines with resistance to key insect pests (e.g. bruchids and bean stem maggot in CB; *Helicoverpa* in CP and PP, *Maruca* in CW and PP) (2012-14)
- Test underutilized/neglected species (eg. *P. coccineus*, *P. dumosus* and/or *P. acutifolius*, *V. subterranean*, *L. sativus*) with potential under changing climate scenarios and identify traits useful in climatic extremes such as high temperatures and drought. (2012-14)
- Generate basic knowledge on different components of drought and heat through morpho-physiological dissection in CP, FB, GN and LN (2012-13)
- Identify mechanisms for resistance to insect pests in different grain legumes (e.g. *Helicoverpa* in CP and PP) (2012-13)

- Analyse root and shoot traits for contribution to drought and edaphic stress tolerance in CB (2012-13)
- Develop and evaluate breeding lines with improved drought/heat tolerance and adaptation to different environments in CB, CP, LN, FB, GN, SB (2012-14)
- Identify/develop multiple stress tolerant lines (e.g. AB, BGM and FW in CP; drought, foliar fungal diseases, BND and aflatoxins in GN; BCMNV, angular leaf spot and anthracnose in CB) with adaptation to target environments (2012-14)
- Develop CB, CW and PP breeding lines with improved water-logging tolerance (2012-14)
- Identify/develop GN breeding lines with improved resistance to *Aspergillus flavus* and subsequent aflatoxins (2012-14)
- Develop breeding lines with improved tolerance to salinity in CB and CP (2012-14)
- Study genetics of resistance to abiotic and biotic stresses in different legumes (e.g. rust, stem rot, rosette and drought in GN; heat tolerance and DRR resistance in CP) (2012-14)

Key partners

- IARCs
- NARS in target countries (e.g. ICAR institutes and SAUs in India; BARI, Bangladesh; NARC, Nepal; DAR, Myanmar; IAR, Nigeria; University of Ibadan, Nigeria; INRAN, Niger; INERA, Burkina Faso; ISRA, Senegal; SARI, Ghana; DRD, Tanzania; KARI-Kenya, EIAR, Ethiopia; DARI, Iran; CRIFEC, Turkey; GCSAR, Syria; and National partners in Uganda, Rwanda, DRC, Malawi, Mozambique, Zambia, Tunisia, Morocco, and other countries)
- ARIs (e.g., UC-Riverside, Penn State University, University of Western Australia)
- National bean program partners in ECABREN and SABRN; TL-II partners

Key milestones

- At least 100 breeding lines with improved resistance to key diseases and insect pests developed across all target legumes (2013)
- At least 20 breeding lines with improved drought/heat tolerance in CP, CW, CB, GN, FB and LN developed and shared with partners (2014)
- At least 15 elite lines with combined resistance to key biotic and abiotic stresses per year across legumes developed and shared with partners (2012-13)
- At least 6 breeding lines with improved water-logging tolerance developed in CW and PP and shared with partners (2013)
- About 20 breeding lines with better adaptation to problematic soils (salinity, acidity) developed/identified (CB, CP) (2014)
- Better understanding of the mechanisms and genetics of resistance/tolerance to biotic and abiotic stresses (CB, CP, GN, LN) (2014)

Output 2.3: Improved germplasm better targeted to smallholder niches using GIS and other novel methods

Key Activities

- Refine and apply modelling tools and GIS to delineate legume adaptation zones and new production systems (2012-13)
- Develop methods for the mapping of potential yields for grain legumes using crop simulation modelling and geostatistical techniques based on the analysis of multi-site trials (2013-14)
- Use crop simulation modelling to pinpoint critical adaptive traits in grain legumes for major

production zones, and use this information as feedback on previous output to guide the search of critical germplasm in reference collection (output 1.2) (2012-13)

- Use growth modelling as a tool to predict legume growth and yield response to weather, soil water, sowing date and diseases (2012-13)
- Assess the impact of future climate (i.e. 2030; 2050; 2080) on grain legumes using spatial crop modelling and GIS technologies and identify new niches for grain legumes in 2030; 2050; 2080 and old area lost due to climate change (2012-13)
- Develop a refined research domain using available spatial information on weather, soil, agro-ecological zones (AEZs) and spatial production and area statistics (2012-13)
- Identify analogous (iso-responsive) test locations that represent future production environments under climate change for improving breeding efficiency of grain legumes (2012-13)
- Generation of surfaces of weather generator coefficient for current climate and future climate scenarios for the target regions (2012-13)
- Map potential yields and yield gaps for current and future climate scenarios for existing and new varieties and determine trait combinations that optimize/stabilize yields in the target areas (2013-14)
- Map the distribution of food legumes diseases, insect pests and parasitic weeds using GIS to identify hot spots for pest resistance screening (2013-14)
- Identify a set of genotypes with potential for improved adaptation to climate change in each grain legume (2012-13)
- Constitute regional and international nurseries of improved germplasm in each CRP grain legume and make these available to partners for their evaluation in target locations (2012-14)
- Conduct PVS trials for each grain legume in each target region to identify farmer and end-user preferred varieties (in partnership with TL-II and other projects) (2012-13)
- Establish a web-based and open access data management system for CRP target grain legumes (2012-13)

Key partners

- IARCs; GIS labs in CG centres
- NARS in target countries (e.g. ICAR institutes and SAUs in India; BARI, Bangladesh; NARC, Nepal; IAR, Nigeria; INRAN, Niger; INERA, Burkina Faso; ISRA, Senegal; SARI, Ghana; DRD, Tanzania; KARI-Kenya, EIAR, Ethiopia; ICTA-Guatemala, INTA-Nicaragua, DICTA and EAP-Honduras; National programs in ECABREN, SABRN and WECABREN; National programs in Pakistan, Egypt, Morocco, Uganda, Malawi, Mozambique, Zambia, Rwanda, Uganda and other countries)
- ARIs involved in crop simulation modelling; Meteorological organisations
- Regional organisations, public and private seed companies and NGOs

Key milestones

- Database on multi-environment trials (MET) generated and made available to national partners (2013)
- Climate change effects on grain legumes assessed with CRP 7 (2013)
- New niches (both current and under climate change scenarios) for grain legumes identified using crop models and GIS spatial technologies (2013)
- Data management Centre for target grain legumes established and publicly available (2013)

- Methodological framework for the analysis of a crop yield gap developed (2014)
- Trait specific germplasm is tested over multiple sites to develop crop response clusters for at least four crops (2014)
- Suitability of new legume crops in different environments evaluated by crop simulation modelling (2014)
- At least two regional/international nursery of improved germplasm in each grain legume constituted and distributed to partners annually (2013, 2014)
- 2-3 farmer and end-user preferred varieties identified for each grain legume in each target region through PVS where women's participation is encouraged and their preferences appreciated (2013)

Output 2.4: Elite lines/cultivars with enhanced nutritional composition and end-user preferred traits developed.

Key Activities

- Assess nutritional level (Fe, Zn, protein) and cooking quality (cooking time) of elite breeding lines and released cultivars of grain legumes for fast-track scaling up in target countries (2012-13)
- Assess genetic variability for nutritional and anti-nutritional components, cooking quality and end-user preferred traits in GCP reference set/mini-core collections of grain legumes (2012-13)
- Assess genotype x environment interactions and effect of soil nutrient status on nutritional levels (Fe, Zn and protein) in grain legumes (2014)
- Develop and evaluate high protein and/or biofortified (high Fe and Zn) breeding lines of grain legumes and evaluate these for yield and adaptation in MET trials (2012-14)
- Evaluate high iron CB germplasm and breeding lines in countries not covered by CRP4 (2013-14)
- Develop and evaluate legume varieties with specific user-preferred seed traits for niche markets (e.g. large seed size and confectionary traits in GN, large seeded kabuli CP and SB, large red LN in South Asia, large yellow LN in CWANA, black LN, large cream color seed in PP) (2012-14)
- Develop GN and SB breeding lines with high oil content and determine the stability of oil content over environments (2014)
- Develop GN breeding lines with a high oleic/linoleic fatty acid ratio that imparts high oil quality in GN (2014)
- Determine the relationships of nutritional traits and/or anti-nutritional factors with productivity and resistance to diseases and/or insect pests (2013-14)
- Develop and evaluate grain legumes breeding lines with faster-cooking time (2012-14)

Key partners

- IARCs
- NARS in target countries (e.g. ICAR institutes and SAUs in India; BARI, Bangladesh; NARC, Nepal; DARI, Iran; CRIFEC, Turkey; GCSAR, Syria; INRA, Morocco; IAR, Nigeria; INRAN, Niger; INERA, Burkina Faso; ISRA, Senegal; SARI, Ghana; DRD, Tanzania; KARI-Kenya, EIAR, Ethiopia; ICTA-Guatemala, INTA-Nicaragua, DICTA and EAP-Honduras; National programs in ECABREN, SABRN and WECABREN; National programs in Pakistan, Egypt, Tunisia, Uganda, Malawi, Mozambique, Zambia, Rwanda, Burundi, Zimbabwe and other countries)

- ARIs (Universities and Institutes in France, USA and Australia), Advanced Nutrition Labs
- Processing industries (e.g. CP Feeds, Rab Processors in Malawi)

Key milestones

- Genetic variability determined and a baseline is established for relevant nutrients, anti-nutritional and/or biochemical factors in CP, CW, GN, LN, PP, FB and SB (2013)
- Information on relationships between anti-nutritional factors and resistances to insect pest and diseases, and between nutritional traits and productivity available in CB and shared with partners (2013)
- High iron CB tested in another five countries in Africa outside of Rwanda and D.R. Congo (2013)
- Stability of nutritional trait expression determined over environments (CB, CP, CW, GN, LN, PP, FB, SB) (2014)
- At least 20 breeding lines with high protein and/or micronutrient content developed/identified in CP, CW, FB, PP, GN, and LN and shared with partners (2014)
- At least 5 breeding lines with high oil content/oil quality developed/identified in GN (2014)
- At least 20 breeding lines with market-preferred seed traits, such as large seed size in CB, kabuli CP, GN and SB developed (2014)
- At least 15 breeding lines with faster-cooking quality developed in CB, CP, CW, FB, LN and PP (2014)

Output 2.5: Elite lines/cultivars with enhanced nutrient use efficiency, high N₂ fixation potential and other traits for system efficiency developed

Key Activities

- Develop and evaluate early- to extra-early breeding lines of grain legumes for short-window cropping seasons (2012-13)
- Develop and evaluate medium and long duration pigeonpea breeding lines suitable to cereal based intercropping systems in ESA (2012-14)
- Assess the extent to which nitrogen fixation is the main limitation to crop yield under drought and identify symbiotic strains that are capable of sustaining high potential under drought conditions (2012)
- Screen germplasm for the capacity to maintain high N₂ fixation potential during the reproductive period and the capacity to nodulate and maintain high N₂ fixation capacity in presence of high soil N and under low soil P conditions (2012-13)
- Selection of root traits, especially root hairs, for enhanced nutrient acquisition in CB (2013)
- Identify/develop legume germplasm with high BNF and/or P use efficiency under field conditions (2012-14)
- Test lentil germplasm on conservation platform and intercropping systems in CWANA and South Asia (2013-14)
- Screen germplasm sets/elite breeding lines/M₂ populations of grain legumes for herbicide tolerance (2013-14)
- Identify/develop legume varieties suitable for mechanical harvesting in CP and LN (2012-13)

Key partners

- IARCs
- NARS in target countries (e.g. ICAR institutes and SAUs in India; BARI, Bangladesh; NARC,

Nepal; CRIFEC, Turkey; EIAR, Ethiopia; IAR, Nigeria; INRAN, Niger; INERA, Burkina Faso; ISRA, Senegal; SARI, Ghana; DRD, Tanzania; National programs in Rwanda Nigeria, Ghana, Kenya, Tanzania, Ethiopia, Malawi, Mozambique, Zambia and other countries)

- CRP 5, N2 Africa, ARIs involved in N2 fixation research (CDC, Canada; several groups in the US and Europe, SARDI and Centre for Rhizobium Studies, Western Australia; EMBRAPA, Brazil).

Key milestones

- At least 15 early- to extra-early breeding lines for short-window cropping seasons developed in CB, CP, PP, LN, GN, CW, SB and made available to partners (2012)
- At least 5 breeding lines suitable to cereal based intercropping systems developed in PP (2014)
- At least 4 breeding lines suitable for mechanical harvesting to reduce manual harvesting, especially by women, identified/developed in CP and LN (2013)
- At least 10 breeding lines with high BNF capacity in CB, CP, CW, FB, GN, and SB developed/identified and tested under a wide range of environments (2013)
- At least 10 P efficient breeding lines developed/identified in CB, FB, GN, LN, CW and SB (2014)
- At least 5 breeding lines with improved herbicide tolerance to reduce manual weeding by women in CP, GN, LN developed/identified (2014)
- Nutrient and water-use efficient varieties (2-3 in each legume) for increasing legume productivity identified (2014)

Strategic Objective 3: Identifying and promoting crop and pest management practices through farmers participatory approaches for sustainable legume production

Output 3.1 Strategies to optimize Biological Nitrogen Fixation by legumes developed and promoted

Key Activities

- Develop standard protocols, including 15N natural abundance methodology, across grain legumes to evaluate for BNF efficiency under different growing conditions (drought, heat low soil P, etc.) (2012-14)
- Assess N contribution by different grain legumes to subsequent cereal crops (2012-14)
- High nodulating and nitrogen fixing indigenous rhizobia isolated and characterized (including molecular characterization by 16s rDNA analysis) for different grain legumes (2013-14).
- On station and on-farm evaluation of selected efficient rhizobia (2013-14)
- Characterize potential antagonistic, entomopathogenic and plant growth promoting actinomycetes and bacteria for their biocontrol and plant growth promoting traits and conserve these by medium and long-term preservation methods (2012-13)
- Supply *Rhizobium* and other PGP microbes to researchers globally (2012-14).
- Assess secondary metabolite production capability of the promising microbes and identify active metabolites responsible for entomopathogenic traits (2014)
- Evaluate compatibility of rhizobia with other potential microbes (2013)
- Standardize mass production technologies and formulations and delivery systems for rhizobia and other PGP microbes (2014)
- Evaluate effects of tillage (till vs no till) on BNF (2013-14)

Key partners

- IARCs
- NARS in target countries (e.g. ICAR institutes and SAUs in India; BARI, Bangladesh; NARC, Nepal; National programs Ethiopia, Sudan, Malawi and other countries)
- ARIs (e.g., Murdoch University, Australia)
- CRP 5, N2 Africa

Key Milestones

- Protocols to select grain legumes for efficient BNF in LN, FB and CW developed under drought, heat and low P conditions (2013-14)
- Efficient host genotypes and strains of *Rhizobium* and other beneficial soil/plant health micro-organisms identified and made available to public/private sector partners (2014)
- Technologies for mass production of *Rhizobium* and other beneficial micro-organisms developed and made available to public/private sector partners (2014)
- Interaction of genotype x rhizobium x environment under drought, heat and low P determined in at least two legumes (2014)
- Interaction of BNF with other microbes (Mycorrhiza, *Pseudomonas*, and inducers of secondary metabolites conferring resistance to pests) documented (2014)

Output 3.2: Methods to increase legume productivity and profitability through increased resource use efficiency developed, tested and promoted

Key Activities

- Evaluate elite breeding lines of CP and LN in rice fallows in South Asia (2012-14)
- Develop suitable agronomic practices for cultivation of CRP grain legumes for different agro-ecologies and cropping systems (e.g., CP and LN in rice fallows in South Asia) (2012-13)
- Evaluate CP, FB and LN genotypes for yield potential under zero tillage conditions (2013-14)
- Evaluate promising lines of CP, FB and LN for their response to supplemental irrigation to enhance productivity (2012-14)
- Evaluate effectiveness of rock phosphate with improved CB varieties selected for productivity at low inputs (2012-14)
- Develop, monitor implementation and evaluate effectiveness of dissemination protocols for lead and satellite farmers with promising varieties and technologies identified by N2Africa team for SB (all N2Africa countries), CB (East/Central and Southern Africa N2Africa countries), GN (West and Southern Africa N2Africa countries) and CP (West and Southern Africa N2Africa countries) (2012-14)
- Evaluate response of CB to residual P availability from preceding crop (e.g., maize) (2012-14)
- Test CB genotypes with contrasting root architecture for their response to low inorganic and organic inputs (2012-14)

Key partners

- IARCs, including IFPRI
- NARS in target countries (e.g. ICAR institutes and SAUs in India; BARI, Bangladesh; NARC, Nepal; GCSAR, Syria; CRIFEC, Turkey; National programs in ECABREN, SABRN and WECABREN; National programs in Ethiopia, Sudan, Malawi and other countries)
- ARIs (e.g., University of Florida)
- CRP 5, N2 Africa, CIAT Integrated Soil Fertility Management project (Malawi, Zimbabwe,

DRC), IITA CFC funded Soybean project (Malawi, Mozambique)

Key Milestones

- Legume varieties and cropping systems for crop intensification/diversification in cereal based systems/rice fallows identified and promoted (2014)
- Appropriate legume production packages developed, demonstrated, and promoted (involving at least 50% women farmers) to enhance legume productivity in different regions (2014)
- Appropriate dissemination protocols for promising varieties and other technologies identified and promoted (2014)

Output 3.3: Tools and protocols for more effective management of insect pests, diseases and weeds developed, tested and promoted

Key Activities

- Identify, characterize, test and promote agriculturally beneficial microorganisms and parasitoids (e.g. *Beauveria bassiana* and *Metarhizium anisopliae*, *Tephrosia volestii*) or derived metabolites from diverse environments to manage diseases and insect-pests (2012-14)
- Assess non-target effects of at least one novel pesticide/bio-pesticide and at least one insect-resistant transgenic crop (e.g. Bt CP, CW or PP) on major beneficial organisms (2013)
- Study and document information on relative geographic distribution, severity, and extent of losses due to insect pests, diseases, and weeds in each legume in different regions for future priority setting (2013-14)
- Identify eco-friendly bio-pesticides for key insect pests of grain legumes and develop mass scale production and delivery systems for selected most effective bio-pesticides as a component of IPM/IDM (2012-14)
- Develop information bulletin for the identification and management of key legume insect pests and diseases (2012-14)
- Develop and promote IPM and IDM technologies for managing insect pests and diseases of grain legumes and conduct training on these technologies with special emphasis on bio-pesticide production and utilization (2012-14).
- Carry out participatory on-farm evaluations of parasitic weed management at pilot sites in West Asia, East and North Africa (2012-13)
- Develop diagnostic kits for seed borne viruses in CRP grain legumes (2013-14)
- Develop effective strategies for management of *Orobanche* spp in target environments.
- Evaluate aflasafe (aflatoxin biological product) for aflatoxin reduction in groundnut in farmers' fields in West Africa (2012-13)
- Characterize and develop diagnostics tools for important pests and diseases of grain legumes (2013 - 14)
- Characterize and model host-virus-vector interaction at RNA and metabolites levels in CB (2012-14)

Key partners

- IARCs
- NARS in target countries (e.g. ICAR institutes and SAUs in India; DAR, Myanmar; BARI, Bangladesh, NARC, Nepal; National programs in ECABREN, SABRN and WECABREN bean

networks; DAES, Malawi; World Vision, Malawi; KSADP, Nigeria; Direction de la Protection de Végétaux, Dakar, Senegal ; L'université Gaston BERGER de Saint-Louis, Senegal ; NARES and NGOs of Benin, Burkina Faso, Niger, Nigeria, Mali, Egypt, Morocco, Syria, Ethiopia and other countries)

- ARIs (e.g., The University of Cambridge, Rothamstead Research, UK; Biosciences eastern and central Africa (BeCA); University of Illinois at Urbana-Champaign)
- Pulse CRSP, AVRDC

Key Milestones

- New bio-control agents (microorganisms, parasitoids, metabolites) for managing diseases and insect pests discovered and promoted (2014)
- Biosafety of pesticides and transgenic crops to the environment assessed in CP, PP, and CW, and resistance management strategies developed (2014)
- Integrated management options for parasitic weeds demonstrated in SSA and WANA region (2014)
- Diagnostic kits for key viruses developed in at least two grain legumes (2014)
- Inoculation methods for endophytes in CP, CB, and PP developed and defense enhancement tested (2014)
- Information on distribution, severity, and extent of losses due to insect pests, diseases, and weeds documented and shared with NARS (2014)
- IPM technologies, including the use of biopesticides for key pests tested, validated and promoted (involving at least 50% women) in farmers' fields (2014)
- Mechanisms of bean-virus-vector interactions elucidated (2014)

Output 3.4: Potential strategies for increasing legume production in response to climate change identified and tested.

Key Activities

- Study and document (linked to CRP 7) changes in geographical distribution of major insect pests and pathogens based on past and present surveys and historic climate data (2012-13)
- Explore different crop simulation models to evaluate the potential impacts of climate change on productivity of grain legumes (2012-13)
- Identify promising/target traits for grain legumes and develop "virtual cultivars" using crop simulation model and assess the response of new "promising virtual cultivars" under different climate change scenarios using crop models (2012-14)
- Study biochemical, molecular and genetic interactions between pathogens/insect pests × host plant × environment in relation to expression of resistance to the target diseases and pests (2012-14)
- Studies on response to elevated levels of CO₂ on crop growth, BNF and yield of grain legumes (2013-14)
- Study the effects of temperature on host resistance and pathogen virulence on key diseases of grain legumes (2013-14)
- Determine effects of heat stress on pod set and photosynthate remobilization of grain legumes (2012-13)
- Identify and promote short-duration drought and heat tolerant varieties of grain legumes as a strategy to mitigate the effects of climate change (2012-14)

Key partners

- IARCs, NARS in target countries
- IFPRI, University of Florida
- CRP 7, Legume phenotyping network

Key Milestones

- Changes in relative abundance and geographical distribution of major insect pests and pathogens mapped (2014)
- Better understanding of grain legume phenotypic/physiological responses to climate change (CC) and use of crop simulation modelling to better target critical traits needed for adaptation to CC (2014)
- Better understanding of the effect of climate change variables on expression of resistance to insect pests/pathogens (2014)
- Varieties with better resilience to climate change identified (mainly for increased temperature and CO₂) (2014)
- Strategies for adaptation to the effects of climate change on production of grain legumes developed and disseminated to NARS partners (2015)

Strategic Objective 4: Develop and facilitate efficient legume seed production and delivery systems for smallholder farmers

Output 4.1: Decentralized seed systems enhanced through systematic diagnosis and implementation of appropriate models

Key Activities

- Review and assess the cost and returns of current legumes seed production and delivery systems and identify potential cost effective production and delivery systems in representative countries (2012)
- Study and document involvement of women in current grain legumes seed value chains (2012)
- Pilot test the identified and proposed models in target regions against the current practices (2013)
- Support the incubation of diverse decentralized seed enterprises in representative countries through skills/knowledge enhancement, material and access to foundation seeds (2012-13)
- Promote informal seed systems through individual farmers/farmer groups/community/NGOs by facilitating source seed supply and seed production (like registration and seed certification) (2012-14)

Key partners

- IARCs
- NARS in target countries (e.g. ICAR institutes and SAUs in India; ECABREN/SABRN and WECABREN; NARS in Rwanda, Uganda, Kenya Burundi, Malawi, Zambia, Zimbabwe, Cameroon, Ethiopia, Tanzania and other target countries)
- TL II project partners; IFAD-954-ICRISAT project partners; N2Africa project partners and M&E Specialist; IITA CFC funded Soybean Project partners in Malawi and Mozambique; Pulse CRSP
- National Seed Authorities, National Seed Programs, Ministry of Agriculture, Agriculture Departments and Policy makers in target countries
- Public and private seed sectors, agro dealers, farmers and farmer

groups/associations/societies, NGOs, National Association of Smallholder Farmers (NASFAM), IKURU- Empresa Commercial dos Produtores associados (IKURU), Instituto de Investigaçao Agrarian de Mozambique (IIAM)

Key Milestones

- Cost and benefits of major seed production/delivery models determined (across legumes crops), documented and findings widely shared to GL community, seed policy makers (national and regional/continental) (2012)
- Implication and effects of gender relations toward grain legumes seed systems at household and community levels better understood (2012)
- At least 2 entrepreneurs per participating country produce and sell acceptable quality seed of at least one grain legume (2013)
- At least 4 NGOs/farmer groups/farmer unions in each participating country facilitate the scaling up of seed production with at least 20 decentralized seed producers (50% being women) per each grain legume crop (2014)
- Diversified decentralized partners produce at least 500 Tons per participating country per season per each grain legume crop (2014)

Output 4.2: Capacity of public and private sector in legume seed systems strengthened

Key Activities

- Assess the existing capacities and efficiency of public and private seed sectors in grain legumes seed production and supply in some representative countries (2012-13)
- Facilitate establishment of public-private partnerships in legumes seed production and distribution (2012-14)
- Strengthen seed production and storage infrastructure of NARS to support both formal and informal seed sectors towards a sustainable seed supply chain (2012-14)
- Facilitate the establishment of revolving funds at NARS seed production units for nucleus and breeder seed production in selected countries (2012)
- Establish functional variety maintenance units for early generation seed multiplication in Algeria, Ethiopia, Iraq (2012-13)
- Develop a manual on variety maintenance procedures for grain legumes (2013-14)
- Provide training to seed producers (both men and women) in seed production, post-harvest handling techniques as well as business and marketing skills (2012-13).
- Develop and disseminate users friendly training module for seed producers on seed production (including package of practices for crop and seed production, seed standards, seed regulations, seed certifications, etc.) processing and storage (2012-13)
- Disseminate information on improved legume cultivars and crop and seed production technologies through electronic (radio, TV, Internet) and print (articles in local newspapers and magazines, leaflets/flyers/pamphlets) media in local languages (2012-14)
- Develop market linkages (formal and informal) between seed producers and buyers in SSA countries (2012-14)

Key partners

- IARCs
- NARS in target countries (e.g. ICAR institutes and SAUs in India; ECABREN/SABRN and WECABREN; NARS in Rwanda, Uganda, Kenya Burundi, Malawi, Zambia, Zimbabwe, Cameroon, Ethiopia, Tanzania and other target countries)

- TL II project partners; IFAD-954-ICRISAT project partners; N2Africa project partners and M&E Specialist; IITA CFC funded Soybean Project partners in Malawi and Mozambique; Pulse CRSP
- National Seed Authorities, National Seed Programs, Ministry of Agriculture, Agriculture Departments and Policy makers in target countries
- Public and private seed sectors, agro dealers, farmers and farmer groups/associations/societies, NGOs, National Association of Smallholder Farmers (NASFAM), IKURU- Empresa Commercial dos Produtores associados (IKURU), Instituto de Investigaçao Agrarian de Mozambique (IIAM)

Key Milestones

- Capacity at NARS research stations to meet the demand of Nucleus/Breeder/Basic seed of legumes strengthened to produce at least 20 tons of foundation seed per season for each grain legume in each participating country (2013)
- Knowledge and skills of seed producers (informal and formal) on seed production, post-harvest handling, marketing and seed rules/regulation enhanced (at least 20 seed producers per country) across legume crops (2013)
- At least one radio/ TV/ video program across legumes in each participating country presented to promote improved grain legumes varieties and agronomic practices (2013)
- 5000 copies of resource manuals developed and disseminated to users in each participating country per crop (2013)
- Public/Private seed producers are facilitated to produce at least 20 tons of foundation seeds per season for each grain legume in each participating country (2014)

Output 4.3: Enabling seed policies for legume seed systems based on thorough analysis of current arrangements

Key Activities

- Review and analyse domestic and regional seed policies and regulations and identify constraints limiting the performance of existing seed sector (2012)
- Develop policy briefs to address constraints and highlight appropriate seed policies and regulations that will facilitate the domestic and regional seed trade and the development of the seed sector as a whole (2013)
- Organize a regional seed policy workshop targeting policy makers and development planners to sensitize for the policy constraints and opportunities for legume seed production and distribution (2014)
- Provide support to government officials in charge of seed policies to encourage development and implementation of the right policies for increased and widespread use of quality seeds and cross border/regional seed trade of grain legumes (2012-14)

Key partners

- IARCs and NARS in target countries
- National Seed Authorities, Ministry of Agriculture, Agriculture Departments and Policy makers in target countries
- National Seed Production Units, National Plant Protection Agencies (NPPOs), National Agriculture Seeds Council
- Public Seed Corporations, Private seed companies and their association, seed traders and their associations (e.g. African Seed Trade Association), farmers and farmers' groups
- Regional economic blocks

Key Milestones

- A policy analysis (national and regional) with regard to legumes carried out in each participating country or region (2012)
- At least two policy briefs developed on a) the value of certification and b) seed quality/risks associated by various modes of seed production and supply (2013)
- Policy makers and seed supply actors sensitized in each of the participating country (2014)
- National and regional cross legume seed policies supporting the integrated grain legumes seed systems enacted in five countries (2014)

Output 4.4: Framework for national seed security for vulnerable regions and households (poor and women) developed

Key Activities

- Carry out legume seed security assessment for vulnerable/poor and women in target disaster prone areas (impact zones) (2012)
- Assess efficiency of the existing legume seed sector in seed production, storage and marketing in vulnerable regions (2012-13)
- Carry out cost benefit analysis of legumes seed systems currently available in vulnerable environments (2013-14)
- Identify and test various potential models to access quality seed of improved grain legumes to farmers in vulnerable environments (2012-13)
- Mainstream promising seed systems models to access quality seeds of grain legumes to vulnerable farmers (2013-14)

Key partners

- IARCs, NARES partners in target countries
- Tropical Legumes II and other projects (e.g. IFAD project in India)
- NGOs, Government agencies, National Seed Programs, Public and Private Seed Sectors, Farmers and Farmers' groups in target countries
- National seed authorities/Ministry of Agriculture/Civil societies/farmers organizations/Public and private seed companies, decentralized seed producers, NGOs

Key Milestones

- At least two cost effective seed systems models to accelerate the access of improved varieties in vulnerable environments across legume crops identified and tested (2013)
- 500 tons of seeds supplied through different seed system models per each vulnerable impact zone (2014)
- 500,000 vulnerable farmer households (65% being women) accessed quality seeds of improved varieties of their choice (across legumes) in selected participating countries (2014)
- One cost benefit analysis of different seed systems across legumes to access quality seeds of improved varieties to vulnerable farmers (2014)

Strategic Objective 5: Enhance grain legumes value chain benefits captured by the poor, especially women

Output 5.1 Enhancing grain legume value chains for the poor, especially women

Key Activities

- Conduct gender-differentiated analyses of grain legume value chains grain legume value chain for identifying constraints and pro-poor and gender-equitable business opportunities along the chain (2013)
- Identify the current and potential legume processed products and develop business plan around selected products (2013)
- Develop and promote ready to use therapeutic and other food products from grain legumes (2013-14)
- Provide business and entrepreneurial skills to actors along the value chain, particularly women, in small scale business management, value addition and product development, and marketing (including packaging and branding) (2012-14)
- Establish small-scale home processing units for grain legumes in selected villages and home processors exposed to basic business skills (e.g. business planning, record keeping, basic accounting) for product marketing (2012-14)
- Identify and analyse key policy bottlenecks and opportunities within grain legumes value chains that can benefit women and provide information to policymakers on ways and means to empower women along the grain legumes value chain (2012-14)
- Build capacity of key value chain actors to facilitate linkages to markets through functional and gender sensitive grain legumes value chains (2012-14)
- Conduct media events on value addition techniques and nutritional value of legumes in target countries (2012-14)

Key partners

- IARCs, NARS in target countries
- ARIs (e.g. Michigan State University, Purdue University)
- Ministries of Agriculture; Ministry of Trade and Industry, Department of Agricultural and Extension Services, policymakers
- Private sector (output markets and service providers), NGOs, women self-help groups and other women groups, NGOs, Farmers' organizations
- Banks and microcredit institutions
- Regional collaborating organizations (EAC, COMESA)
- Dry Grain Pulses CRSP, IITA's CFC funded soybean project, World Vision, CLUSA-Consultative League of USA

Key Milestones

- Initial value chain core processes, actors (gender-differentiated) and dynamics for the priority crop x regions identified (2013)
- Value chain investment opportunities identified that maximize benefits for the poor, especially women (2013)
- Business skills of at least 20 entrepreneurs (both men and women) enhanced in value addition, product development and marketing.
- At least 2 new or existing legume products within each selected market that are most likely to benefit women and improve health and incomes prioritized (2013)
- Technologies and capacity building measures needed for expansion of these opportunities

- for value addition identified feedback to other outputs provided (2014)
- Policy evidence to inform policymakers and development planners provided (2014)

Output 5.2 Institutional innovations to engage poor farmers with input and product markets identified and piloted

Key Activities

- Conduct feasibility studies for establishing producer and/or marketing groups/cooperatives for more efficient and sustainable utilization of resources as well as enhancing the bargaining power of the small holder farmers both in the input and output markets related to grain legumes (2012)
- Conduct studies for creating access to credit for smallholders to increase their liquidity and increase their bargaining power and also their ability to take advantage of seasonal price changes (2013-14)
- Conduct studies on the feasibility of collectively establishing more effective and technologically advanced storage facilities and engaging private sector in establishing such facilities (2013)
- Conduct studies on the feasibility of establishing grain grading and quality assurance system at the community level (2013)
- Design alternative organizational strategies for grain legume stakeholders and define their impact pathways in terms of integration into the value chains, economies of scale, and access of women and the poor to markets, inputs, and services (2013)
- Evaluate the effectiveness and potential impact of organizations or institutional innovations on adoption, integration into the value chains, and access by smallholder grain legume producers (2014)
- Develop sound methodologies to replicate and scale-up organizational interventions to build the capacities of producer associations for improving adoption, integration, and access (2014)
- Generate evidence on the role of policy in enhancing pro-poor market linkages that benefit women farmers (2013-14)

Key partners

- IARCs, NARS in target countries
- ARIs (e.g. Michigan State University, Purdue University)
- Ministries of Agriculture; Ministry of Trade and Industry, Department of Agricultural and Extension Services, policymakers
- The private sector, particularly grain marketers; Finance institutions (Banks, Microfinance institutions, etc,), NGOs, Farmers' groups
- Dry Grain Pulses CRSP, IITA's CFC funded soybean project

Key Milestones

- Region/crop attuned models developed and pilot-tested for organizing women to sell grain legumes into commercial markets, significantly raising legume-sourced incomes (2012)
- Collective purchasing mechanisms devised and pilot-tested that significantly reduces costs of fertilizer and other grain legume inputs for smallholders, especially women (2013)
- Business models developed with commercial and rural banks and micro-finance institutions (2014)

Output 5.3: Post-harvest technologies/practices and value-added products benefiting women identified and promoted

Key Activities

- Analyse and document post-harvest technologies of grain legumes benefitting women (2012)
- Identify potential complementary/nutritious legume-based products for home/small scale production and support product formulation/pilot including acceptability testing (2012-13)
- Identify/develop and promote appropriate processing technologies (soaking/ germinating/ sprouting/ de-hulling/ mixed dishes, etc) for enhancing nutrient bioavailability at home level (2012-13)
- Compare and document the performance of existing animal feed markets for legumes and identify areas of future potential growth (2013)
- Develop and promote effective integrated management options to manage aflatoxin contamination in grain legumes, particularly groundnut, and workout ex-ante profitability of these options to smallholders (2012-14)
- Identify and promote post-harvest processing and storage technologies suitable for smallholder for reducing post-harvest losses in grain legumes (2012-14)
- Evaluate gender differences in preferences for alternative variety traits; assess the welfare impacts of legumes' technologies, and farm investment priorities by women and men based on processing outcomes (2013)

Key partners

- IARCs, NARS in target countries (e.g. Uyole Agriculture Research Institution; Bunda College of Agriculture; University of Zimbabwe, ZARI, University of Swaziland, Njala University, SLARI)
- NGOs, Private sector, local markets and small shops, supermarkets, animal feed traders,
- IITA's CFC funded Soybean Project
- Ministries of Health and Agriculture

Key Milestones

- Post-harvest processing technologies benefitting women documented and prioritized based on social gains (2013)
- At least 2 post-harvest and processing technologies and associated practices, particularly suitable for farm level use or small-scale household operations documented, and strategies developed to identify new markets and scale-up the most suitable technologies (2013)
- Structure, conduct and performance of major animal feed markets for legumes assessed (2013)
- Appropriate strategies to manage aflatoxin contamination, assessed and the relative benefits to smallholders for supplying to these markets determined (2013)
- Post-harvest technologies for reducing losses due to pest and diseases in key legumes identified/adapted/developed and scaling up assessed (2014)

Output 5.4: Drudgery and cost-saving small-scale machinery for grain legume production and processing identified or developed

Key Activities

- Assess involvement of women in different farm operations in legumes crop production (e.g., sowing, weeding, harvesting, threshing, etc.) and impacts of these farm operations on

women (2012)

- Conduct studies to compare the profitability of different production techniques including mechanization of harvesting and threshing (2013-14)
- Promote use of harvesters/threshers and small implements for grain legumes through NARS in target countries (2012-14)
- Conduct studies on the gender differential effects (including labour demand) of different pest control methods both on-farm and in storage (2013-14)

Key partners

- IARCs, NARS in target countries
- Ministries of Agriculture and other Government agencies, NGOs, Women's associations, Women rights agencies, Extension Agents
- Farm and Engineering Services, Farm implement manufacturers (public and Private)

Key Milestones

- Labor demand in smallholder legume production assessed and the potential of increased mechanization to improve profitability documented (2012)
- Weed control methods in legumes, by smallholders identified and their relative impacts on women assessed (2012)
- Options for smallholder threshing or harvesting to improve legume profitability assessed, with particular reference to uses across legume species (2013)

Strategic Objective 6: Partnerships, capacities, and knowledge sharing to enhance grain legume R4D impacts

Output 6.1: Partnership models to enhance grain legume R4D impacts identified and implemented:

- Establish multi-institutional and multidisciplinary teams of researchers for conducting PVS trials to identify and promote improved varieties and production technologies of grain legumes preferred by men and women farmers (2012-13)
- Establish food legume network in Nile valley and sub-Saharan Africa region (2013)
- Establish food legumes networks in West and Central Asia (2013-14)
- Organize coordination meeting of Central American bean researchers in PCCMCA (2014)
- Establish community of practice (CoP) for integrated breeding of CB, CP, CW and GN through Integrated Breeding Platform of GCP (2012-13)
- Encourage and facilitate private sector in PP hybrid seed production (2013)

Key partners

- IARCs
- NARS (TL II and IFAD project partners; National bean research scientists in ECABREN, WECABREN and SABRN; Central Research Institute for field crops –Ankara; INIFAP-Mexico and ORE-Haiti)
- Farmers, NGOs, and government agencies
- GCP

Key Milestones

- The Central American bean network re-established (2012)
- The Cereals and Legumes Asia Network (CLAN) reinvigorated (2012)
- Cross crop legume meetings established in at least four countries in Africa and South Asia

(2012).

- The food legumes networks in the Nile valley and sub-Saharan Africa re-established (2013)
- Effective multi-institutional and multidisciplinary teams work with farmers and other stakeholders to deliver integrated legume research results in at least five countries (2013)
- Private sector engaged to assume a major role in the production of seed of hybrid pigeonpea (2013)

Output 6.2: Enhancing capacities of women and men for grain legume R4D innovations

Key Activities

- Encourage and facilitate CRP3.5 grain legumes research community to make use of Integrated Breeding Platform established by the GCP (2012)
- Capacity building programs organized for NARS partners, ensuring good representation of women scientists, on novel approaches and techniques in grain legumes R4D (2012-14)
- Conduct research in collaboration with universities and national research institutions on development of effective participatory methods, with a focus on enhancing participation of women, in evaluating grain legumes improved production (2013)
- Organize capacity building programs for breeders/ researchers /students /farmers, ensuring good representation of women, on participatory approaches applicable to legumes (2013)
- Organize scientists-farmers interactions meetings in target countries to share views, needs, constraints and opportunities (2013)
- Publish results of food legumes research for development with NARS partners in referred journals, pamphlets, and bulletins (2014)
- Extend capacity for molecular selection techniques under GCP through regional African bean networks of ECABREN, SABRN and WECABREN (2013)
- Establish cross-legume coordination meetings in CRP 3.5 target countries (2012-14)
- Make available for dissemination at least one cellphone animation video illustrating novel IPM technologies in different local languages (2012)
- Train MSc/PhD students (at least 50% women) in various aspects of legumes research (2012-14).

Key partners

- IARCs
- NARS in target countries (e.g. Universities; Agriculture Departments; ITC institutions; NISLT, Nigeria; University of Ibadan, Nigeria; Department of Agricultural Research Services (DARS), Malawi; University of Abomey-Calavi, Benin)
- NGOs, Civil societies, Farmers' associations, Women's associations

Key Milestones

- IT infrastructure strengthened in national programs to connect breeders, IPM groups and agronomists to the Integrated Breeding Platform (2012)
- At least 20 refereed journal articles co-published between national legume researchers and IARC scientists per year, thereby reflecting joint research and co-learning (2012, 2013)
- Institutional capacity in partnering and M&E strengthened as evidenced by regular attendance of researchers, seed sector, NGOs and farmer groups in yearly inter-institutional meetings in CRP3.5 target countries (2013)
- At least 20 students (at least 50% women) completed their (MSc/PhD) theses research in areas related to CRP 3.5 grain legumes (2014)

Output 6.3: Knowledge sharing platforms for grain legumes crops strengthened

Key Activities

- Organize a workshop of nutritionists and experts in chronic disease to review scenarios in developing countries and to set priorities for interaction of agricultural and nutritional sciences around legumes (2012)
- Establish genomic-phenomic databases for CB (in coordination with BeanCAP), CP, CW and GN under GCP (2013)
- Establishing online biometric analysis module for spatial analysis of data from un-replicated field trials and field trials conducted in alpha- design (2013)
- Establish cowpea and soybean pest and pathogen database in IDIA web portal (2014)
- Link legumes databases with aWhere and test farmers' access to aWhere in target countries through TL-I and TL-II projects (2012-14)

Key partners

- IARCs
- NARS in target countries; TL-I and TL-II project partners; University of Ibadan, Nigeria
- ARIs (e.g. USDA, Michigan State University, Colorado State University, UC-Davis, University of Saskatchewan, Agri-Food Canada)
- aWhere

Key Milestones

- A workshop to acquaint legume researchers with results of research on chronic diseases, and to introduce nutritionists to research opportunities in legumes in the developing world held (2012)
- Legume information, genomic-phenomic databases established for four legumes under the GCP (2013)
- Online biometric analysis module developed and tested (2013)
- Links to the soybean community strengthened through integration of databases (2013)
- Legume data incorporated into TL-II initiative using aWhere and farmers' access to aWhere tested in at least two countries in Africa and one country in Asia (2013)

Appendix 12. Partnership of CRP 3.5 with CRP 1.1 and 1.2

CRP 3.5 GRAIN LEGUMES complements the other CRPs, and will be working with several CRPs, especially CRP 1.1 (Integrated Agriculture Production Systems for the Dry Areas) and CRP 1.2 (Integrated systems for the Humid Tropics). Alliance with CRP 1.1 and 1.2 would be of immense importance to address the outputs where the legumes (CP, GN, CB, CW, LN, SB, PP and FB) are addressed in various agro-ecological regions of CWANA, SSEA, LAC, ESA, and WCA that are common with CRP 3.5. CRP 3.5 will provide germplasm and management recommendations for testing in integrated complex systems encompassing production, markets and natural resource management (CRP 1.1 and 1.2). The feedback from CRP 1.1 and 1.2 will enable the researchers of Strategic Objectives 1&2 of CRP 3.5 in developing improved varieties that are better adapted to integrated production systems. This interaction will facilitate joint research to accomplish Strategic Objective 3 through evaluating the varieties and management technologies in common test locations. The interactions planned at regional or action site level will provide a better platform for studying impact and are of added value to address the outputs in a more critical way.

CRP 1.1 has basically two strategic research theme (SRT) 'systems': (i) SRT2, the more vulnerable subsistence systems where risk management is the main strategy, environmental degradation/exploitation is occurring and livelihood support strategies are needed (and intensification is not an option); and (ii) SRT3, systems with higher production potential and market linkages where intensification is an option and sustainable systems are possible. Broadly, drier agro-ecologies have more SRT2 than SRT3 environments and vice-a-versa, though within any location/area/region there will be a mixture of both SRT2 and SRT3. The regional strategy will be to regard priority systems as comprising mixtures or landscape mosaics of different SRT2 and SRT3 type farmers. A key component of the systems approach will be to understand resource use, livelihoods and trade-offs. CRP 3.5 can actively contribute to characterize these systems in terms of constraints (bio-physical, social etc.) to define likely scenarios or trajectories of change i.e., where is the system going and where do we want it to go, giving rise to the desired outcome, identify these levers (research, policy, capacity building etc.) needed to achieve the outcomes through their component expertise. Collaborative research includes: diagnosis; on-farm research on farming systems improvement, testing new varieties and crop diversification; on-farm research on legume fodder and grain productivity enhancing technologies/ interventions and resource use; market linkage and value chain development.

CRP 1.2 is built around three complementary Strategic Research Themes; SRT1: Systems Analysis and Synthesis; SRT2: Integrated Systems Improvement, and SRT3: Scaling and Institutional Innovations. Together, these SRTs will conduct a baseline situation analysis leading to identified entry points for integrated production systems research; design and implement an M&E Framework; assemble, test and refine systems interventions through participatory processes; champion new farm opportunities through R4D Platforms as pathways to assess fuller impacts and adoptability of the most promising opportunities; link these platforms to partner development institutions; and then advance the effectiveness of these institutions to scale up these interventions, with a particular focus on poor households and gender equity.

As the cropping system in a given farm/village vary widely in a given region, the regional coordinators (of CRP 1.1) through detailed discussion define, prioritize and finalize the activities to be carried in that region across the CRPs.

Mechanism for interacting with CRP 1.1 and 1.2

CRP1.1 and 1.2 will be regionally coordinated research program with Regional Science Advisory Committees (RSAC), which will form the basic platform for various CRPS as formal mechanism to work together. CRP 3.5 could formally be associated within each common interest/priority region/action site with the annual planning process, perhaps as a member of a regional steering committee (though exact mechanisms are yet to be decided) and/or by nominating experts for the regional RSAC. Through this mechanism integrated research teams will be established for the characterization and research needed within priority CRP1.1 sites through committed proportion of FTE to the team.

Sites and systems

CRP1.1 and 1.2 will be both globally and regionally coordinated, with research based on regionally important farming systems. Broad regions have been identified. Regionally, the current proposed areas are broadly South Asia, WANA, CAC, WCA and ESA. However, the final list of locations will be decided during inception phase discussions that will happen in 2012.

Appendix 13. Role of Farmers' organizations, extension workers, NGOs and sub-regional organizations and networks

1. Introduction:

CRP 3.5 GRAIN LEGUMES, besides working with other CRPs, works with a range of partners, and networks that operate in their regions, to facilitate efficient implementation of the program. This is achieved through effective coordination for local action. CRP 3.5 GRAIN LEGUMES, along with its core partners strengthen their interactions with Farmers' organizations, NGOs, sub-regional organizations and regional networks for effective impact. Given below are a few examples of existing collaborations with CGIAR centers, and indication of future linkages with CRP 3.5.

2. Farmers' Organizations

2.1. South and Southeast Asia (SSA)

Farmers' Organizations such as Indian Farmers Fertilizer Co-operative (IFFCO), Krishak Bharati Co-operative Ltd., (KRIBHCO) in India, Vietnam Cooperative Alliance (VCA) Myanmar Central Co-operative Society Ltd. (CCS), Phillipine Federation of Credit Cooperatives (PFCCO), National Co-operative Council of Sri Lanka (NCC), are grass-root functionaries close to the farming communities, active in most of the regions where CRP 3.5 legumes are important source of livelihood. These organizations function at the village level, to assist agriculture by supplying inputs (fertilizers, pesticides, seeds, implements etc.) and facilitating short term crop loans. In recent years, these cooperatives are also providing storage facilities for seed and value added products which can provide additional income. CRP 3.5 will work closely with these organizations to improve the efficiency of the system and to have direct interaction with the clients. All the societies aim to enrich the economic and social status of farming communities especially encouraging women and youth to form associations to compliment and supplement the work of agriculture.

2.2. West and Central Africa (WCA)

In Nigeria ICRISAT and IITA work with farmers through village level associations and groups, established through State Agricultural and Rural Development Authorities. These are the main extension services with a pivotal role in farmer capacity building, varietal diffusion, and varietal release. ICRISAT has signed partnership agreements with State of Kano, Katsina and Jigawa to implement the participatory groundnut variety selection and seed system activities.

ICRISAT has been working with a federation of the Farmer organizations (FO) in Mali, the Association des Organisations des Paysans Professionnels (AOPP) on groundnut seed projects, through several member organizations. AOPP provides professional support in lobbying the government for support to farmer organizations in Mali.

In Niger, ICRISAT has now been working two large farmers' organizations: Mooriben, FUMA Gaskiya. Mooriben is a strong farmers association re-grouping 15 farmer organizations, representing a total of 22,000 farmers and FUMA Gaskiya operates similarly with a network of 10,000 farmers in the Eastern region of Niger. Mooriben and FUMA Gaskiya have established a network of input shops, and are particularly devoted to increase seed supply of locally adapted varieties of various legumes as well as facilitating access to the type of inputs necessary to boost groundnut productivity such as phosphorous based fertilizers. In environments where both organizations are not present, ICRISAT and INRAN work directly with farmers' associations by strengthening their capacity to produce, processing and market good quality seed of legumes.

2.3. Eastern and Southern Africa (ESA)

Farmers' cooperative unions (6) in Ethiopia with membership of 150,000 small scale farmers families, National Small Holder Farmers' Association of Malawi (NASFAM), in Malawi with 100,000 farmers families, Farmers Cooperative Unions in Rwanda with 200,000 farmers families, Farmers Districts Association in Uganda with about 80,000 farmers families, IKURU (Farmers organization in Mozambique) with 22,000 household members, and East Province Farmers Cooperative union (15,000 members) in Zambia are a few examples. Farmers play major roles in the development of value chain such as carrying out participatory testing promising technologies (varieties), dissemination of proven technologies, collective market of inputs and outputs, linkage to profitable market and lobbying for appropriate policies and support. Specialist farmers groups are involved in seed production and marketing.

2.4. Central and West Asia and Northern Africa (CWANA)

ICARDA closely collaborates with a number of national Farmer Organizations (Unions, Associations). This collaboration is mostly focused on the modern crop improvement, agronomic management, seed systems interventions, out-scaling technologies/innovations, and related high-priority value-chain interventions to maximize the benefits that grain legumes offer to smallholder farmers in the region. The Consortium of Farmer Organizations of Central Asia and the Caucasus (CFO-CAC) has been actively collaborating with CGIAR Centers within the framework of Sustainable Development of Agriculture in Central Asia and the Caucasus Program, of which the research collaboration on grain legumes is an integral part. CFO-CAC will work closely with CRP 3.5.

2.5. Latin America and Caribbean (LAC)

In Latin America, especially in Central America, CIAT supported the formation of Local Agricultural Research Committees (CIALs by their Spanish acronym) in the decade of the 90s. This effort was subsequently taken up by other institutions, and today many of these are self-sustaining. In Honduras, for example, approximately 140 CIALs are united under a parent organization, FIPAH (Foundation for Participatory Research in Honduras). CIALs test technologies of several types, especially seed based, and are highly capable of evaluating germplasm critically. CIALs have released their own cultivars of bean. Other NARS partners including the Pan-American school, INTA-Nicaragua and MAG-Costa Rica participate in a Norwegian-funded project on participatory plant breeding with farmer participation.

3. Non- governmental organizations (NGOs)

There are several NGOs that are committed for the uplifting the farmers in grain legumes production across the world. The detailed list is furnished in the main document (see Appendix 8), and a few examples are discussed below.

3.1. South and South-East Asia (SSEA)

Centre for World Solidarity (CWS) based in Hyderabad, India works for the development of marginalised sections of the society such as women, and minorities with special reference to agricultural development in rain-fed situations. CWS collaborates with several grass-root level NGOs, fellows and activists. CWS has been implementing sustainable agriculture covering all CRP 3.5 GRAIN LEGUMES.

Rural development Trust (RDT) operational area is spread over 220 villages of Anantapur district of Andhra Pradesh, India. RDT is an active partner with ICRISAT with a main focus on farmer participatory varietal selection (FPVS) and technology dissemination activities.

3.2. West and Central Africa

PLAN Mali: PLAN is an international development and humanitarian organization centered on the

well-being of the child. One of their programs in Mali is to increase and diversify the income of the poor through increased agricultural production and diversification. ICRISAT is collaborating with groups of farmers through PLAN in two regions of Mali to enhance their income, food and nutritional security through improved groundnut varieties.

CARE & World Vision International: *CARE & World Vision International are well established NGOs with a concern to assist the needy people in famines, disasters and other emergencies to overcome poverty and hunger across the world.*

3.3 Eastern and Southern Africa

Several international and National/regional NGOs: CRS in Rwanda, Burundi, Malawi, Kenya. Self Help Africa in Kenya, Ethiopia and Zambia; CARE and World Vision in Ethiopia, Sudan, Rwanda, Zambia, Malawi, Mozambique and Tanzania; SG-2000, Oxfarm America and Farm Africa in Ethiopia. Besides the international NGOs, there are several church based (Kenya, Rwanda, DRC, Malawi, Tanzania and Ethiopia and Zambia) and local NGOs who are research and development partners. Their role is mainly to carryout extension service, mobilize and train farmers, facilitate testing and popularization of new preferred technologies and also mobilize additional and complementary financial and material resources to expand the reach of improved and preferred technologies.

3.4. Central & West Asia and Northern Africa (CWANA)

ICARDA closely collaborates with Consortium of Non-Governmental Organizations of Central Asia and the Caucasus (CNGO-CAC) a local NGO's in the countries of Central Asia and the Caucasus region. This collaboration is mostly focused on the modern crop improvement, agronomic management, seed systems interventions, out-scaling technologies/innovations, and related high-priority value-chain interventions to maximize the benefits that grain legumes offer to smallholder farmers in the region. These establishments have been actively collaborating with CGIAR Centers within the framework of Sustainable Development of Agriculture in Central Asia and the Caucasus Program, of which the research collaboration on grain legumes is an integral part. CNGO-CAC will work closely with CRP 3.5.

Similarly in West Asia and North Africa, there are many Farmers Unions acting as umbrella organizations for farmers. The union has branches in the different regions of the country. Farmers Union is involved in providing inputs to farmers, and represent farmers in the government, and is also a member in the Higher Agricultural Council where policy and strategic issues are discussed. For example, the Jordan Cooperative Corporation, which is a semi- governmental organization, is mandated for multiplication and production of the improved varieties of the major field crop and conduct that by having contracts with selected farmers. Other federations of associations such AMMSP(association marocaine des multiplicateurs des semences et plants); AMMS (Association marocaine des multiplicateurs de semences); FIAC (Fédération Interprofessionnelle des Activités Céréalières), Association Marocaine des minoteries, et., are involved in organizing the production and services in North Africa. ITAS, the Turkish Exporter Union are involved in legume seed production and delivery, and their expertise will be tapped for CRP3.5.

3.5. Latin America and the Caribbean (LAC)

In Haiti CIAT's long term partner has been the Organization for the Rehabilitation of the Environment (ORE), an NGO working in agricultural development. ORE has a well structured seed unit and supplies seed for other development projects in the country. ORE is very interested in biofortified crops.

In Colombia, most interest of NGOs (e.g., Fundación Carvajal; Valle en Paz) has focused on the dissemination of biofortified crops. In Nicaragua, CIPRES has registered a cultivar received from CIAT as an advanced line and tested with farmers. FIPAH in Honduras (mentioned above) is a formally

constituted NGO. Catholic Relief Services (CRS) is a major partner in the area of value chains and issues associated with climate change. Cooperation has been active in Central America and more recently in Colombia. Similarly, work on value chains in Haiti has been executed with Oxfam. *By developing linkages and working with such organizations, CRP 3.5 provides effective platform in achieving the goal.*

4. Sub regional organizations (SROs)

The core members of CRP 3.5 (CIAT, ICARDA, ICRISAT and IITA) have excellent collaboration through several joint projects with the sub-regional organizations (SROs) across Africa, Asia and Latin America.

4.1. South and Southeast Asia

Many international agricultural research centers (such as ICRISAT, ICARDA, AVRDC, etc) are members of the Asia Pacific Association of Agricultural Research Institutions (APAARI). APAARI is a regional body representing 19 national agricultural research institutions in the Asia and Pacific region. It coordinates the regional R4D policies and linkages with several international bodies such as GFAR.

4.2. West and Central Africa (WCA)

The West and Central African Council for Agricultural Research and Development (CORAF/WECARD) is sub-regional organization comprising of 21 member states in the WCA region. CORAF/WECARD has been formally mandated to lead the implementation of CAADP on agricultural research, technology dissemination and adoption by the Regional Economic Communities (RECs). Several projects are funded by CORAF, including many seed production and delivery activities. A recent project funded by CORAF (through the Australian government) is a Groundnut Seed project implemented in 4 countries in West Africa namely Mali, Cameroon, Ghana and Nigeria. CORAF commitment to implementing the CAADP pillar is strong.

4.3. Eastern and Southern Africa (ESA)

CRP 3.5 will work closely with the Association for strengthening Agricultural Research in East, Central Africa (ASARECA) which comprises of 11 countries; and the Centre for Agricultural Research and Development for Southern Africa (CARDESA) comprise of 14 countries in South Africa and the Indian Ocean. These SROs will facilitate and coordinate joint action among member countries. In collaboration with CIAT, ICARDA, ICRISAT and IITA, the SROs are currently supporting several legumes research for development projects e.g. Promoting utilization of bean technologies for livelihood improvement in ECA (Rwanda, Burundi, DRC, Rwanda and Uganda and snap bean project in Kenya, Rwanda, Tanzania and Uganda). Therefore, CRP3.5. will build on these existing relationship and partnership.

4.4. Central and West Asia and Northern Africa (CWANA)

In CWANA, CRP 3.5 will liaise with the Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA) and Central Asia and Caucasus Association of Agricultural Research Institutions (CACAARI) for implementing grain legumes R4D activities.

5. Partnership with the existing Commodity Research Networks

5.1. Africa:

Eastern and Central Africa Bean Research Network (ECABREN), Southern African Bean Research Networks (SABRN) and West and Central Africa Bean Research Network (WECABREN). Programa Nacional de Fortalecimento da Agricultura Familiar (PRONAF) in West Africa are important networks to facilitate legume research. Network for the Genetic Improvement of Cowpea for Africa. (NGICA). PABRA is quite large, with 350 direct and indirect partners from NARS, IARCs, donors, NGOs, sub-regional organizations (ASARECA, SADC-FANR, and CORAF), community-based organizations, seed producers, traders and the commercial private sector. CRP 3.5 initiated discussions with Pan Africa

Bean Research Alliance (PABRA) to possibly expand it to other legumes and make the network across Sub-Saharan Africa.

Agricultural Research Council of Nigeria (ARCN) is responsible for the running of federal agriculture research centers. Currently, the ARCN supervises 18 Agricultural Research Centers research centers located across various agro-ecological zones. One of the Research centers- the Institute for agricultural Research (IAR) has the national mandate for the improvement of both groundnut and cowpea. Nigeria is the largest producer of these two legumes in the whole of SSA. ICRISAT and IITA have had collaborative research on these legumes for over 20 years. ARCN provides strong leadership in coordinating research, by taking a leading role in influencing policy and funding for research

Forum for Agricultural Research in Africa (FARA), an umbrella organization bringing major stakeholders in agricultural research and development together in Africa. FARA supports the SROs and their NARSs in establishing appropriate institutional and organizational arrangements for regional agricultural research and development.

5.2. South and Southeast Asia

Historically, ICRISAT has ample field experience in sharing varieties and technologies with farmers through CLAN networks throughout Asia. The Cereals and Legumes Asia Network (CLAN) is endorsed by APAARI, and is co-facilitated by ICARDA, ICRISAT and AVRDC. CRP 3.5 will work closely with CLAN, as it has a well-established framework. Additional value will be gained by extending the learning across regions/crops through CRP 3.5 R4D activities.

The All India Coordinated Research Programs (AICRPs) guide and coordinate research (agronomy, crop improvement, crop protection, soil and nutrient management, and postharvest technologies) on most of the key crops including chickpea, lentil, pigeonpea, and groundnut in India. CRP 3.5 will work closely with the AICRPs in India.

5.3 Latin America and the Caribbean

CRP 3.5 will work with the existing networks such as PROFRIJOL (bean network), AgroSalud (regional biofortification project), and PCCMA (Central America regional network, including bean) for coordinating the activities of CRP 3.5 GRAIN LEGUMES.

Appendix 14. Commitments and investments of partners

CRP 3.5 Grain Legumes plans to execute the R4D activities in a partnership mode. The partnership includes the initial partners (CIAT, ICARDA, ICRISAT, IITA, EIAR, EMBRAPA, GCP, GDAR, ICAR, Pulse CRSP), other national programs in the target regions (SSEA, ESA, WCA, LAC, CWANA), the regional networks (see Chapter 6 Partnerships and Networks), government and non-governmental organizations (GOs/NGOs), regional/sub-regional organizations, private sector, and farmers' cooperatives and organizations. These partners were selected to build on the existing national/regional/sub-regional initiatives to exploit comparative advantages and synergies among each other so as to enhance partner complementarities. Consideration has also been given to scale of operations and profile of partner clientele. Participation in CRP 3.5 Grain Legumes is based on commitment and mutual interest in grain legumes R4D, and willingness to work together for the common goal of all partners – to help the resource farmers to increase productivity and production of grain legumes that can lead to meeting the four CGIAR System Level Outcomes (SLO): Reducing rural poverty, Securing food supplies, Nutritious and safe food, and Sustainable intensification.

The initial partners have already made their commitment when they joined hands to propose the CRP 3.5 Grain Legumes. We have had discussions (first during the stakeholders meeting in Aug 2010, and later during several interactions during the course of 2010 and 2011) with other proposed partners (see Appendix 8 on Global Partners). NARS partners provide local expertise to develop, refine and evaluate technologies. Country ownership is imperative as NARS, NGOs, farmers' organizations, and farmers will be implementing the planned activities, with support from the CRP. The commitments and investments needed from the NARS, ARI/Universities, other CGIAR centers, and NGOs) are indicated below:

- Human resources – commitment of staff time of scientists, technicians, field staff, extension workers, drivers, and other essential staff.
- Infrastructure and facilities – use of existing office and laboratory space, laboratory equipment, computing facilities, field machinery, research fields, and use of vehicles.
- Financial resources – in-kind and matching grants (based on collaborating institution's capacities) to defray cost of laboratory consumables (glassware, chemicals, reagents, etc.), cost of POL and repair of vehicles; fertilizers and other field supplies .
- Institutional PPP mechanisms – Use of existing PPP platforms for enhancing partnership opportunities with the private sector.

Commitments from regional/sub-regional organizations will involve coordination and facilitation across member countries, and support to member countries through bilateral and/or multilateral projects.

The private sector involvement through institutional Public-private partnership (PPP) mechanisms will include participation in joint development – oriented activities related to value-addition, seed multiplication and distribution, and supply of agriculture inputs (fertilizers, pesticides, etc.) and outputs (markets).

Involvement of Farmers' organizations and farmers will be for participatory technology development and evaluation, formation of cooperatives/federations/producer companies for seed multiplication and distribution, and to act as conduits for bulk purchase and distribution of agricultural inputs.

NGOs have grass-root connections with the farming community and farmers organizations, and help promote community action, evaluation and dissemination of technologies.

Appendix 15. Analysis of trade-offs implied by emphasis on value chains and location specificity of IPGs

Trade-offs

Our understanding of the comment regarding trade-offs is that it asks us to consider i) the investment trade-offs of working on value chains vs. other Objectives within CRP 3.5; ii) there may also be a concern that CRP 3.5 GRAIN LEGUMES is expanding its scope into new and unfamiliar areas. Research-for-development does need to innovate and forge ahead in new directions, but in a manageable way. CRP 3.5 has carefully organized its Strategic Objective 5 (SO 5) work in a way that manages these risks while opening a window of innovation and novel partnerships. These points are elaborated below.

First it is important to note that the trade-off of investment is modest, only 8% of project resources, as indicated in Budget Table 14.2, have been allocated to SO 5.

Second, it should be noted that SO 5 is not a radical take-off in a different direction; rather it contributes strongly to the mainstream CRP 3.5 need to improve its priority-setting. Even ISPC stated that *“there is value here [in SO 5] in terms of contributing to priority setting for SO 2 and SO 3—if we know where the value chain opportunities are to be found, then it might shape the targets for genetic improvement or crop management techniques.”*

Third, SO 5 is also an attempt to address the earlier critique by the CGIAR Consortium Board (of the first draft, 13 Sept. 2010) that *“the focus of the proposal is on increasing productivity rather than on answering a specific development challenge. The activities do not include assessments of smallholder needs and other stakeholders’ needs”; “work on profitability is almost not apparent; no work on determining the costs and the benefits for smallholders of different technological options is proposed – the CB recommends addressing this point” and “there are no concrete activities, outputs, outcomes and impacts [related to gender] that have been built into the proposal. The proponents need to remedy this lack.”* It was in response to these issues and concerns that the value chain objective was added to the subsequent versions of the proposal. A value chain is a systems perspective that is widely used as a framework for integrating social and economic perspectives with biophysical perspectives on crop commodities, to improve planning, priority-setting and impact (citations were given in the previous draft, e.g. Feed the Future, Dry Grain Pulses CRSP, World Food Programme and others). Thus SO 5 serves a core need of CRP 3.5 using a widely recognized approach.

Fourth, CRP 3.5 sees a value chain perspective as particularly useful for increasing benefits for women, which is a mainstream CGIAR priority. There is wide recognition across the CGIAR (and within CRP 3.5) that past understanding of the poor has mostly failed to distinguish gender benefits. Therefore an initial R4D need is to improve our understanding of opportunities to preferentially focus on benefits for women. By investigating where and how within value chains benefits are captured by women, or fail to be captured or potentially could be captured, SO 5 will contribute strongly to improving CRP 3.5’s gender equity effectiveness. The CGIAR recognizes in particular that an upgrading of its work on gender issues requires first of all a better understanding of where the most relevant and impactful opportunities lie. We must purposefully re-examine how and where benefits for women are generated in the grain legume value chain so that the R4D agenda can be adjusted to more effectively address those areas. SO 5 provides the space within CRP 3.5 to do this.

Another FC trade-off concern may be whether SO 5 is becoming engaged itself in commercial market development. As articulated in the proposal, the proponents wish to re-emphasise that SO 5 will not itself engage in all the activities of value chains; rather, it will engage in *partnerships* through which the most appropriate partners address constraints relevant to their expertise. Thus, R4D on value chains will not induce trade-offs of investment into topics that lie beyond the CGIAR’s comparative

advantage. SO 5's R4D activities will identify opportunities that motivate such partnerships to be formed, supported and executed. A relevant example is ICRISAT's Hybrid Parents Research Consortium. R4D established the potential of hybrid pigeonpea, drawing interest from the private sector, which then brought forward support for further research that led to commercial deployment of this technology. This public-private partnership precluded the need for ICRISAT itself to engage in the commercial fine-tuning, promotion and dissemination of the technology. Numerous other examples could be cited.

International Public Goods (IPGs)

The proposal focuses SO 5 on the generation of international public goods. It commits to a focus on five value chains that are of major regional and global importance (p. XX, 'Priority setting'):

- *Cowpea in WCA* – Important lessons on trade-off between grain vs. haulm value enhancement and markets with focus on the poorest subsistence-oriented farmers/women in risky dryland agro-pastoral economies
- *Soybean in WCA (Nigeria, Ghana) and ESA (Malawi, Mozambique, Zambia)* – Important lessons on harnessing a high-potential 'new crop' with strong global demand and excellent nutritional quality to drive emergent market-oriented development with strong involvement of women in postharvest value addition
- *Bean in ESA* – Most important grain legume for local production and consumption in this region; high importance in local economy and diets and for exports
- *Groundnut in SSEA* compare/contrasted with WCA and ESA – Valuable opportunity for South-South learning through value-added opportunities for a crop of high importance in both regions; groundnut is of special importance to women in WCA and ESA
- *Chickpea in SSEA* compare/contrasted with CWANA and Ethiopia – Valuable opportunity bridging CGIAR Centers for inter-regional learning based on a crop of high importance in three regions with particularly interesting trade dynamics (both import and export)

In response to this FC concern, the proponents have now modified the soybean value chain target to include the important emerging sector in Southern Africa (Malawi, Mozambique, Zambia) as well as adding Ghana in West Africa. With this change, all five of the focus value chains are truly international in scope. The IPG value of this approach is through comparing/contrasting how these value chains are implemented across these countries/regions. We believe this will elicit important lessons that can help these countries/regions learn from each other, thus delivering IPG value.

To give just a few examples, all grain legume value chains require clearly-identified markets that motivate farmers to commercially produce. Yet some regions have more effective markets than others. Transparent pricing is also required so that value chain actors are able to monitor and ensure that they obtain optimum prices for their goods and services (especially producers), yet this has not been achieved to an equal degree in different regions. Producers also need to be well-organized to achieve scale, efficiency, and to ensure a consistent volume of supply of produce to sustain their markets, yet some are better organized than others. Some components of value, such as the value of straw and nutritional value, are being captured more effectively in some countries/regions than others. And as explained earlier, some countries/regions are more effective or in different ways in capturing value for women, than others. SO 5 will investigate these important differences and extract lessons that can benefit the other countries/regions.

To give a few very specific examples, work with chickpea and pigeonpea to date has highlighted the importance of grain quality parameters for increased export market income for smallholders; it has also highlighted continuing difficulties in ensuring the strongest possible price negotiating position for those smallholders. Research on the navy bean export value chain in Ethiopia has highlighted the importance of participative partnerships, utilizing farmer knowledge to improve production and quality and to identify more effective mechanisms for organizing producers. Different approaches to

improving the seed systems component of value chains are being attempted in different crops and countries, but the lessons learned are only beginning to be consolidated and shared more widely. Lessons from research on these issues and deliberate compare/contrast learning will enable wider international progress against the challenges that they represent.

Appendix 16. Integration of the crop improvement with resource management

Improved germplasm plays a major role in all production systems, and directly or indirectly can contribute to resource management. Host plant resistance and integrated pest management (IPM) are commonly cited contributions to minimize the use of pesticides that contaminate the environment, and will be pursued in Strategic Objectives 2 and 3 in CRP 3.5 GRAIN LEGUMES. Resource use efficiency is another contribution that could apply to many crops, and within CRP 3.5 this will be pursued in fertilizer efficient cultivars that recover nutrients more efficiently, and in drought tolerant cultivars with greater water use efficiency (WUE). However, the unique contribution of legumes to resource management is in the area of nitrogen fixation. To the extent that nitrogen fixation can be enhanced and exploited, this will reduce the necessity for industrially produced nitrogen fertilizers. This is discussed amply in the relevant sections of the proposal. While selection of Rhizobial strains and implementation of inoculants will have their role, enhancing and stabilizing the N fixation capacity of the host plant must be a major component to be able to contribute to improved resource management. Stabilizing fixation will have both genetic and management components, and will be a major focus of the interaction of genetic improvement with resource management. We do not underestimate the challenge involved, first to make the legume crop self-sufficient in nitrogen, and then to make a significant positive impact on the nitrogen balance of the system.

Enhancing the viability of legume production through both genetic improvement and agronomic practices is a necessity to maintaining legumes in the production system, and thus to conserving the biodiversity of those systems afforded by legume options. Thus, the activities contributing to yield improvement would have an indirect effect on the diversity of production systems. The goal of identifying improved short season legumes cultivars of several species could extend the presence of legumes in cropping systems and further increase crop diversity.

A third major area that should contribute to resource management is that of value chains and the profitability of legume production. A widely held hypothesis is that profitable agriculture will permit investment in resource management practices. While this may not occur in all circumstances, it is difficult to see how such investment will occur without an economically viable system. In this context, the genetic component (improved cultivars) can contribute indirectly to resource management, by enhancing the profitability through increased yields, and by offering options with superior market value (grain types with superior price differential; high oil grains or grains with superior oil quality; etc).

The dimensions of resource management mentioned above will be developed more amply with other CRPs, especially those dealing with cropping systems (CRP 1.1 and CRP 1.2), since the issues cited are largely relevant in a system context, especially those referring to crop diversity and reinvestment in resource management. Nitrogen fixation has clear relevance for the soil component of CRP 5.

Appendix 17. Description of the relationship with initiatives like Tropical Legumes I and II

CRP 3.5 will build on many years of experience within the CGIAR on tropical and sub-tropical legume research, and will provide continuity with on-going efforts of conventional genetic improvement and cutting edge technology, crop agronomy and management, and seed delivery systems. In this context, CRP 3.5 will integrate these current efforts more effectively, to exploit synergies across the Centers and across crops. The Tropical Legumes projects (I and II) are one of the examples of such integration. TL-I and TL-II represent major components within CRP 3.5 in the efforts to address drought and associated production constraints. Indeed, these two projects have set the stage for more extensive interchange among legume research programs, and among disciplines and areas that are as distinct as genomics, seed systems, and soil health management. In addition to TL-I and TL-II projects, CRP 3.5 will work closely with other projects such as the Generation Challenge Program (GCP), N2 Africa, SIMLESA, AGRA/Soil Health, and PASS, especially in SSA.

The TL-I project represents a key initiative of GCP that brings together advanced molecular research laboratories and national research partners in Ethiopia, Kenya, Tanzania, Burkina Faso, Nigeria, Senegal, Malawi, Mozambique, Zimbabwe and India. GCP is involved in developing molecular markers for groundnuts, cowpeas, beans and chickpeas. These markers are being validated, and in some cases being used in breeding programs to hasten development of improved cultivars. GCP and CIAT have collaborated with Bean Coordinated Agricultural Program (CAP) to gain access to 1500 SNPs converted to the Kaspar genotyping system. As a result, Bean CAP is offering to genotype parental lines of interest to African NARS breeders on a 6000 SNP Illumina chip. They will be part of a phenotyping panel for association mapping. Implementation of the SNP genotyping platform for bean and cowpea has been achieved in the Dry Grain Pulse CRSP and was facilitated through the involvement of the University of California, Riverside, and CIAT for common bean. The phase 2 of TL-I that started in 2010 is focusing on the application of these markers in development of improved cultivars. CRP 3.5 will make use of the markers developed and the pre-breeding materials developed under TL-I programs.

TL-II is a joint initiative of three international agricultural research centres, viz. ICRISAT (chickpea, groundnut and pigeonpea), IITA (cowpea and soybean), and CIAT (common bean) that aims to increase productivity and production of legumes in ESA, WCA and SSEA. The project's strategy is fast-track testing and adoption of on-shelf improved legume varieties and advanced breeding lines by farmers using participatory varietal selection (PVS); generate new farmer- and market-preferred varieties and hybrids with desirable traits (high grain yield, tolerance to moisture stress, and resistance to pests and diseases); and establish decentralized, pro-poor seed production and delivery systems. The activities are being carried out in partnership with NARS of 15 countries, including Burkina Faso, Ghana, Mali, Niger, Nigeria, and Senegal in WCA; Ethiopia, Kenya, Malawi, Mozambique, Tanzania, Uganda and Zimbabwe in ESA; and India and Bangladesh in SSEA. TL-II is already working closely with TL-I in integrating the pre-breeding materials developed under TL-I. CRP 3.5 will integrate all work being done under TL-II and use lessons learned to other crops and countries.

Considering the benefits of N fixation in legumes, the newly bred varieties of chickpea, cowpea, pigeonpea and beans, should have improved BNF using efficient Rhizobium strains. The partnership with N2 Africa will be useful to access information on crop-soil-bacteria interactions under different environments. The two initiatives are working closely through mutual exchange of technologies. Varieties developed under TL-II and other projects are being used by N2 Africa; while the Rhizobium inoculum technologies developed by the latter will be used to the benefit of African farmers in the CRP 3.5 GRAIN LEGUMES.

We will be working closely with the Program for African Seed Systems (PASS) of AGRA for seed systems in countries and crops of common interest. PASS is focusing on ensuring that smallholder farmers get access to new varieties, widely, quickly and economically. We realize that the CRP 3.5 seed component highly complements what PASS is aiming to achieve. Working with PASS in training African scientists and facilitating development of networks of African agro-dealers should certainly enhance future achievements of CRP 3.5 in the seed component. The program for the Sustainable Commercialization of Seeds in Africa (SCOSA) (also an innovative, complementary initiative which coordinates with PASS) also has some focus on legumes crops. Where there is a demand for foundation seed production of legumes, we would hope that the different stakeholders can combine forces in this area to ensure sustainability, and strong links will be established between CRP 3.5 and SCOSA.

The Soil Health Program of AGRA is working on improving farm productivity through increasing farmers' access to locally appropriate soil nutrients and promoting integrated soil and water management. The Seeds and Soil Health Programs work together to raise farmers' yields. Both are key to environmental sustainability and helping farmers adapt to and mitigate climate change. CRP 3.5 will work in close collaboration with AGRA and provide legumes cultivars with improved phosphorous and BNF efficiency for testing in different farming systems by AGRA.

The Sustainable Intensification of Maize-Legume cropping systems for food security in Eastern and Southern Africa (SIMLESA) program, supported by ACIAR, and is being implemented by CIMMYT in collaboration with the Association for Strengthening Agricultural Research in East and Central Africa (ASARECA) and the NARS of Ethiopia, Kenya, Malawi, Mozambique and Tanzania and ICRISAT. The focal countries of this partnership program are Ethiopia, Kenya, Malawi, Mozambique, Tanzania and Australia. One of the focus areas of SIMLESA is to test and develop productive, resilient and sustainable smallholder maize-legume cropping systems. CRP 3.5 will be working closely with SIMLESA for developing legumes cultivars and production technologies suitable for maize-legume cropping systems.

Appendix 18. CRP 3.5 Linkages with CRP 2 on policies, institutions and markets

The issue of policy bias against smallholder grain legume producers is generally recognized. Legume cultivation was shifted to marginal lands (as productive lands were allocated to cereals) and did not benefit from improved technology, subsidies and other agricultural infrastructure development. With only modest increase in relative legume yields, supplies lagged behind demand and prices increased. However, the small holder farmer did not receive the fair share in the price due to high processing and marketing margins. CRP 3.5 will work closely with CRP 2 on areas related to value chain and enabling policies to ensure that farmers benefit from legume cultivation.

CRP 3.5 Grain Legumes will be linked to CRP 2 under subtheme 3.1 – Innovations across the value chains. It will contribute to understanding of grain legume value chains by making use of the global and methodological value chain work under CRP 2. For example, analysing alternative options like market information and intelligence systems, auctions and exchanges; forward and options contracts, and innovations in insurance; for making grain legumes cultivation a more profitable production system. Knowledge on research methods, models and data on crop productivity, value chain analysis and policy advocacy for identification of new market opportunities for grain legumes will be an important input for CRP 2 to develop policy information and promote conducive markets for more profitable grain legume production systems.

The CRP 3.5 will work with CRP 2 in sub theme 1.1 – Strategic Foresight and Future Scenarios - to develop plausible scenarios for the future of grain legumes in the changing socio-economic and environmental conditions and also provide inputs for integrating bio-physical factors in the ex-ante priority setting exercise, input-output market linkages for reducing transactions costs, agricultural policies and regulations. CRP 3.5 along with other CRPs (especially CRP 1.1, CRP 3.6, CRP 5 and CRP 7) will provide inputs to subtheme 1.1 of CRP 2 in developing integrated systems modeling framework (e.g. integrated bio-economic household/village level model; multi-market models like IMPACT and DREAM model developed by IFPRI) to assess the policies, institutions and governance structure which constrains technology adoption of Grain Legumes. CRP 3.5 will establish and maintain regular interaction with CRP 2's strategic activities such as refinement of research domains for grain legumes, applicability of technology across domains, constraint identification, evaluation, feedback to enhance ex- ante priority setting at the CGIAR System level and also for ex-post and ex-ante impact assessment of technologies and crop management systems on welfare, nutritional security of the farm household and the sustainability of the natural resources.

CRP 3.5 will also closely link with the CRP 2 sub themes 1.3 – Production and Technology policies; 1.4 – Social Protection Policies and 2.1 – Policy Processes to identify and understand the policy bias (e.g. minimum support price (MSP), input subsidies, trade policies, insurance program etc.) which affects the profitability of Grain Legumes in small farm holders legume based farming system in the target regions. Also provide inputs to CRP 2 to conduct economic analysis of impacts of specific seed interventions on short term and long term food and nutritional security.