



**Gender &
Breeding
Initiative**

Working Paper 2

From Market Demand to Breeding Decisions: A Framework

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ACRONYMS

GBI	CGIAR Gender and Breeding Initiative
LB	Late blight
MCDM	Multi-Criteria Decision-Making
OPVs	Open-pollinated varieties
PMHPRC	Pearl millet hybrid parents research consortium
PPB	Participatory plant breeding
RTB	CGIAR Research Program on Roots, Tubers and Bananas
Sheep CRC	Cooperative Research Centre for Sheep Industry Innovation
STP	Segmenting-Targeting-Positioning
TYLCV	Tomato yellow leaf curl virus

PREFACE

For plant and animal breeders to meet users' needs, they need to understand the priorities that women and men assign to genetically determined traits – such as taste, color, size and shape. Many CGIAR breeding programs know that if they overlook traits important to women users, this can aggravate household food insecurity and poverty. However, breeding programs still don't have enough practical methods and tools to help them decide how to be more gender-responsive and consider gender differences in breeding schemes. Tackling this knowledge gap is urgent if CGIAR centers and Research Programs are to achieve the targets for gender equality defined in the CGIAR Strategy and Results Framework.

In response, the CGIAR Gender and Breeding Initiative was launched in 2017, building on a strategy developed by an interdisciplinary group of breeders and social scientists who came together in 2016 as part of a workshop on "Gender, Breeding and Genomics" convened by the CGIAR Gender Network (which has now evolved into the CGIAR Collaborative Platform for Gender Research led by the CGIAR Research Program on Policies, Institutes and Markets).

The Initiative brought together a broader group of scientists in October 2017 to build on this earlier work and develop recommendations for practical ways to improve the gender-responsiveness of breeding programs; evidence-based methods and tools for gender-responsive targeting, implementation of breeding activities and linkage with variety dissemination; and support a community of practice for active sharing and development of methods and tools.

This working paper is part of a series of knowledge products to share the outputs from the 2017 "Innovation in Gender-Responsive Breeding" workshop, and to share the Initiative's collective knowledge more widely across CGIAR and partner breeding programs.

The Initiative is coordinated by the CGIAR Research Program on Roots, Tubers and Bananas and the International Potato Center, with funding support by [CGIAR Fund Donors](#).

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We thank all those who responded to the survey of breeding programs we sent.

The views expressed in this paper are those of the authors and should not be attributed to any organization with which they are affiliated.

The CGIAR Gender and Breeding Initiative is coordinated by the CGIAR Research Program on Roots, Tubers and Bananas and the International Potato Center, with funding support by CGIAR Fund Donors.

EXECUTIVE SUMMARY

Developing plant varieties or animal breeds that meet the needs of all stakeholders is a tremendously challenging task. Each set of breeding customers, such as growers, product chain actors, and end-use consumers, may have specific needs for attributes of breeds or varieties. Eliciting, defining, communicating and incorporating these traits into breeding programs requires the focused interaction of different disciplines and stakeholder groups throughout the process.

In this paper we propose a framework to capture and respond to needs and demands to be addressed through breeding. The framework is split into four phases, three of which are developed in detail herein: developing product profiles from market demands; developing breeding priorities based on product profiles; and turning breeding priorities into breeding decisions.

We have drawn on a number of real-life examples and experiences that address each of the phases described in this paper, as well as on a broad survey of public and private sector breeding programs. We summarize lessons learned and suggest effective approaches and tools for implementation. Three of these key learnings are summarized below.

Any product attribute that is demanded or needed by the market, and which is not clearly identified and considered throughout the breeding process will remain wishful thinking and never be delivered on, unless by chance. The decisions made by breeding programs as to which attributes to target must include gender-related traits in order for plant and animal breeding to become gender-responsive.

Similarly, any poorly-understood, unrealistic or unfeasible trait that is in demand or needed, must be addressed and discussed, and the inability to deliver on it communicated back to stakeholders. Such feedback mechanisms from breeding programs to markets - or their representatives - are essential to ensure an alignment between expectations and deliverables, and potentially identify alternatives when breeding cannot deliver. Any demands, including gender-specific ones, must be realistic, well documented and agreed upon in order for a breeding program to be successful.

Finally, the objectives and priorities of a breeding program must be defined in a way that ensures delivery of significant (measurable, visible) value to its stakeholders. Gains achieved through breeding need to be large enough to drive adoption of new breeds or varieties. This is particularly important for traits that are difficult to quantify and for which small gains, though real, might have little perceived value. For breeding programs to contribute towards improved livelihoods and well-being for both men and women, they must deliver new breeds or varieties that are significantly improved for important gender-specific attributes.

From Market Demand to Breeding Decisions: A Framework

1. INTRODUCTION

1.1 INTENT AND APPROACH

This paper was produced as part of the CGIAR Gender and Breeding Initiative (GBI), which aims to understand how animal or plant breeding is currently responding to gender-specific needs, and to propose ways by which breeding programs could be more gender-responsive.

The purpose of this paper is to contribute to a framework for the identification of key decision points in a breeding program where gender considerations need to be highlighted to make it more gender-responsive. To do this, we outline and describe the context and impact of decisions that are made at different stages of a breeding program. Key procedures, sequences, and processes for moving from the collaborative assessment of market demands and development of product profiles, to the setting of breeding priorities, and making of decisions in breeding programs are all illustrated with examples. These examples cover different crops, one animal case, and product and partnership contexts. With this framework, breeders, social scientists, managers, and other experts should be better equipped to identify entry points for information and approaches that will lead to more user-informed and demand-led breeding and variety/ breed development. In turn, leading to greater adoption and equity of benefits from investments in crop and animal breeding.

The material used in this paper included the following:

- Responses to a survey sent to breeding organizations—public, private, and global
- Examples provided by a number of breeding organizations
- Authors' knowledge of the field
- Companion input papers and deliberations from an “Innovation in Gender-Responsive Breeding” workshop convened by the CGIAR Gender and Breeding Initiative in Nairobi, Kenya, 2017.

The survey was run through SurveyMonkey and contained just over 50 questions. It was sent to about 250 individuals involved in breeding for a variety of crops or animals (with an overrepresentation of crops over animals), in the public or private sectors, and on all continents (Figure 1). Most questions had preformatted responses with a scale of “strongly agree, agree/disagree, strongly disagree.” A total of 110 responses were received and analyzed. There were too few responses from individuals working in animal breeding to allow disaggregation. These were therefore omitted from disaggregation-based analyses.

Examples of current practice were obtained from earlier or ongoing cases. They represent some of the ways in which organizations translate market demands into breeding priorities; however, they are not necessarily best practices and should not be taken as such. Some of the examples used are conceptual compilations of real-life situations. The intent of the individual animal or crop cases is thus to illustrate the processes presented in a generic way, to provide a basis for analysis of scenarios and opportunities upon which best practices may be built.

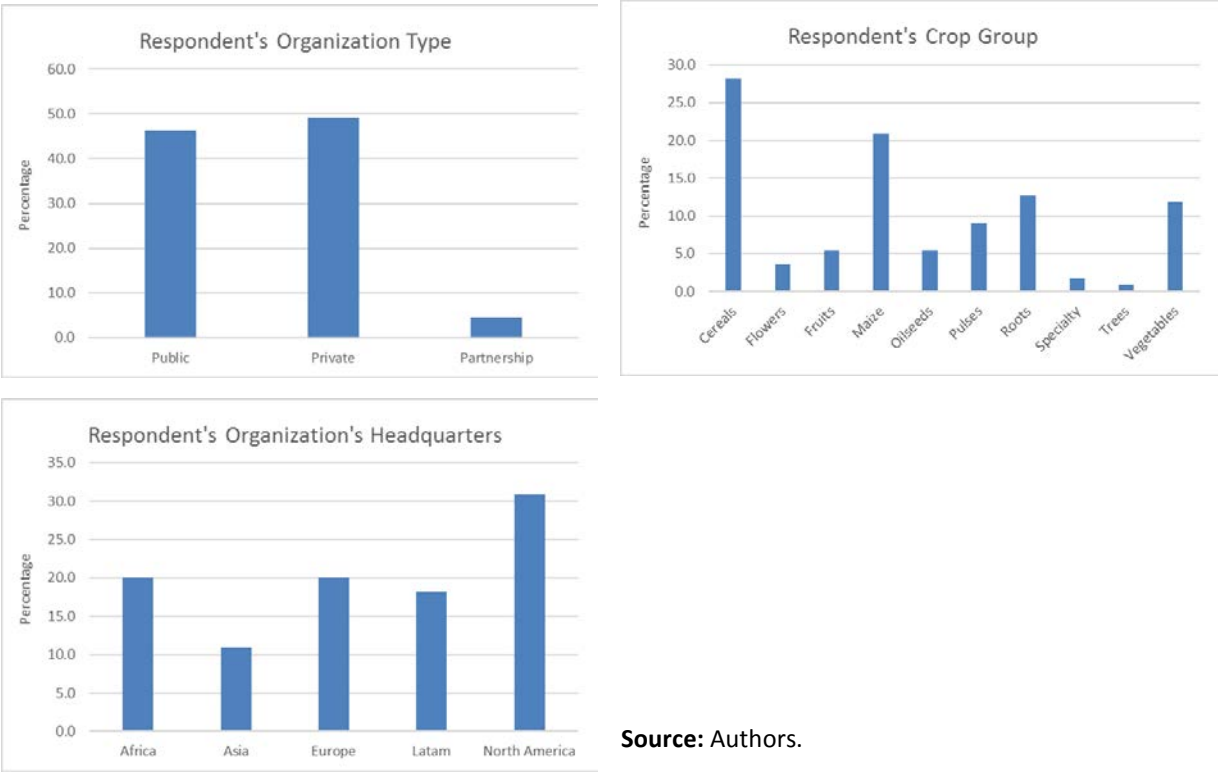
The authors drew on their knowledge of crop breeding, including setting breeding priorities from market demands, and programmatic concepts of constraints, needs, and opportunities in the public and private sectors.

Sound breeding decisions ought to be based on market understanding. Making such decisions is a complex process that involves many stakeholders. The overarching aim of breeding programs is to deliver genetic gain and increase the speed of delivery of novel, improved varieties or breeds to farmers and all the way to end-users. In this paper, this overall process has been split into four distinct and successive, but interrelated, phases:

- Definition of and prioritization among market segments
- From market demands to product profile(s)
- From product profile to breeding priorities
- From breeding priorities to breeding decisions.

The first phase is the subject of a companion paper for the same Initiative and will therefore not be discussed here at length. For the remaining three phases, processes and outputs will be presented and discussed. The aim is to provide readers with all the elements necessary to develop their own best practices given their own specific contexts.

Figure 1. Demographics of survey respondents.



Source: Authors.

1.2 THE NEED FOR BREEDING OBJECTIVES AND PRIORITIES

Breeding often deals with the development of new plant varieties or animal breeds expected to be grown or raised and contribute to increasing agricultural productivity and/or sustainability. (Other purposes such as pleasure and hobbies are also addressed by flower and animal breeding, for instance.) These varieties or breeds are expected to create value, usually for their immediate customer—the grower (crop or animal)—but also for other value chain actors. Crop varieties or animal breeds are also often developed with processor and end-use consumer needs or preferences in mind.

Examples include vegetables, often bred for improved shelf-life, taste, or health properties; specialty crops such as maize or cassava bred for transformation into ethanol; or dairy animals, where milk composition is often a major selection criterion.

In summary, breeding is expected to create value, along specific value-creation axes, commonly referred to as the value chain. The value created by breeding has been unequivocally demonstrated. In a number of cereals, for instance, approximately 50% of yield increases could be traced back to improved varieties.

Thus, breeding is undoubtedly objective driven, aimed at creating value that is often measurable in monetary terms (crop or animal productivity, crop or animal resistance to diseases) or not (end-consumer health, end-consumer product experience). From the observation that breeding is objective driven arises the need to define (and prioritize) breeding objectives.

1.3 THE NEED TO FORMALIZE BREEDING OBJECTIVES AND PRIORITIES

Ancestral growers in Europe used to grow crops or raise animals, and process and consume the products harvested or collected from these crops or animals. Many smallholder farmers in the global South still do. When growing crops or raising animals, farmers typically visually identify what they think to be their best plants or animals, and preferentially use these over others to obtain seed for the next season's planting, or constitute their next generation's herd. They were (and are) also probably very proactive when stumbling upon an attribute that they did not anticipate the need for yet recognized its value. Growers were thus sometimes breeders, processors, and end-use consumers, albeit not formally labeled as such.

Because they grow crops or raise animals, and process and consume their products, such growers know their needs or preferences very well. They breed accordingly, most likely with these needs or preferences as their somewhat unconscious breeding objectives. So, despite the lack of formalization of their grower, processor, or end-user needs or preferences, such growers very much act upon these needs or preferences when selecting plants or animals.

Many contemporary growers are no longer breeders; likewise, contemporary breeders are not growers (although a few may be). As in most aspects of life, modernity has brought about division of work, specialization of individuals and organizations, greater accountability, and often increased complexity.

Producing crops or raising animals is now typically the role and responsibility of growers. Similarly, breeding new crop varieties or animal breeds is now largely, although not solely, the role and responsibility of plant or animal breeders and dedicated institutions. This separation of work has created the need for growers (and processors and end-consumers) to express their needs and

preferences in a way that can be heard and understood by breeders and their institutions or companies. Reciprocally, this separation of work has created the need for breeders to collect needs and preferences from all their customers and eventually translate them into breeding decisions.

Separation of work has created the need to communicate grower, processor, and consumer needs and preferences to breeders. As well, that those needs are being met needs to be verified throughout the crop variety or animal breed development process, or at least at critical intervals that can provide insights into the breeding cycle. This communication process also always includes elements of foresight and predictions of future changes of needs and demands. The breeding process is slow, and significant changes may take 10–15 years to become useable by growers.

Setting breeding objectives and priorities can be defined as the process by which needs are formulated into actionable breeding steps or decisions. When asked about whether their organizations followed a formal process to define breeding objectives and priorities, 90% of the survey respondents answered positively. This percentage was slightly, yet not significantly, higher for respondents from the private sector (92%) than for those from the public sector (87%).

2. DEFINITION OF TERMS

2.1 BREEDING CUSTOMERS

- Growers: Individuals or organizations who grow plants or raise animals with the aim of harvesting or collecting one or more specific products (grain, whole plant, tubers, milk, meat, wool, etc.).
- Product chain actors or processors: Individuals or organizations that take products harvested or collected by growers, possibly transform them (although not necessarily), and provide them to end-use consumers. In some cases, growers can also be product chain actors.
- End-use consumers or end-consumers: Individuals or organizations that use products for food, feed, energy, or other purposes. In some cases, growers can also be end-use consumers.

2.2 MARKETS AND PRODUCTS

- Market segment: A geographic area or a group of people having a relatively homogeneous demand for a commodity (for the purpose of this paper, crop varieties or animal breeds). For instance, a market segment may be corn growers planting very early-maturing corn for ethanol in the US Midwest. Another market segment may be corn growers planting late-maturing corn for ethanol in the southern United States. Yet another market segment may be growers growing rice for home consumption along the Senegal River. The population of users who make up a market segment may either all be located in a single agro-ecology or distributed across several different agro-ecologies. The extent to which an agro-ecology and a market segment coincide will depend on the extent to which user demands (preferences) for a breeding product are determined by climate, soils, land use, and other constraints as distinct from other considerations (e.g., suitability for a certain type of processing, price, color, appearance, storability, etc.).
- Product profile: A set of targeted attributes that a new plant variety or animal breed is expected to meet in order to be successfully released onto a market segment. Attributes must be understood as traits with a specific level, this level being defined either in absolute or relative terms. For instance, a product profile may list grain yield (11 t/ha or more; or 15% over variety V1 across a range of soil fertility conditions), tolerance to downy mildew (same as or better than variety V2), or total milk fat content (no less than breed B3).
- Breeding priorities: Set of attributes/criteria to be considered during the breeding process, in view of existing knowledge, experience, and germplasm. For each attribute, a quantified description of the desired outcome (maximization or minimization, specific level—to be reached and maintained, opportunity) and a rank or priority are assigned (the lowest rank being assigned to the trait where the most effort will be put to deliver the desired outcome).

2.3 BREEDING PROCESS

- Breeding decisions: Decisions taken by breeders at different time points (stages) of the breeding process to advance or discard a selection unit (plant, animal, progeny, progenitor, clone, experimental variety or breed) and guided by the breeding priorities, using specific decision-making tools (e.g., assessments of the targeted traits, estimates of breeding value, presence/absence of specific markers, selection indices, combining ability). Breeding decisions encompass decisions made from choosing parents or germplasm to obtain genetic

diversity, all the way to release of a finished variety or breed. Breeding decisions are about what is being selected for and when.

- Breeding strategy: Detailed plan of action based on the breeding priorities for achieving the targeted product to meet the expectations of the identified profile. This includes breeding decisions as well as all elements relative to their implementation: methods, tools, technologies, resources, and others. Breeding strategy is about what is selected for, when, how, and why.

3. DEFINITION OF AND PRIORITIZATION AMONG MARKET SEGMENTS

Particularly for crops, breeding objectives and priorities are often set in relation to geography instead of demography, even in the case of breeding programs serving resource-poor farmers, traders, processors, and consumers. Information about production constraints of a crop in an area are always considered (e.g., temperature, rainfall, soil type). Orr et al. (2018), in a companion paper for the GBI, argue that these production constraints are important, but that understanding socioeconomic constraints and demand remains vital for adoption. Accordingly, breeding objectives and priorities need to be set with a combination of geographic and social targeting that together provides a profile of a given customer population, its variety/breed preferences, and end-uses of the crop or animal breed in question, within a geographic production domain. They further argue that demographic characteristics such as differences in resource ownership or access, gender, age, and ethnicity need to be considered when breeding objectives and priorities are set, as these are highly correlated with social drivers of variety/breed preferences, such as ability to purchase farm inputs or to market surpluses. Finally, they suggest that gender and social targeting for resource-poor farmers/sellers/processors requires a marketing approach. They show a Segmenting-Targeting-Positioning (STP) framework from consumer marketing that can be adapted for gender and social targeting in breeding programs.

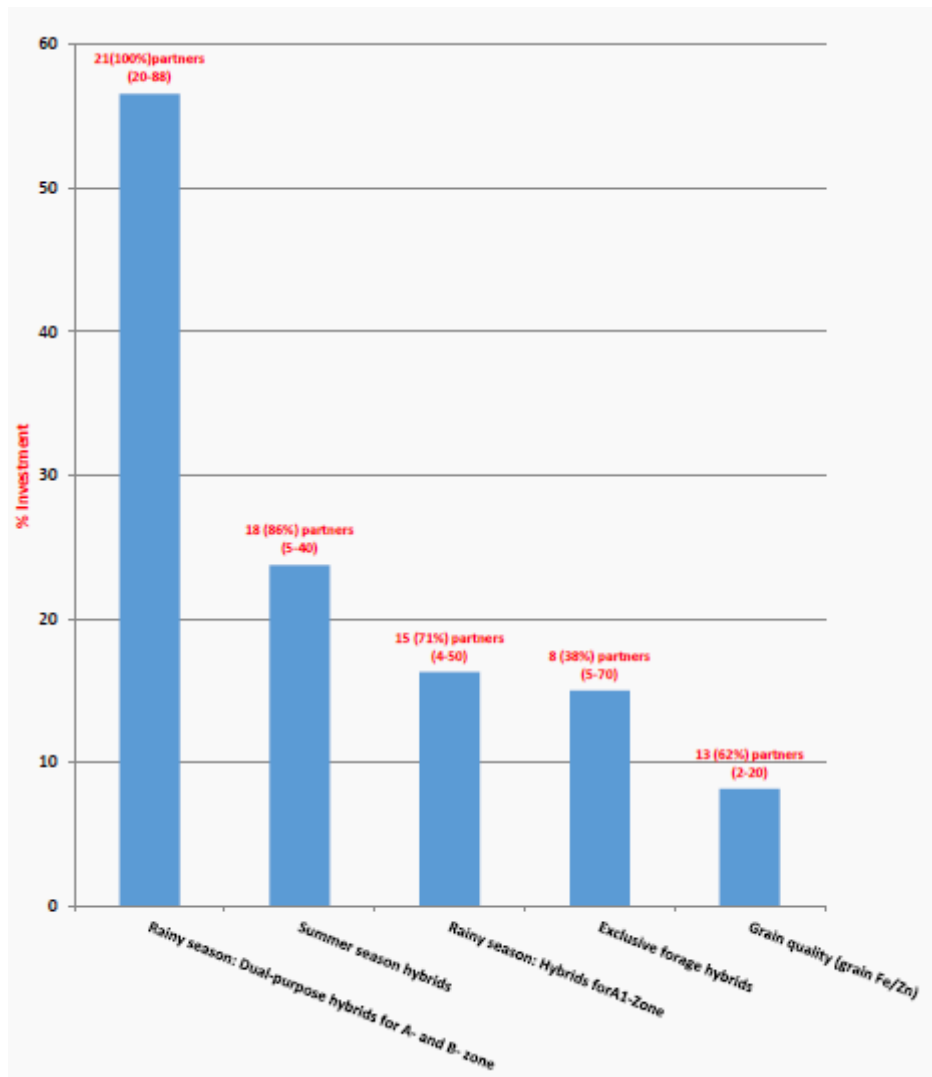
Orr et al. (ibid.) extend their arguments beyond gender and social targeting, considering gender and social groups as stakeholders, and suggest deploying the STP framework among all breeding stakeholders in a specific region. The framework provides a systematic way for breeding programs to target specific market segments in terms of their size, stability, and relevance.

Currently, information about these customers and their preferences in most developing country contexts is usually based on small-scale studies, making it difficult to define breeding objectives or priorities at the national or regional level. In consequence, the newly developed products may not meet customers' needs, resulting in low adoption. Consumer marketing uses large databases to target consumer segments Orr et al. (ibid.), inventory large open-access, socioeconomic and biophysical datasets, and show how these can be used to identify a minimum dataset of biophysical and socioeconomic variables that can then be layered for product profiling and stakeholder (including gender and social) targeting at the national or supra-national levels. This results in "customer profiles" that complement or inform the "product profile" used by breeding programs. These customer profiles are used to define the market segments for which relative priorities and specific product profiles can be developed.

One interesting example of prioritization among market segments comes from ICRISAT's pearl millet hybrid parents research consortium (PMHPRC). Members of the consortium are public or private breeding entities that use lines developed by ICRISAT to develop and commercialize pearl millet hybrids.

Members of the consortium are consulted on a regular basis. They were asked to provide information about their organization's spending or investment in each of five pearl millet market segments. These data, once consolidated, provided a classification of the different markets based on the perspectives of consortium stakeholders (Figure 2).

Figure 2. Market segment prioritization based on percent investment of PMHPRC members in five different pearl millet market segments.



Source: Reproduced from Jayalekha et al. (2016).

4. FROM MARKET DEMANDS TO PRODUCT PROFILE(S)

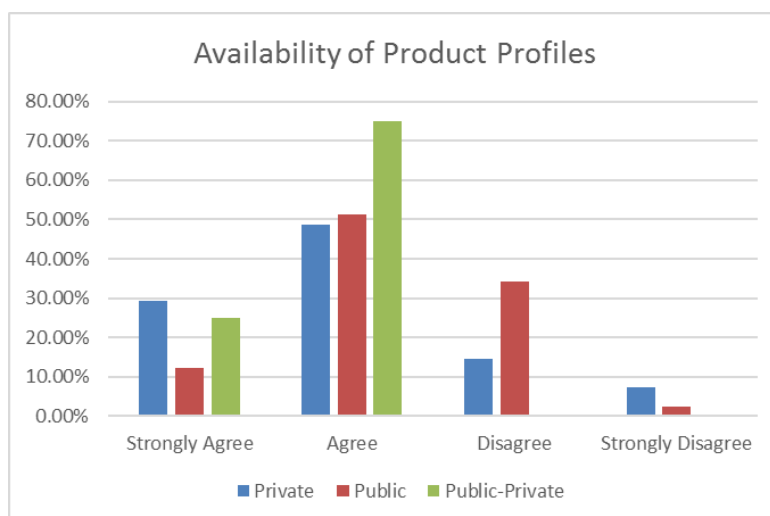
Once market segments have been identified and some have been selected as targets into which to deliver improved products (crop varieties or animal breeds), it is necessary to describe these markets in terms of needs. Market studies typically allow the collection of demand from different market actors: growers, product chain, end-consumers. Market demands typically include customer demands that be needs and/or preferences. They might not include all attributes required for a product to be released successfully in a specific target market, nor might they include hidden or latent needs: these issues or problems that customers have but have not yet realized. For instance, growers may not mention resistance to a specific disease as a necessary attribute, especially if that specific disease has caused only minor, hardly detectable losses in the recent past, or if they are not aware of the impact of a disease on performance. Breeders or pathologists, however, will know that this specific disease represents a significant threat to the crop or animal and will request that it be added to the list of attributes to be bred for. Similarly, attributes relative to seed production (most important for hybrids, where production of the seed may be difficult, or for crops where seed is not the harvested commodity such as bulbs, roots, or tubers) will typically not appear on the lists of any market's customer preferences. Yet these might be critical to the success of a crop variety, making it economically viable or not.

Translating market demand or customer preferences into one or more product profiles therefore requires collecting input from all possible stakeholders, beyond customers only. It also involves establishing priorities among all demands/needs, to distinguish between critical and noncritical ones. It further requires that clear product profiles be developed in a way that can be taken up by breeding organizations to be translated into the relevant breeding priorities. Finally, product profiles must be reviewed often enough to remain relevant and aligned with changes in market and or demand.

As indicated above, translation of market demand can result in one or more product profiles. There may be situations where demands within a market segment are quite distinct or even antagonistic, making it difficult (or impossible) to fulfill these demands with a single product. Examples include situations of dual-purpose crops (where, for instance, green whole plant or dry grain is harvested), or climatically highly unstable and unpredictable environments (where two or more varieties allow these environmental risks to be mitigated). In such situations market demands would lead to the development of two or more different product profiles, and two or more varieties to address the diverse sets of needs/opportunities identified.

Results from the global survey suggest that a large majority of private breeding programs rely to some extent on product profiles, whereas only somewhat more than half of public sector programs do so (Figure 3). The proportion of organizations that rely systematically on product profiles is, however, much smaller, with just over 20% of private programs and 10% of public programs. A significant percentage of breeding organizations recognizes not using product profiles to drive their breeding efforts. In addition, and as will be seen below through the examples, different organizations understand product profiles in different ways, to the point that certain product profiles may not be formal enough to ensure subsequent relevant definition of breeding priorities.

Figure 3. Proportion of breeding organizations that use product profiles to describe their target markets' needs for breeding purposes, according to survey responses.



Source: Authors.

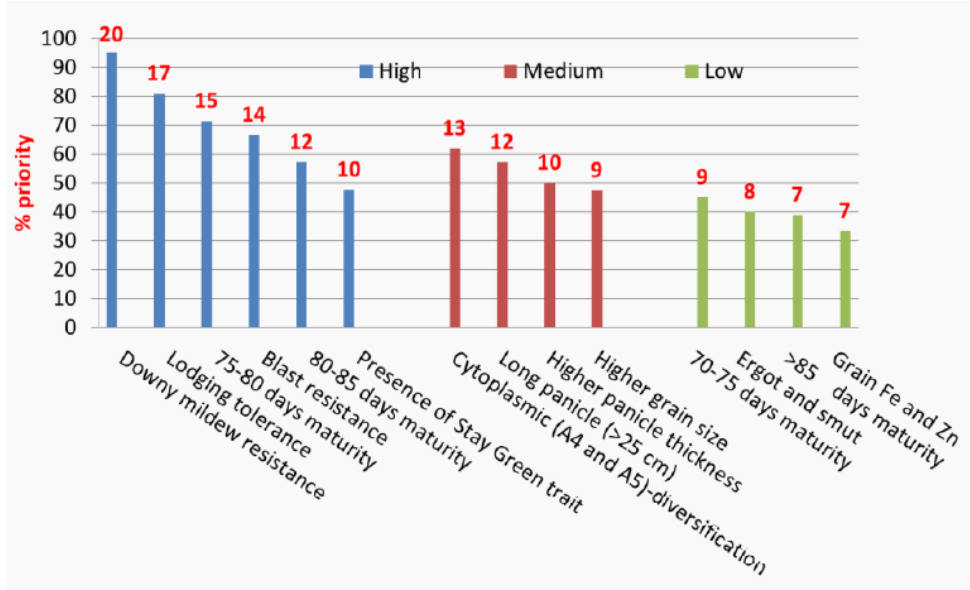
4.1 PEARL MILLET IN INDIA

A first example of how product profiles can be developed is that of ICRISAT's PMHPRC. One of ICRISAT's roles in the PMHPRC is to develop parents of hybrid varieties. These parents are then taken up by public or private companies' members of the consortium who, in turn, develop and commercialize hybrid varieties.

Stakeholders engaged in the consortium, mostly senior breeders, are consulted periodically and asked to provide input that serves to identify breeding priorities, both in the short and long terms. Stakeholders provide input on traits of importance for their respective organizations and for each of five previously identified market segments, based on that organization's strategy, vision, or needs.

Such stakeholder consultations, once consolidated, resulted in short- and long-term prioritized lists of traits demanded by the markets that the PMHPRC serves. These compilations of traits and trait specifications to be met constitute product profiles. Figure 4 shows an example of a short-term product profile; Figure 5 displays an example of a long-term product profile. For the short-term product profile, traits are allocated to one of three priority categories—high, medium, or low—with an additional ranking within each priority level.

Figure 4. Short-term product profile for pearl millet hybrids for PMHPRC’s market segment defined as “rainy season dual-purpose hybrids for A and B zones.”

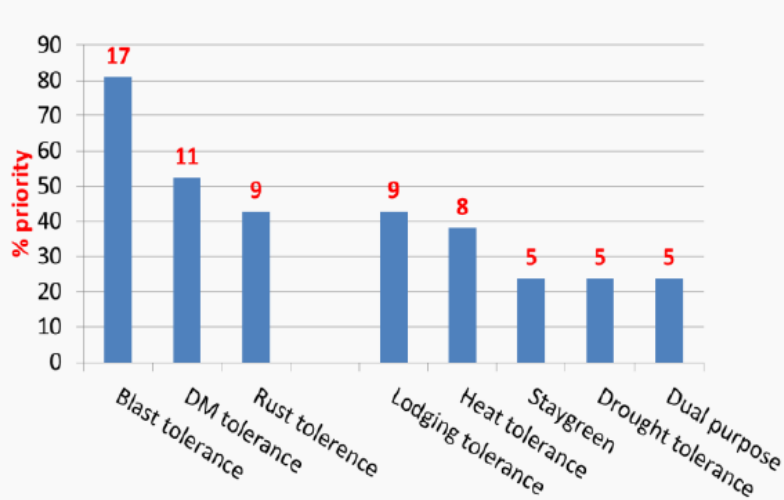


Source: Reproduced from Jayalekha et al. (2016).

Notable differences could be seen between short- and long-term priorities. Rust resistance, for instance, was classified as moderate to low priority in market segments where it was listed as a desired but not essential trait (and not listed in other segments) among short-term priorities. However, it moved up to the second priority when long-term priorities were considered.

This example constitutes a practical example of how product profiles can be developed. It has been working well for the PMHPRC as demonstrated from the feedback provided by stakeholders to ICRISAT. Because the number of stakeholders is limited, the process is simple and easy to put in place. One potential weakness, though, is linked to this small stakeholder base that may or may not adequately represent all market demands. It might be advisable in this case to periodically consult with a broader stakeholder base than only PMHPRC members.

Figure 5. Long-term product profile for pearl millet hybrids for ICRISAT’s PMHPRC, consolidated across all market segments.



Source: Reproduced from Jayalekha et al. (2016).

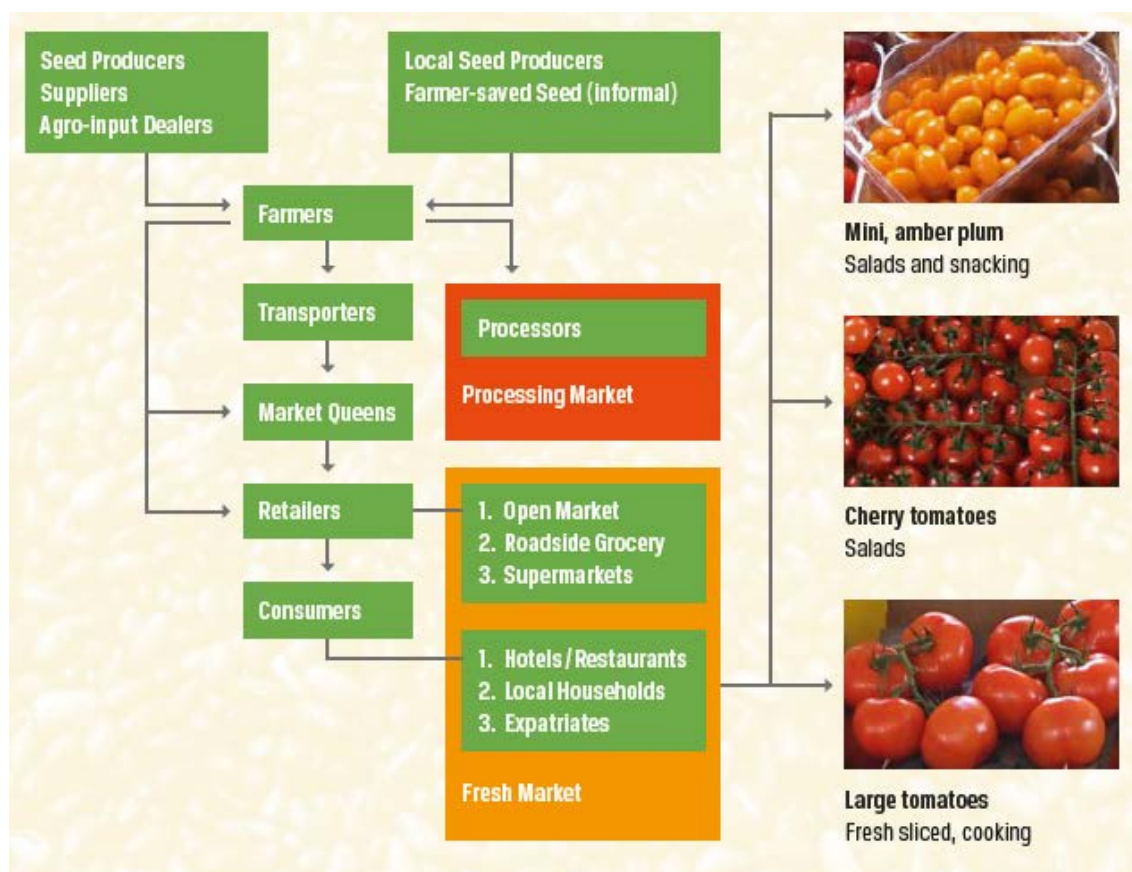
4.2 TOMATO IN GHANA

Tomato is a very important vegetable crop for Ghana. Breeding was, however, largely discontinued for a number of years, except for that conducted by farmers who selected materials in their fields and developed a few commercially important lines.

A recent initiative has been attempting to relaunch public tomato breeding in Ghana. The first step in that endeavor was to identify and characterize tomato market segments and value chains. The result showed several clearly distinct market segments with processing tomatoes on one side, and fresh tomatoes on the other side. The fresh tomato market was further subdivided into large, cherry, and mini, amber plum tomatoes.

Value chain actors were subsequently identified as actors to be consulted to understand market needs. Those considered in a very broad sense included seed producers, farmers, retailers, and consumers (Figure 6).

Figure 6. Tomato market segments and value chains in Ghana.



Source: Reproduced from Danquah et al. (no date)

A workshop was first organized, followed by the establishment of a consortium comprising representatives of all value chain actors plus local regulators. The output of this workshop and the continued work of the consortium are being used as input toward the drafting and updating of product profiles for tomato varieties in Ghana.

Valuable output has already been generated from stakeholder consultations. Tomato yellow leaf curl virus (TYLCV) resistance, for instance, has been identified as the most important trait to breed for across all market segments, with short-term objectives. The shared understanding of the importance of TYLCV resistance has dictated that strong selection pressure be applied for TYLCV resistance throughout the breeding programs, as well as the launch of research projects aimed, for instance, at developing diagnostic markers that will have the power to increase the efficiency of TYLCV resistance screening.

Heat tolerance, too, has been identified as an important trait to breed for; yet for the longer term, as it is a desirable attribute of adaptation to climate change.

To date, product profiles are still being developed before they are provided to public breeding programs. So, although it is too early to assess how well product profiles correspond to market demands, this example is strong in terms of the process for identification and consultation of stakeholders to be involved in the development of the product profiles.

4.3 POTATO FOR SMALLHOLDER FARMERS GLOBALLY

Another example describes the identification and relative prioritization of improvement areas for the CGIAR Research Program on Roots, Tubers and Banana (RTB). This example differs from the two previous ones in that it not only considers improvements that can be brought about by breeding, but all areas of improvement together as well.

The approach started with a global survey carried out in 2012 and 2013 on constraints to the production of each RTB crop (i.e., cassava, banana, yam, potato, and sweetpotato) and associated research options to alleviate them. This exercise was led by agricultural economists specialized in impact assessment. Surveys for each crop were sent to stakeholders deemed able to provide expert opinions.

The potato survey provided respondents with a list of 91 research options, organized around the areas of crop improvement, crop and resource management, seed management, genetic resources, value chains, postharvest utilization, and marketing, as well as socioeconomic research and extension. Important features of the data collected included personal and professional information on the respondents in terms of gender and age, disciplinary background, years of experience in potato, respondents' organization, and the country/ region and agro-ecology that each respondent's work addresses. Representation of the public sector community, the private sector, the development community, as well as other stakeholders was sought, providing surveys in multiple languages and encouraging circulation of the invitation in the recipient's networks. For each of the research options, respondents were asked to assign a score from 1 (not important) to 5 (very important), according to their perception of the importance of that option for helping to reduce poverty and improve food security through crop research and capacity development.

Survey data were divided by geographic region (sub-Saharan Africa; Latin America; and Southeast, Southwest, and Central Asia) and agro-ecology (Tropical highlands, Subtropical highlands, Temperate highlands, Mid-elevation tropics, Subtropical lowlands, Temperate lowlands, and other).

The exercise provides rankings among and between types of research and technologies, of which breeding new varieties is only one. Of the top 10 research options ranked, 5 were breeding objectives (Table 1).

Table 1. Highest ranked options for potato research according to a targeted survey of expert opinions.

	All regions		Latin America	SSA	ESEA	SWCA	CGIAR	Male	Female
	Mean score	s.e. (mean)	Mean score	Mean score	Mean score	Mean score	Mean score	Mean score	Mean score
Late blight control and management	4.71	0.04	4.63	4.77	4.85	4.06	4.52	4.68	4.80
Breeding for late blight resistance	4.60	0.05	4.56	4.52	4.76	3.82	4.36	4.57	4.78
Breeding for drought tolerance/water use efficiency	4.51	0.05	4.56	4.34	4.59	4.88	4.70	4.47	4.67
Breeding for earliness	4.49	0.04	4.48	4.66	4.48	4.88	4.78	4.49	4.49
Improving production and distribution of elite planting materials (formal)	4.45	0.05	4.31	4.42	4.67	4.76	3.92	4.42	4.60
Improving soil fertility (micro-nutrients and fertilizer)	4.44	0.04	4.33	4.68	4.53	4.53	4.25	4.42	4.55
Germplasm enhancement and pre-breeding	4.41	0.05	4.42	4.43	4.39	4.69	4.38	4.35	4.64
Breeding for high yield	4.38	0.05	4.13	4.59	4.54	4.83	4.03	4.36	4.44
Improving seed storage	4.34	0.05	4.23	4.56	4.41	4.65	3.88	4.30	4.51
Development of farmer organizations and farmer clusters linked to markets	4.33	0.05	4.46	4.60	4.26	4.06	4.15	4.27	4.51
Improving potato cropping systems	4.32	0.04	4.28	4.46	4.33	4.29	4.41	4.27	4.51
...
Breeding for resistance to mites (LOWEST RANKED)	2.89	0.07	2.93	2.90	2.91	2.67	2.85	2.80	3.23

^a 1 = not important, 2 = low importance, 3 = important, 4 = very important, 5 = most important.

Source: Reproduced from Kleinwechter et al. (2014).

The dataset provided valuable insights. Highest ranking demands, in terms of varietal traits, were shown to include late blight (LB) resistance, drought tolerance/water use efficiency, earliness, and yield. However, since within a region potato is produced in several very distinct bio-physical zones and cropping systems with differential market trends and use preferences, examination of the data would be most valuable when the information would be dissected by both agro-ecology and market segment. Here also, data might be more robust if demand had included the sampling of producers and consumers alongside of the experts.

Based on this and other work, an ex-ante impact assessment of the top and best-supported selected research options was carried out using an economic surplus model. Numbers of households and numbers of poor people expected to benefit from adoption of the technologies were also assessed.

Some of the most highly ranked breeding options (i.e., earliness, virus resistance, and LB resistance), along with several non-breeding options, were included in the economic assessment. The technology-based parameters considered in the impact assessment model included changes in production and productivity and changes in production costs (e.g., labor, seed replacement, fungicide use, etc.) that could be expected due to adoption of the technology. The research and dissemination process-related parameters were the duration of the research phase (i.e., research lag), the number of countries and regions targeted by the research option, the annual costs for research and development, an assumption on the costs of dissemination per unit of area on which the technology is adopted, and the probability of research success. Adoption domains (countries, areas, size of household, number of poor), prices, yield ceilings, and adoption estimates were variously sourced, combining expert opinion on adoption and FAO data on area cropped. Conservative estimates of adoption were used, for example, considering that even if the use of resistant varieties could reduce

fungicide use, farmers generally fail to realize the full benefits of the technology (e.g., they continue to spray against LB as if the varieties were susceptible).

The results of the ex-ante assessment of the selected potato technologies revealed significant differences in terms of net present value (NPV) and internal rate of return on the investments across the different research options.

LB- and virus-resistant varieties had the largest expected net benefits and high rates of return in the high-adoption scenario. Early varieties followed as part of a second group of promising options, with NPVs of economic benefits estimated at about 15% of those of virus-resistant varieties, for example. This is due to the uncertainty in the development of the options—specifically a long research phase duration in the case of earliness—for which highly heritable sources are not in hand and population improvement is required, whereas negative correlations among traits hinder breeding progress. But even considering research investment needs, early varieties showed a rate of return on investment in research similar to those of LB- and virus-resistant varieties.

This ex-ante study is of particular interest because it validates relative priorities (in this case, that LB resistance created more value than earliness) collected through stakeholder surveys. Therefore, the relative priorities of the two traits based on survey responses were aligned with value creation and were adequate in terms of maximizing impact.

4.4 SORGHUM IN MALI

Despite farmers' extensive use and management of varietal diversity, their adoption of newly bred sorghum varieties has been relatively low in Mali and other West African countries. Adoption rates in the 1990s were found to be approximately 20% for varieties derived from reselections within landrace varieties, and only about 5% for the so-called second generation varieties bred for intensified production using more exotic germplasm (Yapi et al. 2000). The better grain quality of landrace-derived varieties for local food preparations was found to be one of the main reasons why farmers adopted them more frequently than second generation varieties. Other reasons included their better adaptation to the farmers' environmental conditions. In fact, low soil fertility was mentioned as one of the major constraints to adoption of new varieties (ibid.).

The sorghum team thus initiated farmer participatory evaluations and assessments to specify farmers' demand for characteristics of future improved sorghum varieties across the Sudan Savanna zone of Mali, using the approach and tools detailed by Christinck et al. (2005). Briefly, these studies indicated that the highest priority was accorded to traits that farmers summarize as "good adaptation to their zone," followed very closely by improved grain yield. These traits need to be associated with white grain color and good grain quality for local preparations, earliness, and drooping, loose panicles with an optimal density of panicle branches. The initial interactions with farmers, based on evaluations of a wide range of available varieties grown in their own fields, indicated that varieties derived from introduced *caudatum* race germplasm only rarely met the minimum adaptation and grain quality criteria. The program thus started more intense evaluations of *guinea* race germplasm as a basic germplasm for a revised breeding program.

From further interactions with farmers during participatory variety evaluation discussions, the criterion "good adaptation to the zone" was understood in more detail. For the Sudan Savanna it included a flowering date within 10 days of the predominant local varieties, good early growth, plant

height tall enough so that grazing cattle cannot feed on the panicles, and competitiveness with early weed growth.

Crop physiology studies revealed that the best way to achieve stable flowering dates across the commonly wide range of sowing dates required that varieties be photoperiod sensitive (Clerget et al. 2007, 2008).

Entomologists and pathologists were working on resistances to the headbug–grain mold complex, as being essential for achieving high yield and acceptable food grain qualities. Resistance and tolerance to Striga, a parasitic weed, were further highlighted as essential for yield stability and adaptation to poor soil fertility conditions.

Cropping system studies, accompanied by soil analyses, clearly showed that fertilizer application to sorghum was very low and that plant available phosphorous, especially in women’s fields (Leiser et al. 2017), was significantly below threshold levels for tropical soils. Cropping system discussions further showed that although sorghum stover was not traded, some farmers were interested in increasing their capacity to feed ruminants, especially draft animals, during the dry season by harvesting and storing dry sorghum stover.

These interactions between farmers and the sorghum breeding team were summarized for a product profile. The profile indicated that grain yield improvements needed to be at least 20% so that farmers can notice it, while maintaining a flowering date of approx. 25 September with a range of sowing dates (from the beginning of June to the end of July); a minimum plant height of 2.5 m with dropping rather lax panicles; glumes that open widely; and white grain with a minimum of discoloration from the glumes, without lodging. Resistance to headbugs and grain molds, as well as Striga, was considered essential. The reselected local variety Tieble (CSM 335) was designated as the control/benchmark for these traits. Discussions about a second product profile, including improvements of stover quality for intake and digestibility by large ruminants, were initiated.

4.5 PRIVATE INDUSTRY-INSPIRED GENERIC CASE

In this section we discuss how prioritized lists of product attributes can be built from market demand. Others, in particular the Syngenta Foundation for Sustainable Agriculture, have been looking at how breeding can be made to align with/focus on demand through what is being called demand-led breeding. These two approaches, which proceed from slightly different angles, are complementary and can be symbiotic.

Demand-led breeding has been defined as customer-focused plant breeding, where input from all customers is being taken into consideration from the beginning onward. In that respect, demand-led breeding is very like participatory plant breeding (PPB) in that (1) customer input impacts the process at the earliest stages and (2) customers include more than only growers (Weltzien et al. 2003; Christinck et al. 2005; Witcombe et al. 2005). However, PPB has focused more often on food security crops, grown for home consumption, with less developed markets (Sperling et al. 2001).

Demand-led plant breeding considers all phases of a plant variety—from its production (seed production), dissemination (seed channel), use for growing another product, and one that will be harvested (agronomics), to transport, conservation, and processing of the harvested product (crop, food, and feed processing), and finally consumption as food, feed, energy, materials, and the like (Table 2).

This approach to customers defines the stakeholder categories and, for each, the types of attributes they may be demanding from plant varieties.

Table 2. Example of stakeholder categories and attributes each may be demanding from plant varieties for a specific market segment.

Consumers		Agronomic Performance	
<ul style="list-style-type: none"> • Taste • Flavor • Form and shape • Color • Texture • Cooking qualities • Shelf or storage-life • Nutritional qualities • Safety 	<ul style="list-style-type: none"> • Yield in range of agro-ecological climates • Yield in nutrient poor soils • Resistance to abiotic stresses – drought, heat, flooding, rain, wind and lodging • Responsiveness to fertilizer or low inputs • Responsiveness to crop protection inputs • Resistance to priority list of pests and disease, genetic diversity and resilience • Water usage • Performance to crop rotation • Germination time and length of growth cycle • Plant architecture and space • Ease of harvesting • Postharvest storage life • Genetic diversity and durability to varying biotic and abiotic stresses • Quality and yield of plant biomass as animal fodder 		
Crop and food processing		Seed production	
<ul style="list-style-type: none"> • Resilience to transport • Suitability as raw materials • Speed of process • Quality of end consumer product • Storage of end product 	<ul style="list-style-type: none"> • Fertility • Germination rates • Propagation and production • Resistance to seed borne viruses, bacteria and fungi • Costs of seed production • Speed of scaling 		
Seed channel			
<ul style="list-style-type: none"> • Defined benefits and differentiation from existing varieties • Pricing and profitability • Freedom to operate – access to germplasm and royalty payments • Intellectual property and plant protection rights • Certification systems • Seed production systems operational or capacity building required • Costs of distribution 			

Source: Reproduced from Anthony (2013).

Stakeholders, once identified, are asked to express their demands as a list of attributes. It is also recommended that, for each attribute, stakeholders describe their desired level with respect to that of a known plant variety. The availability of such a benchmark will provide a starting point for discussing the relevance of desired levels. It will also tremendously facilitate the relative valuation step described below.

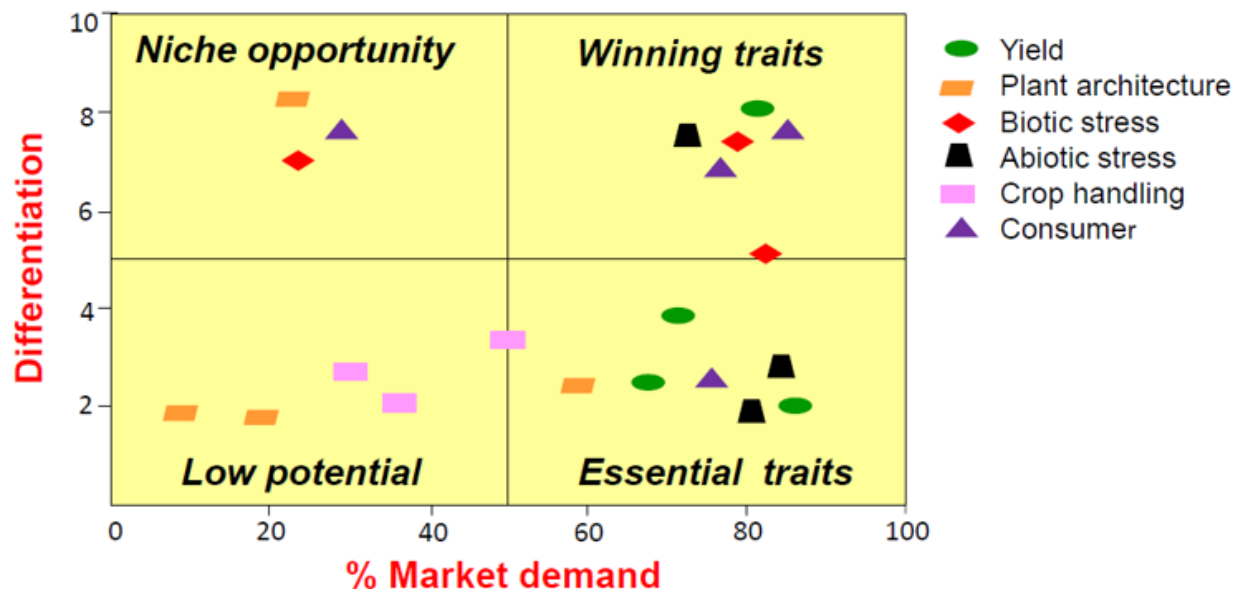
It is further suggested that these attributes be evaluated along two dimensions:

- Importance to customers or market demand of the attribute: how likely are they to request/purchase the variety, assuming it has the specific attribute (on a scale from 1 = not likely to 10 = very likely)?
- Differentiation or market value of the attribute: what size of benefit would the attribute deliver, or what premium would the customer be willing to pay to access varieties with this attribute (from 1 = very small to 10 = very large)?

The consolidation of input from all stakeholders allows all attributes to be positioned onto a four-tiered graph out of which relative priorities can be extracted (Figure 7):

- Low demand and low value (lower left quadrant) contains traits with low potential
- High demand and low value (lower right quadrant) contains essential, must-have traits
- Low demand and high value (upper left quadrant) contains niche traits
- High demand and high value (upper right quadrant) contains winning traits.

Figure 7. Classification of product profile traits according to perceived market demand and differentiation value.



Source: Reproduced from Anthony (2015).

Winning traits should obviously have high priorities in product profiles. So should “must-have” traits. Similarly, low potential traits should most likely have low priorities in product profiles.

Niche traits, however, are less easy to deal with. They are typically traits that are desired by some stakeholders but not others, or even desired by some but rejected by others. Giving a higher priority to some than to others will mean that variety design tends to favor some stakeholders over others. Such decisions need to be well thought-out to ensure final successful adoption of improved varieties by markets and minimize the potential for exclusion of important stakeholder groups from the benefits of production. In a way, decisions to be made about how to prioritize niche traits are a powerful tool to adjust the balance of power among different stakeholders.

4.6 PROCESS PROPOSAL

Establishing product profiles for markets targeted by breeding is the first in a series of steps that will lead to the definition of breeding priorities and breeding decisions.

Several learnings can be drawn from the above examples in terms of critical elements that need attention when analyzing market demands and needs, to formulate corresponding product profiles:

- Consult with all relevant stakeholders, both upstream and downstream of variety/breed adoption, (i.e., more than “just” those who define market demands)
- Include all necessary attributes (traits) in the product profile, and ensure that they are clearly and unequivocally defined
- Rank or classify attributes from a market demand/need perspective
- Express market demands/needs for all traits either in absolute terms or relative to levels of known references (varieties/breeds).

All the above examples show processes that aim at developing product profiles from market demands and needs. These real-life examples do not necessarily fully comply with the four critical elements outlined above, yet all present valuable features that can be used as inspiration for other situations.

ICRISAT’s Indian pearl millet consortium example relies mostly on relatively few experts supposed to know and represent all stakeholders, rather than on many different stakeholders. It proposes a very clear and seemingly reasonable process to rank traits based on expert (stakeholder representatives in this case) input.

The Ghanaian tomato example, contrastingly, proceeds from a large stakeholder consultation; however, stakeholders do not seem to be involved in the consolidation of the input they provided. No information is provided as to whether they would be involved in the validation of the consolidation and prioritization.

The potato example, like the Ghanaian tomato example, proceeds from a large stakeholder consultation that involved large surveys. Survey data are used not only to qualify but also to quantify demand and needs, so that consolidation of the demand and needs also proceeds fully from stakeholder consultation. Through ex-ante assessment, the economic value was estimated for the benefits to accrue to end-users from varieties that carry the traits listed.

The Malian sorghum example is most similar to the potato example in that demand, needs, and their consolidation are based on direct stakeholder consultation. Particular to this example is that stakeholders are consulted through participatory breeding. Information on demand and needs is generated from stakeholders’ reaction to existing varieties or experimental material in a sort of feedback mechanism, rather than the drafting of product profiles from a blank sheet.

Finally, the example inspired by the private sector is similar to other examples where stakeholders are directly involved in the process. Its main difference with these is the level of formality in the process—that is, every step of the process seems to be defined precisely from input to output. Although the value of such an approach might be indisputable, it might be overly formal for breeding programs of moderate size and limited actors. The real value of this approach for those programs is thus probably more as an inspiration than a case for a direct transposition and implementation.

Eventually, the product profile development process results in an output that may be a document of the type shown in Figure 10 (other formats such as balance scorecards, described elsewhere, would also be appropriate). This document lists the sum of attributes collected through consultation with all stakeholders.

Each trait may be allocated to one or more categories. Categories somehow represent stakeholder groups: “Agronomy” and “Labor” are mostly grower traits; “Processing” is a chain actor trait; “Consumer” an end-use consumer trait; and “Seed supply” a seed production and distribution trait. Allocating traits to categories allows us to describe and drive how priorities are being distributed across categories (evenly or not, reflecting willingness to deliver improvement to all categories vs. orientation more toward one or the other).

A performance or level reference should ideally also be provided for each trait. This could be an absolute level (which is most practical for traits for which expression is environment independent and that can be measured unequivocally on a scale understood by all), or a relative level using a known and accessible genetic material as a reference.

Finally, each trait can be given a priority level. Product profiles generally define trait priorities using three levels—sometimes five but rarely more. This is confirmed by the survey that was run and the examples presented in this paper. When three levels are used as shown in Table 3, they are usually 1 = high/must-have/required; 2 = medium/important/needed; and 3 = low/nice-to-have/accessory. Trait priority levels may also be aligned with their economic levels (the same as those commonly used in selection indices).

Table 3. Option for generic product profile template (example).

Trait	Trait Category	Reference*	Market Priority Level
Grain yield	Agronomy	Check 1 +5%	1
Stover yield	Agronomy	Check 5	1
Early vigor	Agronomy / Labor	Check 1	2
Tillering	Agronomy	Check 6	2
Lodging resistance	Agronomy	<20%	2
Plant height	Labor	90–110 cm	2
Maturity	Agronomy	Early	3
Thousand kernel weight	Agronomy/seed supply	40–50 g	3
Seed size	Seed supply/processing	Check 3	2
Milling yield	Processing	Check 2 + 5%	1
Texture	Processing/consumer	Check 6	3
Protein content	Consumer	>7.5%	1
Oil content	Consumer	5–8%	3
Fiber content	Consumer	>= Check 3	2
Mildew resistance	Agronomy	Resistant	1
Virus resistance	Agronomy	>= Check4	1
Smut resistance	Agronomy	Intermediate	3
Heat tolerance	Agronomy	Intermediate	2
Drought tolerance	Agronomy	Check 5	2
Al tolerance	Agronomy	Moderate	3

*Reference expressed as a variety name without any other indication indicates that the desired trait level is that of that variety.

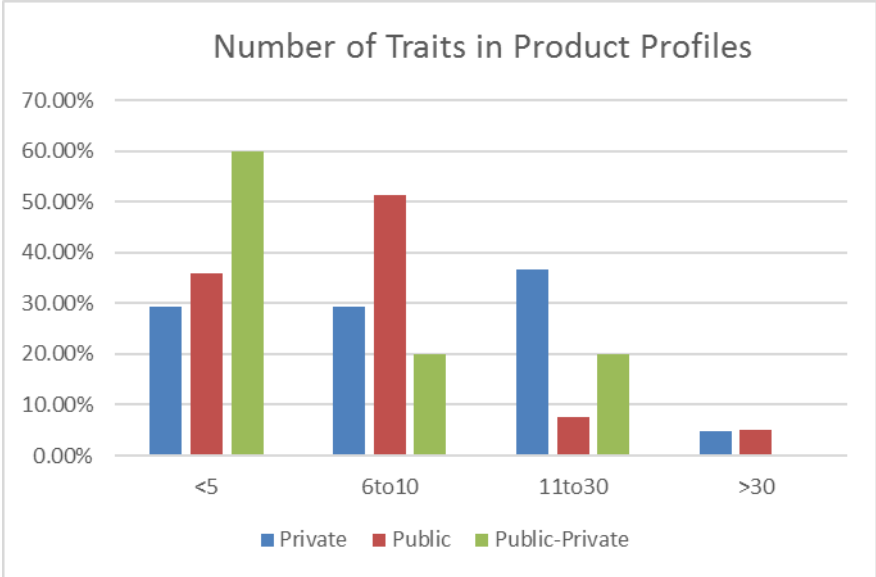
Source: Authors.

Given the number of stakeholders who should be involved in the development of product profiles, it is expected that such profiles may comprise long lists of traits. Results from the survey, however, show that about 60% of the product profiles in private breeding organizations contain 10 or fewer traits (Figure 8). That number increases to about 80% for both public organizations and public-private partnerships.

Several elements may explain this discrepancy between expectations and observations. First, some of the traits listed in product profiles may be “composite” traits. Nutritional value, for instance, would be an example of such a trait as it cannot be measured directly but as a combination of content in various components (proteins, fibers, vitamins, etc.). Using composite traits in product profiles makes profiles look simpler but fails to precisely describe how products ought to be. It also makes going from trait profiles to breeding priorities more complex and error-prone.

Second, traits may have been omitted from the trait profile. This can happen if some stakeholders were not consulted, or for traits that do not need to be improved. It may also come from inconsistent interpretation of “product profile” (i.e., some respondents may have indicated their breeding priorities which are a subset of the traits in the profile, even though definitions were provided with the survey). Omitting traits from product profiles leads to omitting them from all subsequent steps, including breeding priorities and breeding decisions. The evolution of traits omitted from the product profile through breeding is therefore (and consequently) random and often leads to the loss of favorable attributes that segregate in breeding material.

Figure 8. Numbers of traits in products profiles, according to survey responses.



Source: Authors.

5. FROM PRODUCT PROFILE TO BREEDING PRIORITIES

Now that demand, not only from the market but also from all who participate in making the release of a new variety or breed successful, has been expressed very clearly as a prioritized list of traits upon which breeding is being asked to deliver (i.e., the product profile), a response from breeding is needed. This response is basically what breeding priorities should be: a prioritized list of traits for which breeding commits to deliver significant (measurable) gains through variety/breed development.

When responding as breeders to the demand formulated in a product profile, several factors need to be considered:

- Technical feasibility of the demand. It should impact breeding priority upwards if high and downwards if low. If, for example, the product profile requires resistance to a specific disease for which no genetic resistance has been identified or engineered despite extensive research, the ability to successfully breed for that trait is low (or null). The trait should therefore be given a low breeding priority for an active product profile. Giving it a high breeding priority would most likely result in devoting significant efforts and resources to a breeding endeavor that would be meant to fail within time and budget available for the product, and prevent gain from being achieved for other traits. Another example would be a situation where there is a negative genetic correlation between two traits, resulting in gain on either trait to occur at the expense of the other trait. Unless the correlation can be somewhat broken, giving high breeding priorities to both traits would likely result in wasted resources and no improvement for one or both traits. A wise approach would be to select one trait to be improved, at the expense of the other, or aim for an equilibrium without further changes for any trait.

Such situations would probably warrant trait-specific research to be conducted prior to breeding for such traits in a multi-trait context. Approaches to integrate trait research into the framework of product profiles and breeding priorities are discussed in section 7.

- Economic feasibility of the demand. Somewhat similar to technical feasibility, giving a high priority to a trait that would require a large investment to be bred would prevent gain for other traits from being achieved. If the amount of resources needed to deliver any gain on a specific trait is very large compared with the total amount of resources devoted on an annual basis to the corresponding breeding program(s), the trait could almost be considered as economically unfeasible. On the other hand, traits that are very feasible, resource-wise, should not necessarily see their breeding priority elevated compared with product profile priority. An objective that is easy and inexpensive to achieve is not necessarily worth pursuing. Pursuing too many such objectives may eventually result in a significant cost that may prevent the pursuit of more important and costlier objectives.
- Level of trait in breeding germplasm with respect to the demand. As indicated earlier, product profiles should include reference levels for all traits. Such reference levels provide an unambiguous description of the expected outcome of breeding for each trait. Besides technical and resource feasibility described above, how easy or difficult it will be to reach target performance levels will depend on the distance between the current performance levels of breeding germplasm and the target performance levels. One extreme case would be when current performance level of breeding germplasm is already at target performance. For such traits, no improvement is needed to be delivered through breeding, yet no loss is to be

experienced either. Breeding efforts needed for such traits are therefore minimal (simply not losing) unless strongly negatively correlated to a trait under strong selection pressure, and breeding priorities can be set to low priorities. The above holds true irrespective of the product profile priority of the trait(s). Such situations can be observed in the case of resistances to diseases for instance. Let us assume that a resistance is a must-have trait and that all material in a specific germplasm group carries this resistance. For some crops, any new breeding population and progeny generated from within this germplasm group will homogeneously carry the resistance. This means that no selection for the resistance will ever be necessary (which should not prevent from testing for fortuitous loss of the resistance), and its breeding priority could be set to the lowest priority of all traits in that breeding priority list. When the cost of maintenance of such traits must be considered, however, such as in the case of non-hybrid heterozygous crops and animals, the priority might be medium.

- Timing of the response. Variety/breed development processes typically last multiple years. When new attributes are demanded and formalized through product profiles, depending on the performance level of breeding material at different stages of the breeding process, response time may vary greatly. It may be short (less than three years) if material that is already advanced in the breeding process meets requirements. It can also be very long (multiple breeding cycles) if performance level of breeding material is very remote from targets. Consequently, any specific product profile may be met by multiple, termed (short, long) sets of breeding priorities.
- Like product profiles, breeding priorities need to be reviewed and revised periodically. Breeding is an activity that needs enough constancy in order to deliver gains. Market demand, on the other hand, may change frequently, often because of year-to-year variations. The challenge when translating product profiles into breeding priorities is to recognize and address the critical changes in demand while not getting distracted by ephemeral demands—that is, those that might appear on a product profile one year and disappear the following year.

5.1 SHEEP IN AUSTRALIA

Australia's Cooperative Research Centre for Sheep Industry Innovation (Sheep CRC) is an organization that includes Australia's leading sheep industries and was established to deliver innovation in wool, meat, and the sheep that produce them.

Extensive consultation with Sheep CRC's industrial partners and beyond led to the identification of three main innovation axes:

- Making sheep easier to manage
- Meeting increasing consumer expectations for meat and wool
- Increasing the uptake of new technologies by the industry.

These three innovation axes integrate market demands and needs from all market actors: end-use consumers, processors, growers, and breeders. Each axis is made of several traits, all of which were eventually translated into breeding objectives. Sheep CRC defines breeding objectives as “animals you would like to breed that are appropriate for your production system and market.” They further explain that by setting breeding objectives one can identify genetic priorities and plan the selection methods that will allow to reach the goal.

According to Sheep CRC (no date), breeding objectives should target traits for which:

- Improvements can be delivered and measured within the constraints of target environments and production systems
- Improvements will contribute to the development of fit-for purpose products
- Improvements will create most value (and profit)
- Progress is genetically feasible and realistic with respect to time and resources.

It is further noted that the more traits that are included in breeding objectives, the slower the progress for each, although progress against the overall objective can still be high.

Breeding objectives often contain lists of traits without any timeline or level to achieve such as, for example, white, bright, fine wool, with heavy fleece weights on large-framed sheep that are resistant to flystrike.

Based on the above observations, Sheep CRC recommends that breeding objectives include not only the traits of importance, but also the level they should achieve and the time frame in which this will be achieved. Including specific targets for individual traits, and quantitative commitments for delivery in terms of frequency and time frame, the above example would result in the following:

Within 5 years, 80% of ewes at first shearing (11 months) will have:

- Fiber diameter of 17.5–19.5 microns
- Greasy fleece weight above 4.5 kg
- Body weight above 40 kg
- Breech wrinkle: 1–2 score
- Wool color: 1 or 2 score.

Levels are said to facilitate the monitoring of progress toward the objectives. By doing so they allow the identification of where changes need to occur in the breeding and selection process to help achieve the goals.

5.2 SORGHUM IN MALI

This example is part of Example 4.4 presented above in the section “From market demands to product profile(s).” Context information will therefore not be repeated here and can be consulted above if needed.

The main issue the sorghum program had to consider for deriving breeding objectives to meet the targets set with the defined product profile was which type of germplasm to use as a base material. The type of germplasm in question was *caudatum*/kafir race material from sorghum breeding programs around the world (USA, Australia, India), tested in Mali and other West African countries, or local guinea race germplasm from the West Africa region, which had been used by breeders to reselect and purify local varieties but not for targeted improvements of performance. The advantage of the guinea race germplasm was that it was photoperiod sensitive, and had all the required adaptation traits, grain quality traits, and resistances to biotic and abiotic stresses listed; yet no experiences and studies about the options for yield increases existed. The introduced *caudatum* race germplasm had high diversity for yield-related traits, but was photoperiod insensitive and had problems with grain qualities as well as resistances to the listed biotic and abiotic stresses. Insights from genetic resources analyses further showed that the guinea race sorghums tended to be more

resistant to storage pests. These studies also showed a high level of underexplored genetic diversity (Deu et al. 2006).

In view of the many advantages in terms of traits of the guinea race material, and in view of the overall objective to maintain genetic diversity of sorghum in its centers of diversification, ICRISAT's West and Central Africa Sorghum program decided to focus its efforts on options for improving guinea race sorghums for the development of new varieties for the Sudan Savanna of Mali and other countries in West Africa.

The breeding priorities were thus to improve grain yield by at least 20% over the local control variety 'Tieble' while maintaining adaptation, grain quality, and resistance traits. Options for reducing plant height, with respect to the need for lodging resistance, and physiological yield considerations were also included among the breeding priorities.

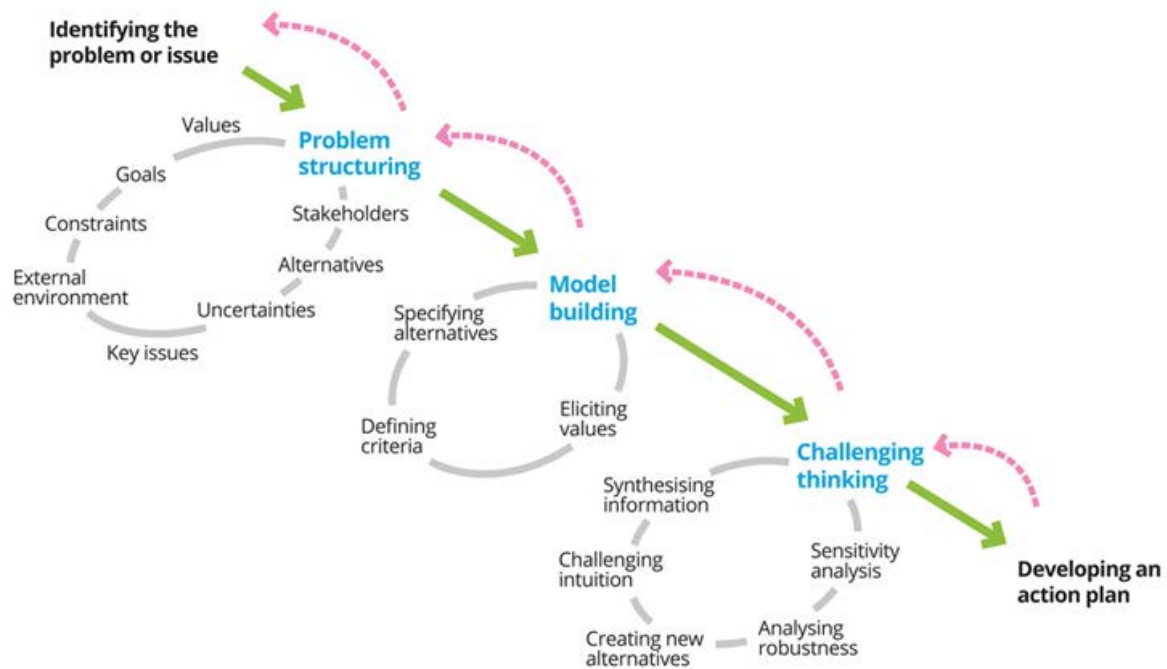
5.3 MULTI-CRITERIA DECISION-MAKING

Multi-Criteria Decision-Making (MCDM) was introduced by V. Belton and T.J. Stewart in the early 2000s as "an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter." MCDM is a very broad concept that has been mobilized in many areas including health, business, agriculture, and government. It is based on the identification and characterization of four components which for setting breeding objectives would be:

1. Traits or combinations thereof (alternatives) to be prioritized or ranked. Different alternatives can be seen as different product proposals (product profiles) to match a specific market context (demand)
2. Criteria by which the traits are evaluated and compared
3. Weights representing the relative importance of the criteria
4. Decisionmakers and other stakeholders, whose preferences are to be represented.

Based on an identified problem or issue, MCDM will lead toward the development of an action plan through three distinct phases: problem structuring, model building, and challenging thinking (Figure 9).

Figure 9. Multiple Criteria Decision-Making process designed by V. Belton and T.J. Stewart.



Source: Reproduced from Belton and Stewart (2002).

MCDM's process (mostly model building and challenging thinking) has been implemented in a commercially available software package, 1000minds. 1000minds has been used very broadly, including in plant and animal breeding. It aims to make MCDM accessible and user-friendly to the largest possible audience, while mobilizing very comprehensive and effective approaches to decision-making.

When developing breeding objectives, 1000minds would be used as follows:

- Definition of criteria: Criteria, for assessing traits, which may include (a) importance of the trait, (b) probability of achieving that trait level, (c) fit with other strategic priorities, and (d) time frame
- Definition of alternatives: Traits or combinations of traits that are important to any or all of the stakeholders
- Decisions: Development of relative weights of criteria, based on consultation of individuals (stakeholders, stakeholder representatives), asking them for their trade-off preferences when considering two alternatives at a time (PAPRIKA method)
- Preference levels: Weights on the criteria, which reflect their relative importance to the stakeholder for the breeding product
- Ranked alternatives: 1000minds-generated ranking of alternatives from first to last according to preference levels and definition of alternatives.

When implementing 1000minds in sheep farming in Ireland, surveys were given to experts and farmers to capture preferences for target traits in defining breeding objectives. Farmers were grouped into two market segments: lowland and hill farming systems. Groups of experts were asked to respond as though they were farmers in each market segment. The part-worth utilities obtained from the surveys were converted into relative economic value terms per unit change in each trait and compared with economic values for the traits obtained from bio-economic models. The traits "value

per lamb at the meat processor” and “lamb survival to slaughter” were the two most important traits for the experts responding as lowland and hill farmers, respectively.

In another 1000minds design experiment, Ikeogu tested the decision-making tool for cassava. Alternatives were developed based on three grower-defined traits, each with three levels as shown in Figure 10. The three traits were fresh yield, dry matter content (DMC in Figure 10), and resistance to cassava mosaic virus (CMD in Figure 10). When attempting to introduce additional traits, the test revealed the need for better understanding and definition of these traits before implementing the method in a comprehensive manner. Open-ended interviews will be required to establish definitions and reference ranges for traits such as “good *gari*,” “big roots,” and “matures early,” prior to effective use of 1000minds. This shows a clear difference from the application of 1000minds in more industrial agricultural applications where traits are better understood and variation among users, including gender differences, may be of significantly less importance.

Figure 10. Traits and trait levels used to test alternatives in a breeding-objective-definition exercise for cassava in Nigeria, using MCDM-based software 1000minds.

The screenshot shows the 1000minds software interface for defining breeding objectives for cassava. It is organized into three sections, each with a title bar and three levels of trait selection:

- Fresh yield:**
 - <20t/ha: lowest ranked
 - 20-50t/ha: 2nd-lowest ranked
 - >50t/ha: highest ranked
 - invert ranking
- DMC:**
 - <30%: lowest ranked
 - 30 --50%: 2nd-lowest ranked
 - >50%: highest ranked
 - invert ranking
- CMD:**
 - High (Rk 4-5): lowest ranked
 - Medium (Rk 3): 2nd-lowest ranked
 - Low (Rk 1-2): highest ranked
 - invert ranking

Source: Authors.

5.4 PROCESS PROPOSAL

In an effort to build on the product profile proposal, we suggest that breeding priorities be delivered as an add-on to each product profile. Doing so thus clearly links demands and responses, providing explicit breeding responses to market demands in some kind of a “contract” between markets and breeding programs.

Practically, we propose that three pieces of information be added to the product profile document presented earlier (Table 3), for each of the traits listed in that product profile, resulting in a breeding priority document as illustrated in Table 4.

Table 4. Suggested generic product-profile-specific breeding priority template (example).

Trait	Trait Category	Reference	Market Priority	Selection Objective	Desired Short-Term Impact	Desired Long-Term Impact
Grain yield	Agronomy	Check1 +5%	1	Maximize	3	1
Stover yield	Agronomy	Check 5	1	Maximize	11	8
Early vigor	Agronomy/ labor	Check 1	2	Reach threshold		
Tillering	Agronomy	Check 6	2	Reach threshold		
Lodging resistance	Agronomy	<20%	2	Reach threshold	2	3
Plant height	Labor	90-110cm	2	Reach threshold	7	5
Maturity	Agronomy	Early	3	Reach threshold	9	9
Thousand kernel weight	Agronomy/ seed supply	40-50g	3	Reach threshold		
Seed size	Seed supply/ processing	Check 3	2	Reach threshold	12	12
Milling yield	Processing	Check 2 + 5%	1	Maximize	6	11
Texture	Processing/ consumer	Check 6	3	Opportunistic		
Protein content	Consumer	>7.5%	1	Maximize	1	6
Oil content	Consumer	5-8%	3	Reach threshold	10	10
Fiber content	Consumer	>=Check3	2	Reach threshold	5	4
Mildew resistance	Agronomy	Resistant	1	Maximize	8	7
Virus resistance	Agronomy	>=Check4	1	Reach threshold	4	2
Smut resistance	Agronomy	Intermediate	3	Opportunistic		
Heat tolerance	Agronomy	Intermediate	2	Reach threshold		
Drought tolerance	Agronomy	Check5	2	Opportunistic		
Al tolerance	Agronomy	Moderate	3	Opportunistic		

Source: Authors.

The proposed additional three pieces of information are as follows:

- Selection objective: Indication of the magnitude of ideal change in trait level. There are a number of traits for which there is no ideal level in the sense that more (or less) is always better. The primary example of such a trait is yield. For those traits selection objective is set here to “Maximize.” For other traits, reaching a specified threshold (upward or downward) or an interval between two levels represents the ideal trait level(s). Such traits could be resistances to some diseases where “good-enough” resistance, although not necessarily complete resistance, needs to be achieved. For those traits the selection objective is set here as “Reach threshold.” Finally, there are traits for which improvements may be desired, yet only after all other desired improvements have been met. Recognizing this situation will allow the decision maker to capture opportunistic improvements rather than let them “drift.” Very limited gains, if any, will be achieved for these traits. For such traits selection objective

is set here to “Opportunistic.” All traits listed in the product profile might, although not necessarily, be given a selection objective, even for trait levels that do not warrant any change or improvement.

- Desired short-term impact: Ranking of traits in order of largest to smallest desired impact through breeding within a term defined as short term. Impact is defined as the magnitude of the change in trait level that is to be delivered through breeding. Impact can also be seen as a level of differentiation or value creation. Traits ranking first in desired impact should be those that will drive differentiation of new varieties or breeds from previous ones, and thereby drive value creation for stakeholders globally. Within the framework of gender, for instance, ranking a gender-related trait first or second in terms of desired impact would almost certainly ensure that new varieties or breeds will have incorporated this gender-related trait. All traits should ideally—though not necessarily—have different impact ranks. Ranks beyond a certain level (10 or 12) may be omitted because they indicate mostly insignificant changes. Desired short-term impact can be seen as short-term breeding priorities.
- Desired long-term impact: Ranking of traits in order of largest to smallest desired impact through breeding within a term defined as long term. Impact should be understood here exactly as above for desired short-term impact. “Long term” is defined here as a second phase immediately following short term. Just as above, all traits should ideally have different impact ranks, and ranks beyond a certain level (10 or 12) should be omitted because they indicate mostly insignificant changes. Desired long-term impact can be seen as long-term breeding priorities.

Technical and resource feasibility of traits play significant roles in defining these traits’ desired impacts. Because desired impact, whether short or long term, is meant as an almost guaranteed delivery, low feasibility hampers the ability to deliver and thus the ability to almost guarantee delivery. Thus, low feasibility will generally lower short-term impact for a trait in favor of long-term impact, unless feasibility is so low that both short- and long-term impacts are forced to be reduced to nothing (or almost nothing). Similarly, the level of current germplasm will affect desired impact of traits. If current germplasm is already at the desired level, no further improvement is required and desired impact, both short and long term, can be set to low priorities (high-rank levels).

As a result, high-priority traits in a product profile would be given the highest priorities in terms of desired impact, unless feasibility is low. Low-demand-based priority traits, however, will generally not be given high breeding priorities either.

Apparent discrepancies between product profile priorities and breeding priorities, for a specific market segment, should always have a sound basis. Moreover, those in charge of breeding should be able to explain such discrepancies to those in charge of collecting and consolidating demands and needs. An agreed breeding priority document (see Table 4, for example) should be considered a “contract” between market and breeding, upon which breeding is expected to deliver products within the market it is expected to adopt.

6. FROM BREEDING PRIORITIES TO BREEDING DECISIONS

Once a breeding response to market demands and needs has been formulated through breeding priorities, an action plan needs to be devised to translate those priorities into concrete breeding decisions and actions.

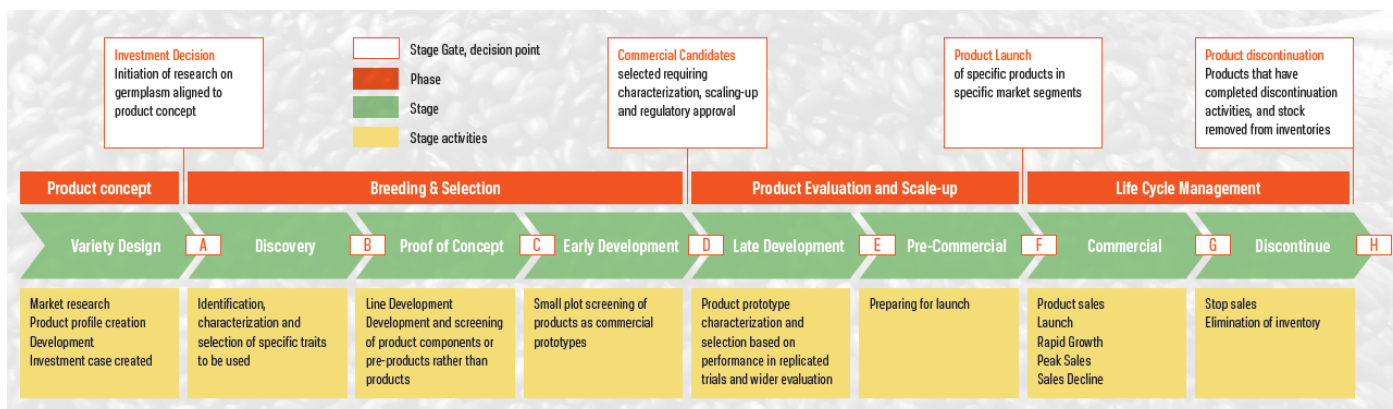
Breeding or breeding decisions are essentially of two types, promote or discard. Such decisions are made throughout the breeding cycle, defined as all the steps starting with the identification of “ingredients” (parents to be crossed to generate genetic diversity, or segregating genetic material containing genetic diversity) to the delivery of market-ready products. These steps are also known as stage gates A to F in the breeding stage plan presented in Figure 11. (The breeding cycle is a part of the breeding stage plan, the latter containing pre-breeding planning and post-breeding product life-cycle management.) Given the complexity of breeding objectives and the numerous operational constraints of breeding, it is generally not possible to select for all traits simultaneously. Translating breeding priorities into breeding decisions is about when and how selection is being carried out for the different traits throughout the breeding cycle.

Breeding priorities, as defined earlier, can impact the breeding cycle in two ways, depending on whether breeding programs exist for the target market for which product profile and breeding priorities have been newly developed.

If no breeding program exists, breeding priorities are used to select genetic material (parents or other segregating material as seen above) to initiate a breeding cycle starting at stage gate A of the stage plan (Figure 11). The only impact point of breeding priorities is thus stage gate A.

If one or more breeding programs exist for the target market, genetic material should be available in most or all stages of the breeding cycle (i.e., between stage gates A and F of the stage plan). All material available, irrespective of the stage it is in, can be assessed relative to the newly available product profile and breeding priorities. Any genetic material in the late development or pre-commercial stages of the breeding cycle that meets or exceeds product profile requirements and breeding priorities represents very short-term delivery opportunities and should be selected and promoted toward commercialization. The same should be done with material at any stage of the breeding cycle, although representing mid- to long-term delivery opportunities as one moves toward the early stages of the breeding cycle.

Figure 11. Generic plant breeding stage plan.



Source: Reproduced from Syngenta Foundation (no date).

6.1 SORGHUM IN MALI

This example is part of Examples 4.4 and 5.2 presented above. Context information will therefore not be repeated here and can be consulted above if needed.

Based on the breeding priorities that had been identified, the program initiated diverse efforts to generate genetic diversity with guinea race sorghums, to allow for grain yield improvements. This included the development and further diversification of an existing guinea race population with a gene for male sterility (Weltzien et al. 2006; Rattunde et al. 2016), bi-parental crosses, also with *caudatum* race materials, as well as exploring heterosis and hybrid breeding. More recently, the development nested back-crossed populations, using a new farmer-preferred guinea race line as a recurrent parent had been used.

During the early generations, visual selection is focused on panicle traits, plant height and grain color, and disease resistances as the diseases appear during line advancement. With the research on more detailed understanding of desired grain quality attributes for home consumption (the primary use of sorghum in West Africa), the program is increasingly involving experienced women farmers in the visual evaluation of grain quality during the early generations.

For the recurrent selection program, grain yield evaluations start with S1 lines, and are followed by a multilocation S2 trial for final selection for constituting the next breeding cycle of the population. F4 lines are evaluated along with the S2s and results used for line advancement. F5/F6 bulks are evaluated in large-scale multilocation trials, also managed by farmers. These include cooking quality evaluations, as well as Striga resistance testing on-station. The regular evaluation of breeding material by farmers allows for regular adaptations and revisions of both the product profile and the breeding priorities.

On the basis of more detailed understanding of the adaptation to low soil fertility, especially poor phosphorus (P) availability, the selection criteria have been changed to include yielding ability under low P conditions, as described by Leiser et al. 2015.

6.2 MULTI-TRAIT DECISION PLANT BREEDING SCHEME

Product profiles and breeding priorities generally require multiple traits to be selected for simultaneously, which is not a simple task. There are scientific hurdles due not only to the multiplicity of traits, but also to their complex, sometimes antagonistic relationships. There are operational challenges such as the cost of or ability to measure numerous traits on large numbers of individuals of breeding populations. Finally, and as seen above, there are business complexities specifically related to the setting of objectives.

Much has been written on selection for multiple traits. Gallais (1990) provided a thorough theoretical review of all approaches, whereas Hallauer and Miranda (1981) presented applications of multi-trait selection methods in the context of maize breeding. Several alternatives exist that differ in the time sequence along which multiple traits are being selected. Their relative merits often depend on the traits under selection and the relationships among them.

When dealing with multiple traits, progress will depend on individual trait attributes, and on relationships among these traits. A good knowledge about traits, individually as well as about their relationships, will critically help in the design of the most relevant selection approaches.

Some of the critical attributes to understand about each trait include those impacting genetic gain such as amount of genetic diversity and ability to reliably measure the trait. Little genetic diversity will limit the improvements that can be achieved; the same will result from not being able to reliably measure a trait.

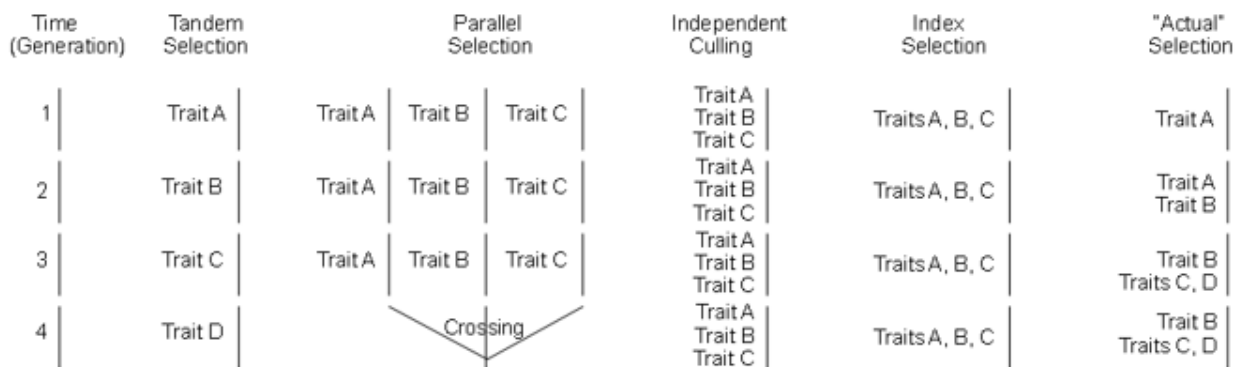
Relationships among traits are most often characterized using correlations among traits. Observed, or phenotypic, correlations can be genetic, environmental, or both in origin. Genetic correlations can be advantageous when traits under selection are positively correlated; that is, when individuals showing (un)favorable values for one trait generally also show (un)favorable values for the other traits. In such a situation selection for one trait will result not only in progress for that trait but also for all positively correlated ones. Genetic correlations can also be disadvantageous when traits under selection are negatively correlated (i.e., when selection for a favorable change in one trait results in an unfavorable change in another trait).

A large number of multi-trait selection approaches have been described in scientific literature (see, too, Figure 12). They can be grouped into four categories:

- *Tandem selection*, where traits are selected one after the other in successive generations. There will be good progress on all traits if traits are positively correlated. If traits are negatively correlated, progress made in one generation on one trait will either reduce or even erase progress made on other traits at previous generations, or limit the progress that could be made on other traits in subsequent generations.
- *Parallel selection*, where traits are selected in independent breeding populations and brought together through crossing. When traits are either not or negatively correlated, progress made on each trait will be diluted in the last crossing phase. When traits are positively correlated, crossing individuals from the different, parallel schemes will result in partial or complete addition of progress.
- *Independent culling*, where traits are selected simultaneously yet independently. When traits are not or negatively correlated, using a very high culling threshold for a trait will lead to selecting individuals with below average to very low values for other traits. In the case of negatively correlated traits, the best individuals for either trait will not be selected.

- *Index selection*, where traits are selected simultaneously using a performance indicator that is a weighted combination of all trait-breeding values. One of the challenges with index selection is the choice of weight values. Weights can represent relative economic values of the traits, be computed to maximize genetic gain for certain traits or the index, allow selection to maximize certain traits while restricting progress on others, or be defined subjectively or through trial and error. When traits are correlated, index weights must be chosen carefully in order to obtain the desired response to selection. Correlation among traits will result in response to selection not only from selection on the traits themselves but also from selection on correlated traits. In the case of negatively correlated traits, trying to achieve much progress on one trait will severely limit what can be achieved in terms of impact on the other traits.

Figure 12. Schematic view of different multi-trait selection approaches differing by the time sequence at which traits are selected.



Source: Adapted from Gallais (1990).

There is general consensus that index selection is the superior approach, although, in specific situations, other approaches may be superior.

In practice, new varieties need not only be superior overall packages of traits but also meet specific improvement thresholds for a number of individual traits. Also, different traits are often not recorded at the same time but, rather, from planting through harvesting. In that context, alternatives to index selection such as independent culling or tandem selection, alone or combined, might prove to be the approaches of choice. Similarly, other elements, such as operational considerations or new technologies, might also lead one to depart from the theoretically optimal index selection approach.

In a plant breeding program, the number of selection candidates typically decreases drastically, from a very large number at the start of the selection process to very few as one moves closer to commercial cultivars. Submitting large numbers of selection candidates to selection is very favorable, allowing for strong selection pressure and hence increase genetic gain, assuming sufficient genetic variability. Working with large numbers, however, requires being able to measure traits reliably on large numbers of entries. And although this is quite feasible for traits that are simple, easy, and inexpensive to measure, it will become impractical for traits that are complex, difficult, or expensive to measure. These latter traits will often not be recorded early in the selection process but, rather, later when the numbers of selection candidates can be accommodated within operational constraints. In practice, multi-trait selection will often rely on selection for some traits early in the

process and for others (including or not the first set) later, resulting in some variation of tandem selection.

Similarly, the advent of genotyping and genomics is pushing selection schemes to depart from the optimal index selection approach. The availability of genotypic diagnostics (for genetically simple traits) or genomic predictions (for genetically complex traits) allows selection candidates to be evaluated very early. This is the case not only in the breeding scheme but also very early in the course of generations, at the plantlet or even seed stage, in what is commonly referred to as pre-screening. Multi-trait selection consequently becomes a two-step selection: pre-selection for one or more traits based on genotypes, followed by multi-trait selection based on phenotypic data. These two steps can take place in the same generation or in different ones for the reasons mentioned earlier. In practice, actual multi-trait selection schemes will likely be combinations of tandem selection, independent culling, and index selection rather than pure index selection as theoretically optimal.

6.3 PROCESS PROPOSAL

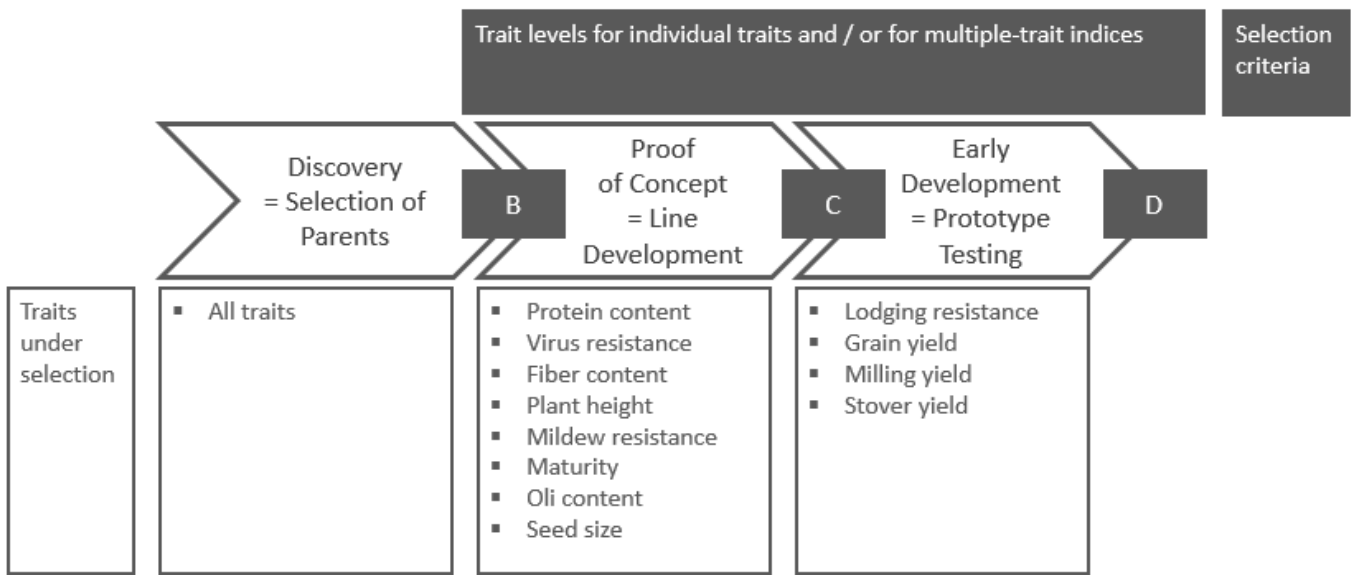
The translation of multi-trait breeding priorities into concrete actions along the breeding cycle is not a simple task. Decades of research on multi-trait selection have not yet led to the identification of the most effective selection scheme, where effective is meant with respect to delivery of the ideal product as specified in the product profile. This clearly reflects the complexity of the problem.

Biological, genetic, and operational constraints on one hand, and technological opportunities on the other, are shifting trait prioritization somewhat from defining weights to deciding on the selection sequence (which trait goes first). This is clearly illustrated in the above example on sorghum breeding in Mali.

Ideally, highest priority traits should go first to ensure that expected gain is realized. This is not always feasible. Figure 13 shows a proposal for trait selection along three early stages of breeding, based on the product profile and breeding priorities presented above (Figures 10 and 14). Here, only one of the three highest priority traits, protein content, is being selected for in the first phase of progeny selection, line development. The other two, lodging resistance and grain yield, are only being selected for in the second phase of progeny selection, early development.

The challenge in translating breeding priorities into breeding decisions is clearly to design a process (which includes which traits are being selected for when and how) that is both effective in delivering on demand and efficient operationally. Focusing excessively on meeting demand at the expense of operational efficiency will hamper the ability to deliver products, and eventually fail to deliver value to the market. Meanwhile, focusing excessively on operational efficiency at the expense of breeding priorities will lead to the development of products that are too remote from demand. And although they might be launched on the market, they are rapidly abandoned because of insufficient value creation (or lack thereof).

Figure 13. Schematic representation of trait-breeding decisions on three early stages of a stage plan (covering most of the breeding cycle), using stages defined in Figure 11 as references.



Source: Authors.

7. TRAIT RESEARCH/PRE-BREEDING

Besides breeding activities aimed at a timely response to product profiles, several “tangential” efforts are often made to bring more challenging objectives into the selection arena.

Such trait research or pre-breeding may seek to efficiently access traits from beyond a program’s mainstream or advanced, variety-ready germplasm base; or to develop genetic and mechanistic, often biochemical and molecular insights and tools that enable gains in traits toward new breeding objectives. Trait research focuses on the understanding and incorporation of new or poorly defined traits (e.g., a preferred cooking type, new sources or more durable forms of disease resistance, previously neglected nutritional traits, etc.) into long-term breeding pipelines. It is expected to result in new materials, methods, tools, knowledge, or processes that enable new, needed traits to be incorporated into future crop varieties/ animal breeds. When exotic germplasm is used, pre-breeding is conducted in parallel to the mainstream breeding activities, such as in support populations that are upgraded for trait levels or improved for agronomic traits so that new types of diversity can be introduced without impeding the program’s advance toward established breeding. Embarking on medium- to long-term population development does not result in new varieties after a single recombination and selection cycle. It should, however, result in better parents that will help meet the medium- to long-term breeding objectives. Materials and information from trait research may be applied in cross-breeding (i.e., via introgression or incorporation, by genetic transformation, or by genome editing).

Trait research and pre-breeding are often conducted in an exploratory manner and are not driven by the same product development objectives and urgency as breeding is. The incorporation of the outputs of such higher risk research into breeding for product development without setting breeding programs back in their advance toward established goals is a challenge. It is therefore necessary to explore ways by which trait research and pre-breeding can be integrated into the framework of product profiles and breeding priorities to ensure the most effective and efficient possible development of improved products (including the more challenging trait improvements) to the markets. Intuitively, trait research and pre-breeding should focus on traits of high importance to the market but for which breeding cannot deliver much improvement. These are typically high market priority traits, as defined in the product profile, with low technical feasibility. Situations of low technical feasibility due to lack of genetic variation are best addressed through pre-breeding (with or without specific trait research). Situations of low technical feasibility due to other causes are best addressed through trait research, including phenotyping, genetic dissection, and other approaches.

7.1 BIOFORTIFIED POTATO

Micronutrient malnutrition constitutes major public health problems throughout the world. It is largely associated with plant-based diets, affects more than 2 billion people, and is thus more widespread than energy and protein deficiencies that affect nearly 800 million people. Women of child-bearing age and children under 5 years are the most vulnerable.

New collaborations have been forged between plant breeders, nutritionists, biochemists, impact specialists, and seed and food sector players of CGIAR centers, universities, national programs, and advanced research institutes under the HarvestPlus consortium. The aim is to develop and deliver products of the relatively new food-based approach, known as biofortification, for reducing micronutrient malnutrition. Data from nutritionists supporting mineral supplementation of foods as a

complementary approach to this plant breeding initiative informed crop improvement teams of the increments of the three most critical micronutrients (iron, zinc, and B-carotene or pro-vitamin A). These are required for biological impact on the nutritional status of populations at risk of this so-called hidden hunger and could, in principle, come from micronutrient-dense staple crop varieties.

Recognizing that potato is a moderate source of iron and zinc for which genetic enhancement had not been explored before, CIP breeders examined the overlap between dietary deficiencies of these minerals and potato consumption in order to identify populations who could benefit from iron- or zinc-biofortified potato (Bonierbale et al., 2007). Breeders collaborated with nutritionists to set qualitative breeding goals based on potato intake, trait heritabilities, and the bio-accessibility and retention of iron and zinc in cooked potato.

These trait-specific collaborations have involved a number of critical steps to ensure relevance of the traits to the target markets and the operational feasibility from pre-breeding to trait incorporation and product delivery. Some of those critical steps are listed below:

- The definition of the value of biofortification to market segments resulted from the identification of populations at risk of micronutrient malnutrition for whom potato is a staple crop.
- Effective levels of traits needed for impact on health status were translated into measurable and achievable breeding targets as threshold levels of iron and zinc (in ppm) of potato tuber composition.
- Capacity was built for sampling and screening large amounts of germplasm by chemical methods and the correlated rapid assay, X-ray fluorescence.
- A survey of breeding populations, farmers' cultivars, and world-important varieties located sources of iron density in the less globally adapted cultivated diploid genepool, and established baselines for iron and zinc content of current potato varieties.
- The breeding program estimated genotype x environment interaction, heritability, and correlations between iron and zinc concentrations and other traits in current product profiles (Paget et al., 2014).
- Pre-breeding in the diploid genepool succeeded in doubling iron and zinc concentrations, while maintaining functional frequencies of unreduced pollen to enable transfer of the new trait levels to the globally adapted, tetraploid breeding populations.
- In-vitro digestion showed the bio-accessibility of iron in potato to be high (63–79%) with respect to that in other staple crops such as pearl millet, wheat, and beans (Andre et al., 2015).
- Inter-ploidy crossing combined elevated mineral concentrations from recurrent selection in the diploid pre-breeding population with disease resistances in the better-adapted tetraploid breeding materials. Yield that was slightly depressed in pre-breeding for iron and zinc was recovered in this inter-gene pool breeding step.

A population of diploid potato with 35-ppm iron and 30-ppm zinc was eventually selected to act as donor of desired traits into tetraploid elite material. At the end of the pre-breeding process, a tetraploid potato population was obtained that displays high yield, multiple disease resistances, table quality, and iron and zinc concentrations twofold higher than baseline levels. Such levels are approaching the breeding targets for populations with high potato intake. Further work remains to be done to identify clones adapted to target agro-ecologies that maintain as favorable a package of traits as possible, including iron or zinc.

7.2 IRON PEARL MILLET IN INDIA

Iron deficiency causes varying degrees of impairment in cognitive performance, learning ability, lowered work capacity, and pregnancy complications. Despite efforts to curb it, iron deficiency remains the most widespread nutrition deficiency in the world, with women and children being the two groups who suffer the most.

Although not a mega-staple, pearl millet is an important staple food in several parts of India, including Maharashtra, Rajasthan Gujarat, and Uttar Pradesh. In these regions impairments linked to iron deficiency are frequent. At the same time, per capita consumption of pearl millet is very high, thus presenting significant potential to provide additional iron in the diet.

Several years ago, HarvestPlus, which focuses on crop biofortification, launched an initiative to develop high-yielding and iron-rich hybrids and improve some of the then commercial open-pollinated varieties (OPVs) for iron density. High yield was added to high iron in the objectives because of the continuous market demand for higher yielding cultivars.

Breeding for high-iron pearl millet progressed rapidly. A first high-iron pearl millet variety, 'Dhanashakti', and a first high-iron pearl millet hybrid, ICMH 1201, were released in 2014. More varieties and hybrids have been released since.

These achievements have been the result of a thoroughly planned approach (HarvestPlus, no date), rooted in the market from the early to the very late stages. The approach consisted of the following 10 steps:

1. Identify target populations who can benefit from biofortification.
2. Set appropriate nutrient target levels for selected populations. Initial targets were set at 30% of mean daily requirement, and later increased up to 70%.
3. Screen crop varieties and germplasm for use in breeding. This includes assaying elite lines as an opportunity to capture "quick wins," to assaying unadapted germplasm as a potential source of very high iron levels.
4. Breed new biofortified varieties of staple food crops with higher micronutrient levels. Objectives were to meet target levels for lines and hybrids, and 75% of target levels for OPVs.
5. Test performance of new crop varieties in the field, including testing for impact of the environment on general performance and iron level.
6. Measure nutrient retention in crops and foods, in particular through processing.
7. Evaluate the body's capacity to absorb and use micronutrients from biofortified crops; determine pearl millet iron's bioavailability.
8. Officially release biofortified varieties and consider a go-to-market approach through institutes and private seed companies involved in pearl millet breeding rather than directly. Role of HarvestPlus is therefore to help these institutes and private seed companies with breeding for mineral content.
9. Promote marketing and consumption of biofortified crops and foods and include market analyses, breeder seed production support, and advocacy strategy.
10. Measure both improvement in nutritional status of target populations as well as change in nutritional status after introduction of high-iron pearl millet in diet.

A study recently published by Finkelstein et al. (2015) found that pearl millet bred to be richer in iron (i.e., the OPV 'Dhanashakti') was able to reverse iron deficiency in school-aged Indian children in six months. In just four months, iron levels improved significantly. Currently, more than 360,000 people in India are growing and consuming iron pearl millet; but the goal is for this biofortified crop is to reach more than one million households by 2018.

A detailed analysis of the approach revealed several critical success factors:

- Targeting of poor farming households right from the start. Their adoption of high-iron pearl millet is viewed as key to improving nutrition in India.
- Engaging the commercial seed sector. Because farming households in India acquire seeds from commercial vendors regardless of socioeconomic status, delivering high-iron pearl millet seeds through the commercial system ensured that all pearl millet farming households could be reached with high-iron pearl millet varieties.
- Targeting of several popular hybrid varieties more likely to be adopted by less privileged households.

Process proposal

The above two examples clearly illustrate that pre-breeding or trait research, when addressing traits of high importance or that create high value (not necessarily in economic terms) for a market, and coupled with subsequent deployment in market-relevant varieties, can be very successful in delivering traits and value that could not have been delivered within the same timeline through conventional breeding alone.

It therefore seems rather obvious to recommend that pre-breeding and trait research be fully aware of and driven by product profiles and breeding priorities. But because pre-breeding or trait research might not always be conducted within breeding organizations, they might not always have direct access to product profiles or breeding priorities. In such cases, pre-breeding and trait research should attempt to get access to product profiles and breeding priorities from one or more breeding organizations on which they will later depend to deploy their outputs.

8. CONCLUSIONS

The complexity and diversity of considerations and actions required make the successful development of improved plant varieties or animal breeds for markets a challenging yet essential endeavor facing all effective and efficient breeding programs. In this paper we have proposed and illustrated a process by which market demands and needs can be organized toward the high probability of successfully delivering value-creating products.

This process comprises three phases:

- **Product profile development:** An inventory of market demands and needs for each target market should be summarized in a formal document referred to as a product profile. We are advocating that product profiles be somewhat unconstrained—that is, not limited in the number of traits they contain. We believe that product profiles should be seen as lists of requests and that, at this stage, all requests should be documented rather than filtered in any way. Product profiles, as suggested here, provide ample space to include socioeconomic and gender preferred traits.
- **Breeding priority development or breeding response to product profiles:** Breeding priorities are lists of traits on which a breeding organization commits to deliver improvement within a certain time frame (short or long term). In contrast with product profiles, we recommend that breeding priorities be rather constrained, which is what allows breeding priorities to be seen as a commitment, almost a guarantee of delivery. Because breeding priorities are constrained and product profiles are not, breeding priorities will most likely not address all market demands and needs collected in the product profile. However, they will send to the market a clear message about what will be addressed and delivered upon. This response from breeding to the market might actually trigger changes in market demands, which in turn might trigger changes in breeding response. Such a dialogue should eventually settle on breeding priorities recognized by the market as ambitious and value-creating, and by breeders as realistic. This dialogue, and the resulting commitment, is most useful when market demands are being made to address socioeconomic- or gender-specific traits.
- **Breeding decision planning:** Although breeding priorities are seen as a commitment from breeding programs to the market, they remain wishes to be acted upon. Planning what breeding decision will be made at which point along the breeding process is what will drive breeding output. To ensure that the output conforms to breeding priorities, it is critical that breeding decisions fully enable the delivery on breeding priorities, resolving any issue that might happen. The development of such a breeding decision plan will show very clearly how decisions on socioeconomic and gender related traits will be made along the breeding process. This, in turn, will allow the determination of whether the plan will have (or not) the ability to deliver improvements committed to on these traits, and adjust the plan accordingly.

From the variety of examples presented in this paper we can see that there is not a single best way to complete each of the three above phases. Each organization will need to find its best way/s, potentially deriving inspiration from the examples provided here.

Nevertheless, several critical elements appear repeatedly across many of the examples:

- Knowledge (markets, stakeholders, traits, germplasm, operations, etc.)
- Consultation of and transparency vis-à-vis all stakeholders
- Realistic yet significant targets
- Avoidance of unnecessary complexity.

In this paper, we proposed several approaches and supporting documents (templates) as potential frameworks with which to develop product profiles, breeding priorities, or breeding decisions. Beyond approaches and documents, this paper intended to promote some formalization of the whole process and the description of individual steps that can help identify key decision points in a breeding program where specific gender and other socioeconomic considerations can be incorporated to make the process more gender-responsive.

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