



International Center for Tropical Agriculture
Since 1967 Science to cultivate change

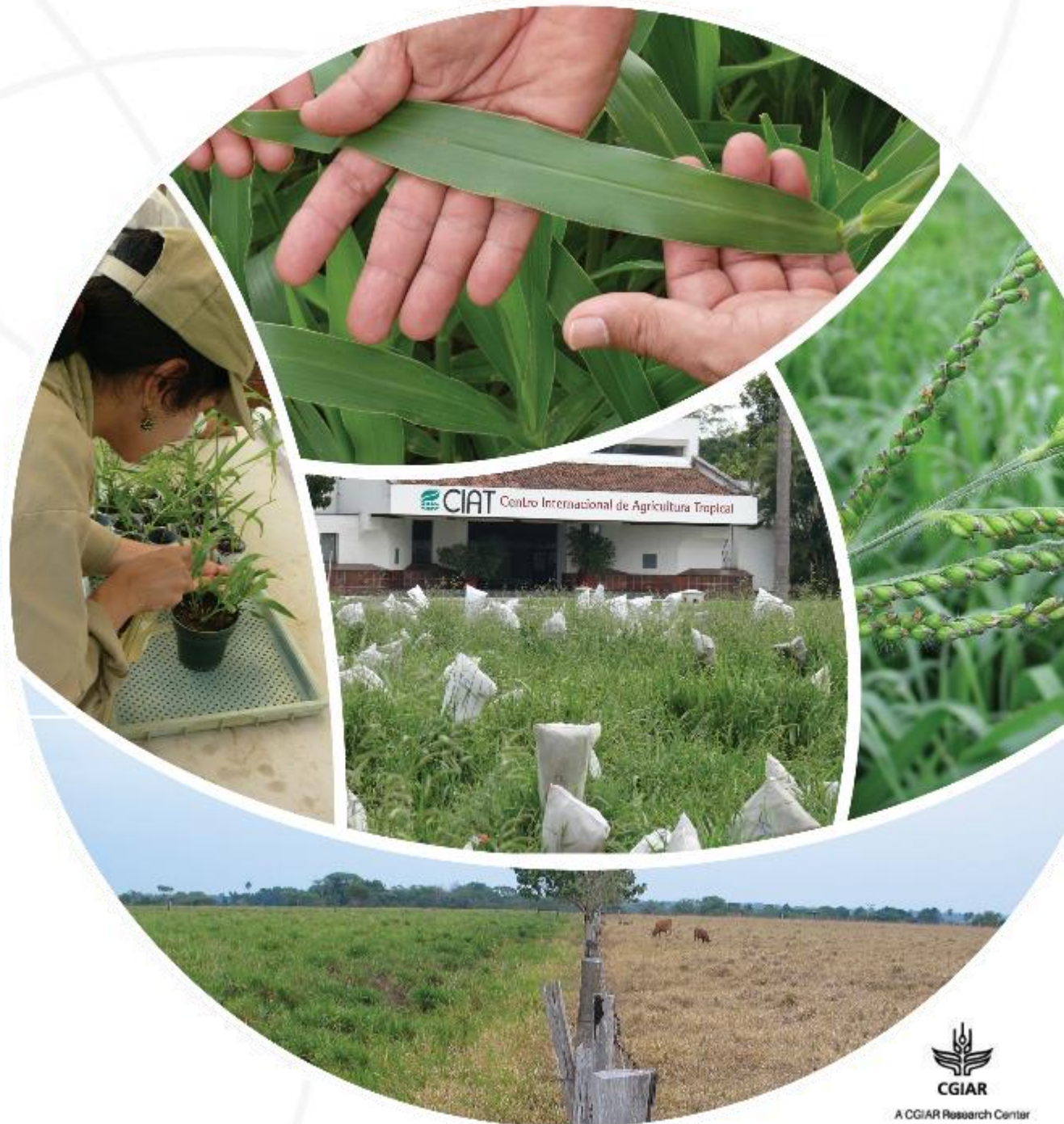
Report on identification of gaps and forage breeding objectives

May 17th, 2018

Valheria Castiblanco

Plant breeder | Tropical forages

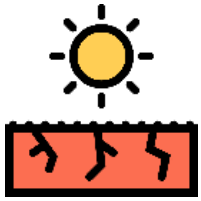
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A CGIAR Research Center

Overview

Forage breeding program at CIAT aims at developing new technology options that respond to the demands of specific agro-ecological zones:



Drought
tolerance



Water-logging
tolerance



Biotic
stresses



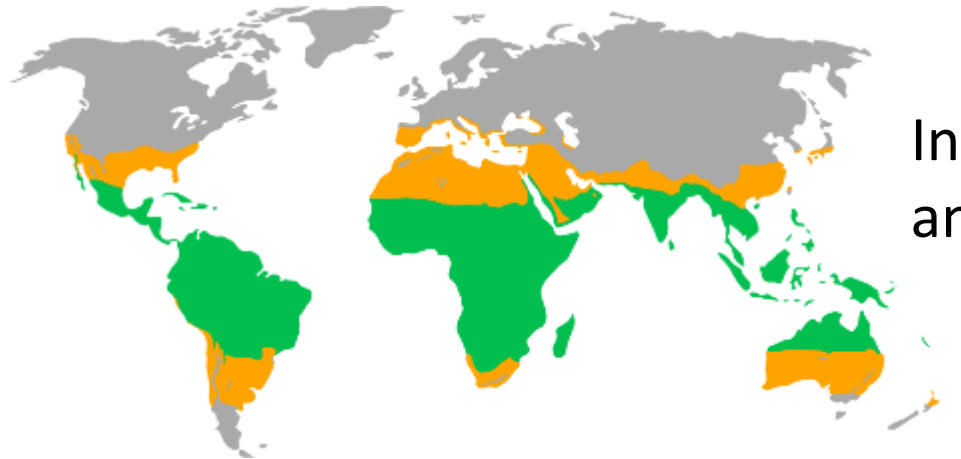
Feed
quality



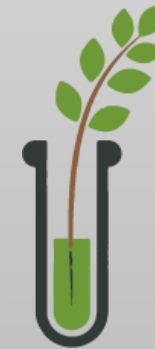
Nutrient/Water
Use Efficiency



Markets
(seed production)

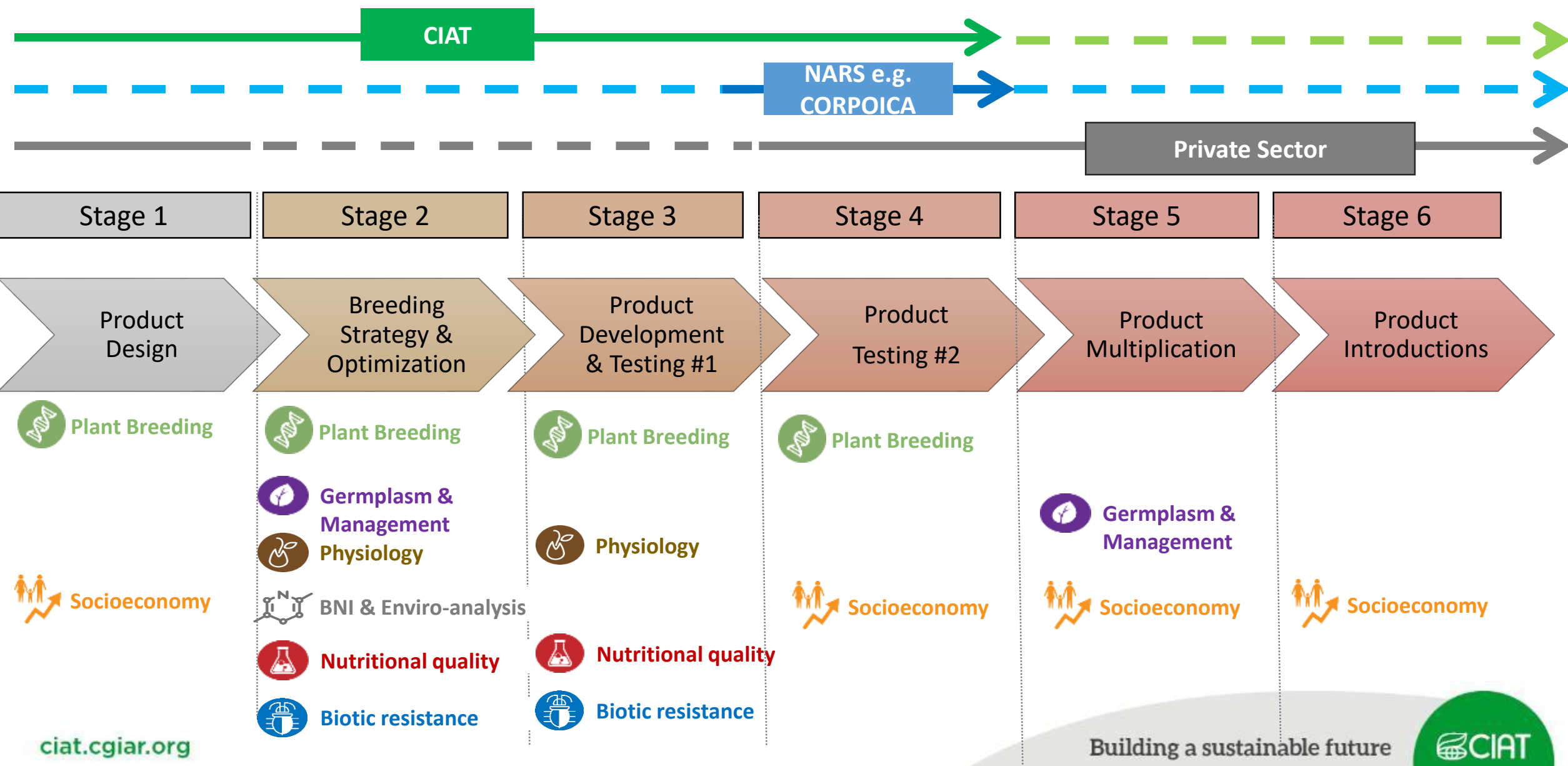


In the **global tropics**
and **subtropics**

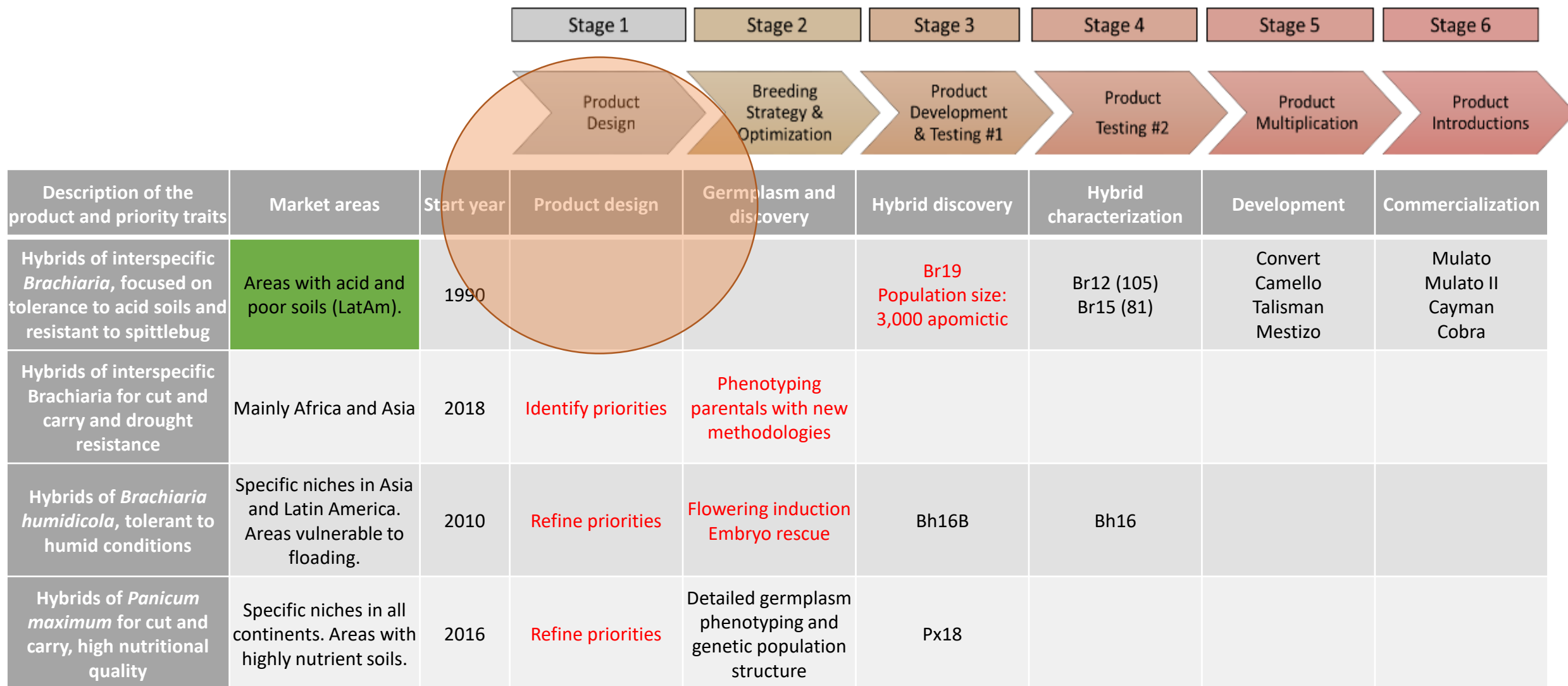


Our forage breeding program is **unique at the CGIAR**, by being the only program of recurrent selection which exploits heterosis for a tetraploid **apomictic** crop.

Team, partners and VDP

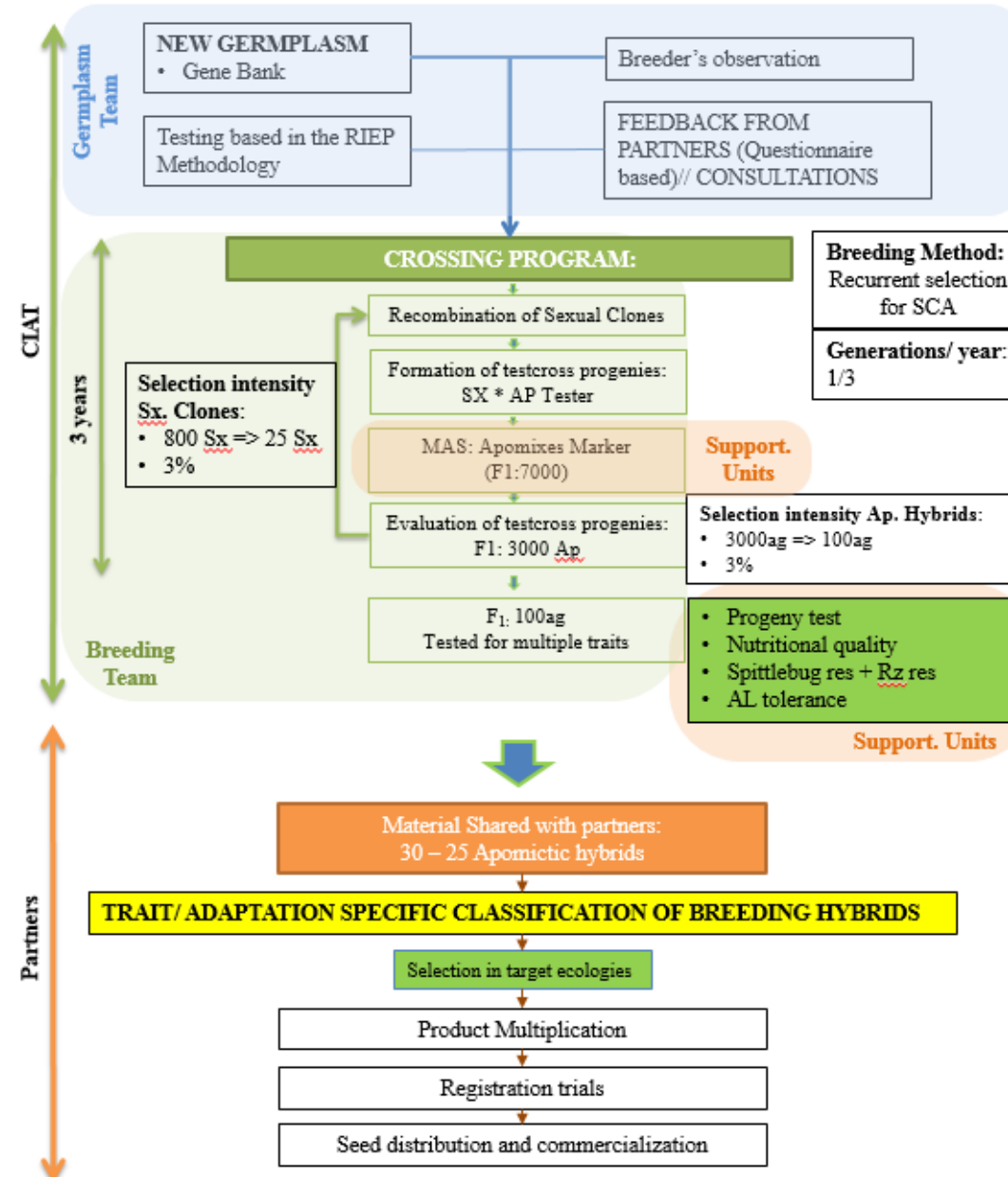


Product lines and stages of development



Brachiaria interspecific hybrids Breeding Pipeline

TARGET: To develop Hybrids of interspecific Brachiaria, focused on tolerance to acid soils and resistant to spittlebug





Product design

First priority target areas

Production areas in Latin America

190 Mha

Total pasture area only in Brazil

120 Mha

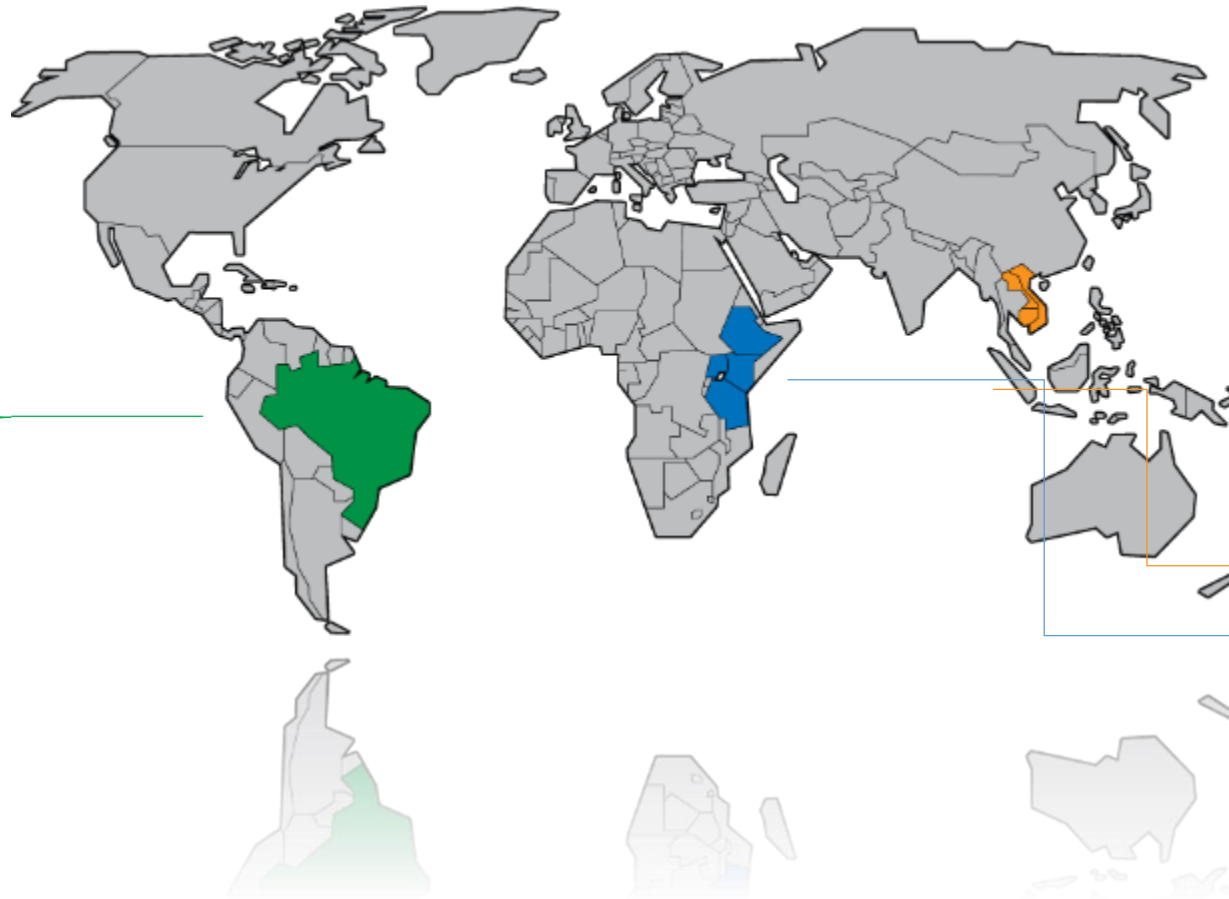
Planted pastures

8 Mha

Are renewed each year

USD 600M

Seed market value in Brazil



Market area preferences

Latin America: The goal has been to maintain the nutritional quality of the *B. ruzisiensis* materials and adaptation of *B. decumbens* while improving biotic resistances mainly against Spittlebug but also *Rhizoctonia solani*.

Asia: Cut and carry system.

Africa: *2M ha of *Brachiaria* required calculated based on actual amount of animals in 48 Sub-Saharan African countries. *800,000 – 1,800,000 smallholder dairy farms (1 to 3 cows) – producing 80% of the milk. *Cut and carry system.

Note: Size of the target area in Africa and Asia has not been measured.

History of forage breeding at CIAT





Product design

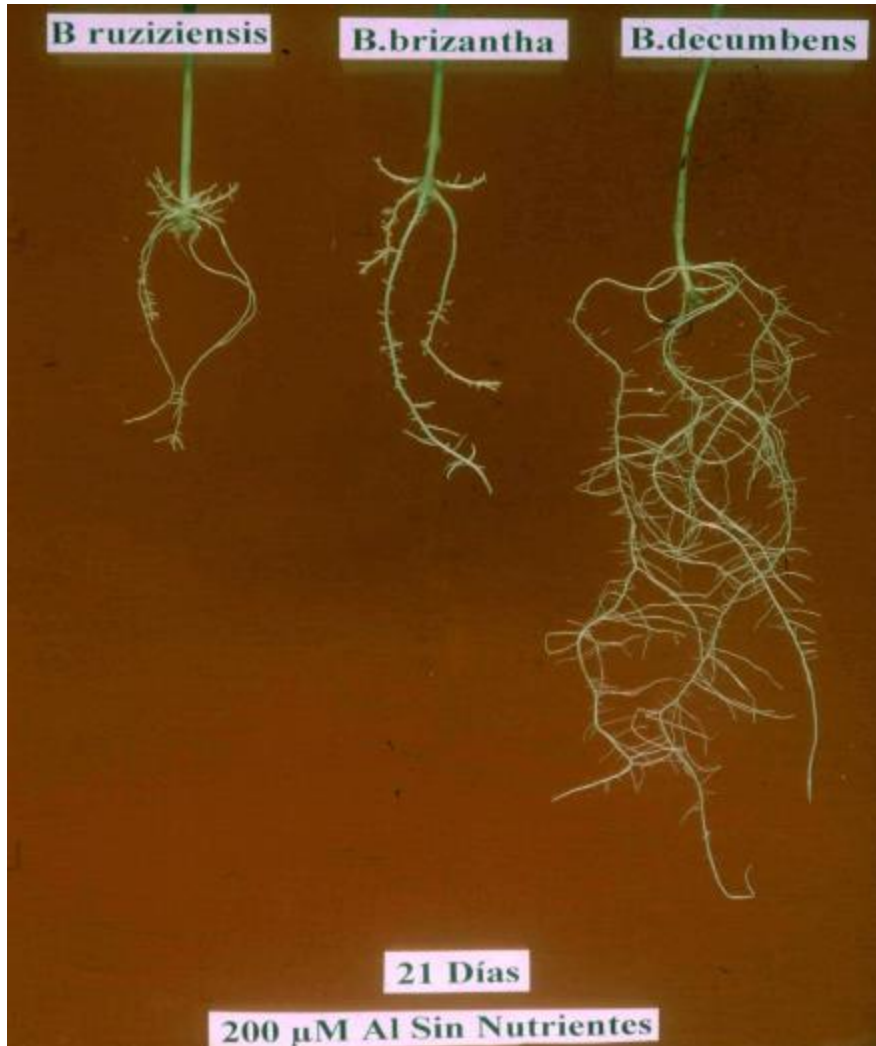
Brachiaria from Africa to the Americas





Product design

Brachiaria decumbens cv. Basilisk



- Tolerance to poor, acid soils
- Tolerant of Al toxicity
- Easily propagated by seed
- Competitive against weeds
- 1940 ~2.56 ha/head
- 1980 <1.5 ha/head



Product design

Spittlebug Damage





Product design

Brachiaria brizantha cv. Marandu

- Accession released by EMBRAPA in 1984
- Planted on 50 Mha (Jank et al. 2014)
- World's largest monoculture in terms of acreage
- Few cultivars occupying large, continuous expanses = heightened risk





Product design

Hybrids of interspecific *Brachiaria* for acid soils and resistant to spittlebug

			Priority ★	Ideotype Worst value accepted	<i>B. brizantha</i> cv. Toledo CIAT 26110	<i>B. brizantha</i> cv. Marandú CIAT 6780	<i>B. decumbens</i> cv. Basilisk CIAT 606	Híbrido interespecífico Mulato II
Stage 1	Biomass	(tonMS/ha/year)	1	> 20	25-35	15 - 20	15-20	20 -25
Stage 2	Quality	Protein Content	2	> 11.0	8-13	9-12	6-8	12-16
		% NDF		</= 60	63 - 72	65 – 75	65 – 75	56 – 65
		% ADF		</= 40	34 – 40	35 - 45	35 - 45	28 – 38
		% DIVMS (rumiantes)		> 72	55 - 60	55 - 65	55-65	60 - 65
	Biotic stress	Spittlebug Resistance - Visual damage score	3	< 2	Susceptible	Resistant	Susceptible	Resistant - antibiosis
		Rhizoctonia solani	5	< 2		Suceptible		
	Abiotic stress	Al tolerance	4	4.0-8.0 pH			3.9-7.5 pH	
		Waterlogging 15-21 days (%reduction compared to drained plants)	7	> 50	40-30 (moderately sensitive)	30-20 (sensitive)	50-40 (moderately tolerant)	20-10 (extremely sensitive)
		Waterlogging 15-21 days (SPAD values)	7	> 25	25-20	25-15	28-20	25-15
		Drought (soil kept at 50% field capacity) (%reduction of foliar area compared to plants kept at 80-100 %)	6	> 50	40-50	40-50	40-50	40-50
		Drought (soil kept at 50% field capacity) (Leaf rolling scores) Scale 0: no wilting; Scale 6: wilted, symptoms of senescence	6	< 2	3-4	3-4	2-3	2-3

Products and stages of development

			Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
			Product Design	Breeding Strategy & Optimization	Product Development & Testing #1	Product Testing #2	Product Multiplication	Product Introductions
Description of the product and priority traits	Market areas	Start year	Product design	Germplasm and discovery	Hybrid discovery	Hybrid characterization	Development	Commercialization
Hybrids of interspecific <i>Brachiaria</i> , focused on tolerance to acid soils and resistant to spittlebug	Areas with acid and poor soils (LatAm).	1990	Revise priorities		Br19 Population size: 3,000 apomictic	Br12 (105) Br15 (81)	Convert Camello Talisman Mestizo	Mulato Mulato II Cayman Cobra
Hybrids of interspecific <i>Brachiaria</i> for cut and carry and drought resistance	Mainly Africa and Asia	2018	Identify priorities	Phenotyping parentals with new methodologies				
Hybrids of <i>Brachiaria humidicola</i> , tolerant to humid conditions	Specific niches in Asia and Latin America. Areas vulnerable to flooding.	2010	Identify priorities	Flowering induction Embryo rescue	Bh16B	Bh16		
Hybrids of <i>Panicum maximum</i> for cut and carry, high nutritional quality	Specific niches in all continents. Areas with highly nutrient soils.	2016	Identify priorities	Detailed germplasm phenotyping and genetic population structure	Px18			

*Activities that are about to be done for each product at each stage.



- *B. decumbens* (65) cv. 'Basilisk' (amargo)
- *B. brizantha* (309) cv. 'Marandu', 'Toledo', 'Piatã', 'La Libertad'
- *B. humidicola* (66) cv. 'Tully' (dulce) & 'Llanero'
- *B. ruziziensis* (41)
- *P. maximum* (126) cv. 'Mombasa', 'Tanzania'

RIEP Testing scheme

Regional trials A

- Establishment (characterization of large collections)

Regional trials B

- Agronomic evaluation and dry matter production (Vigor, height, coverage, incidence of pests and diseases)

Regional trials C

- Animal effect on forages (palatability, quality nutritional, persistence, trampling resistance)

Regional trials D

- Animal response in terms of productivity by area (weight gain kg/ha/year)



Differences in ploidy
(intra- and inter-specific
differences)



Lack of basic information
about the cytology and
reproduction of the grasses



APOMIXIS:
Asexual reproduction by
seed



Adaptation to acid
soils

B. decumbens
(apomictic)



Resistance to
spittlebugs

B. brizantha
(apomictic)



“Genetic bridge”

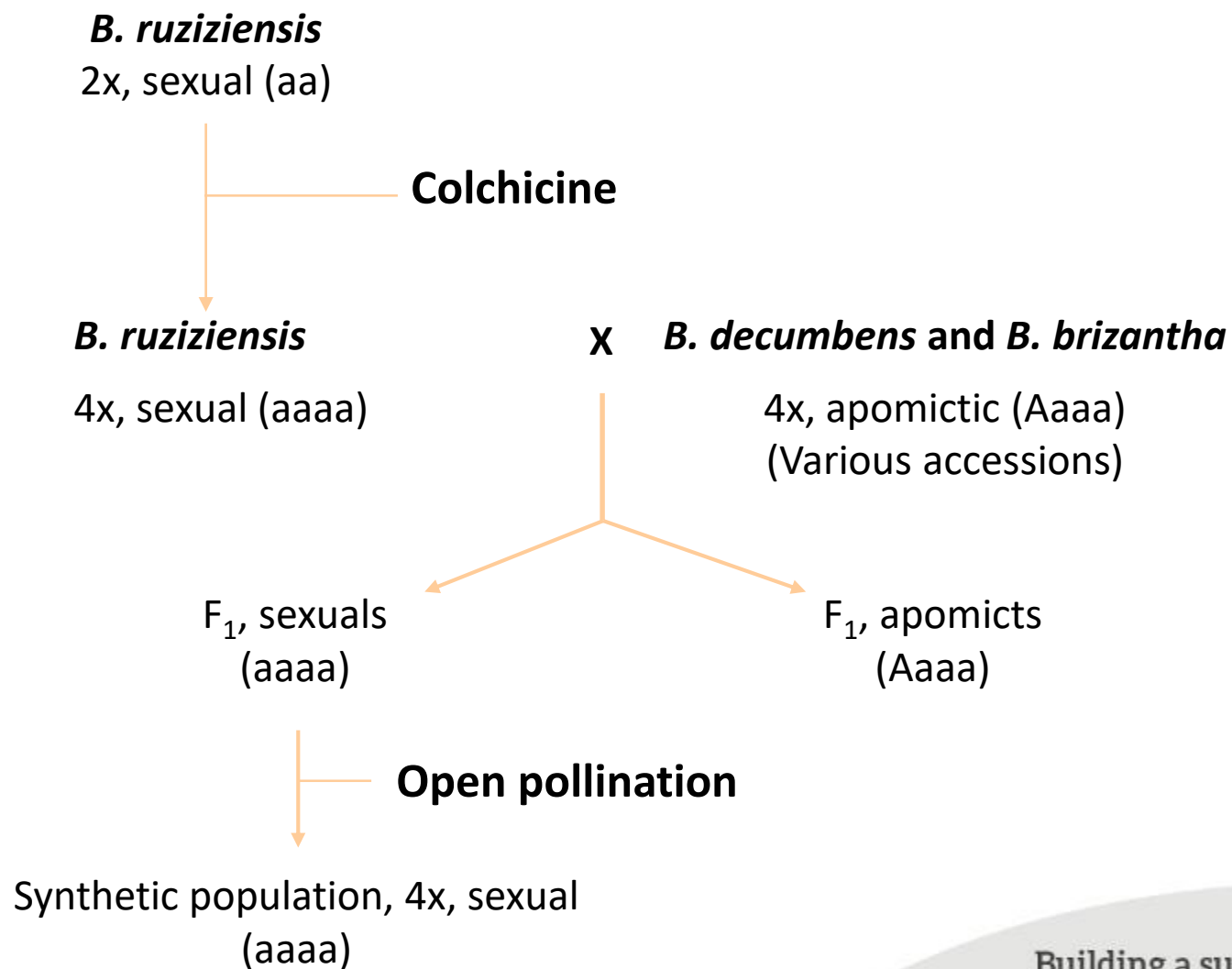
B. ruziziensis
(sexual tetraploid that can be
fertilized by apomictic species)

Hybrids with positive attributes of
B. decumbens and *B. brizantha*



Breeding Strategy & Optimization

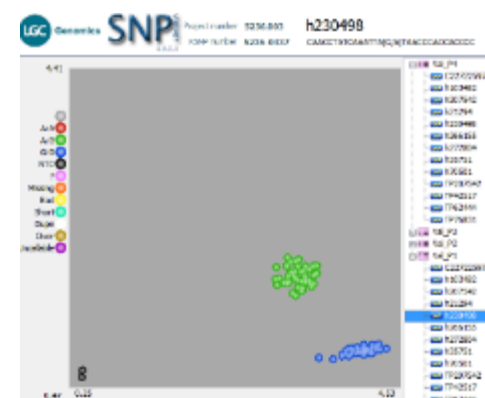
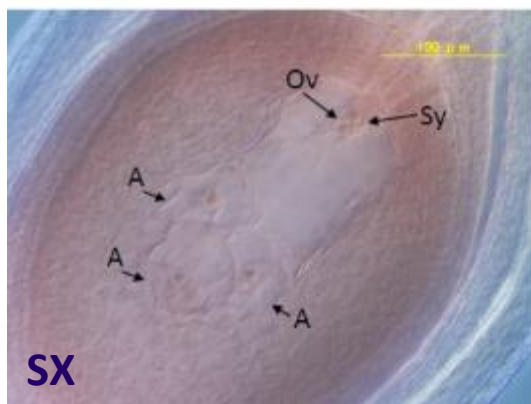
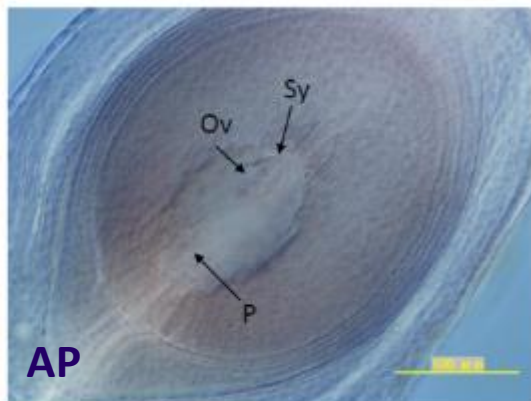
Origin of a synthetic, tetraploid sexual *Brachiaria* population





Breeding Strategy & Optimization

Scoring Apomixis



Embryo Sac Analysis
months

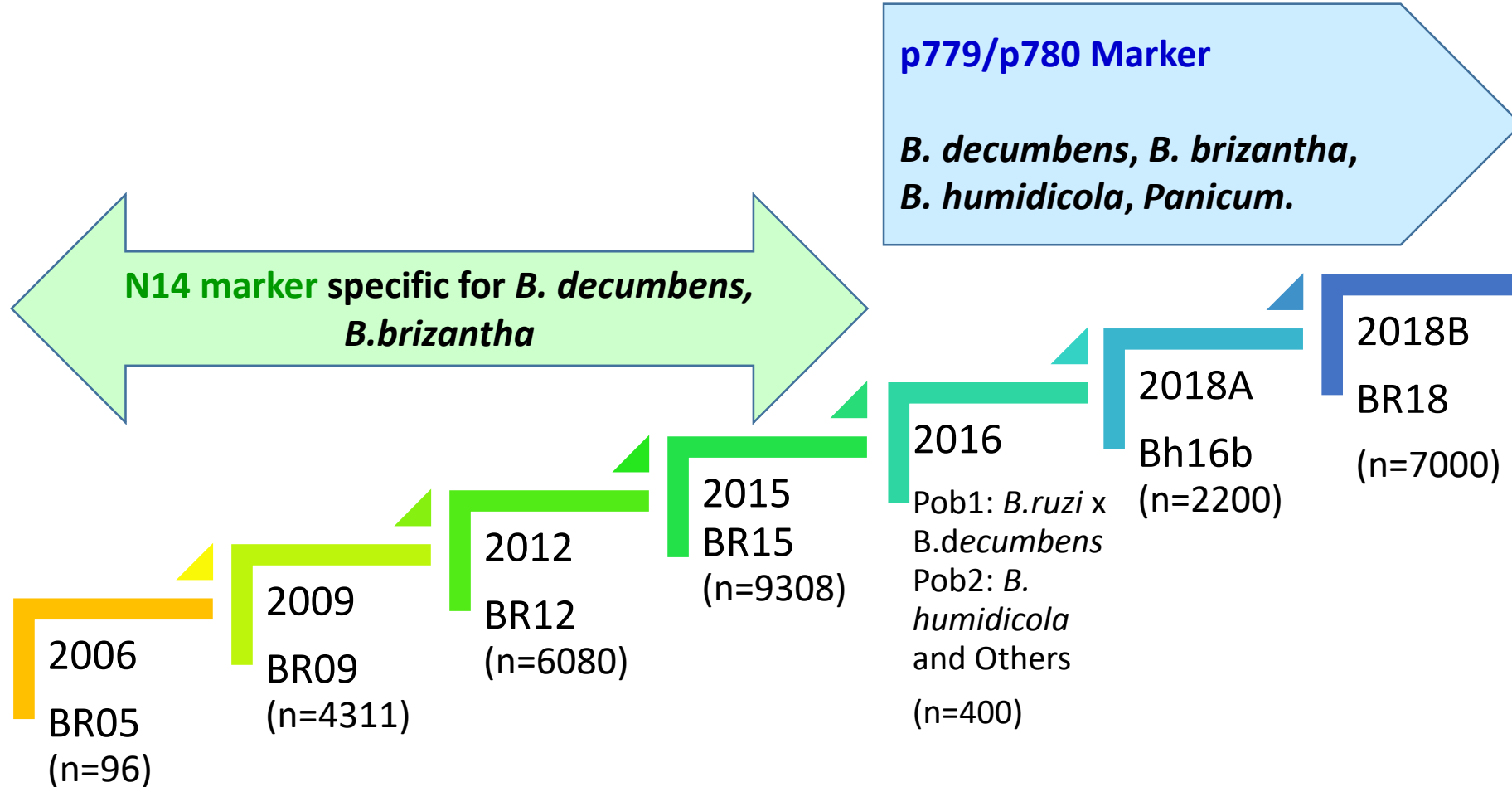
Progeny Test
years

MAS
weeks



Breeding Strategy & Optimization

10 years of Marker Assisted Selection for Apomixis



Number of genotyped plants is shown in parenthesis



Breeding Strategy & Optimization

GENETICS

A Parthenogenesis Gene Candidate and Evidence for Segmental Allopolyploidy in Apomictic *Brachiaria decumbens*

Margaret Worthington, Christopher Heffelfinger, Diana Bernal, Constanza Quintero, Yeny Patricia Zapata, Juan Guillermo Perez, Jose De Vega, John Miles, Stephen Dellaporta and Joe Tohme

Genetics July 1, 2016 vol. 203 no. 3 1117-1132; DOI: [10.1534/genetics.116.190314](https://doi.org/10.1534/genetics.116.190314)

Research partners:

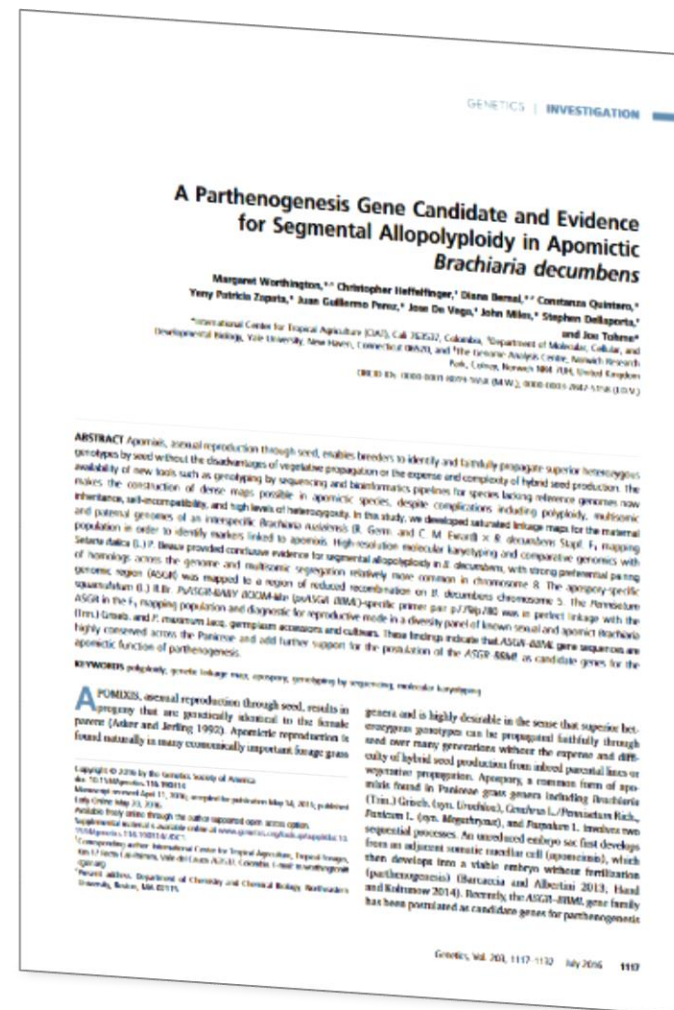


Yale University



Earlham Institute

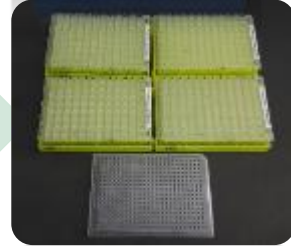
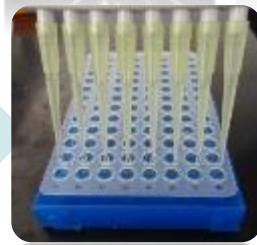
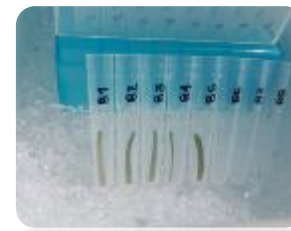
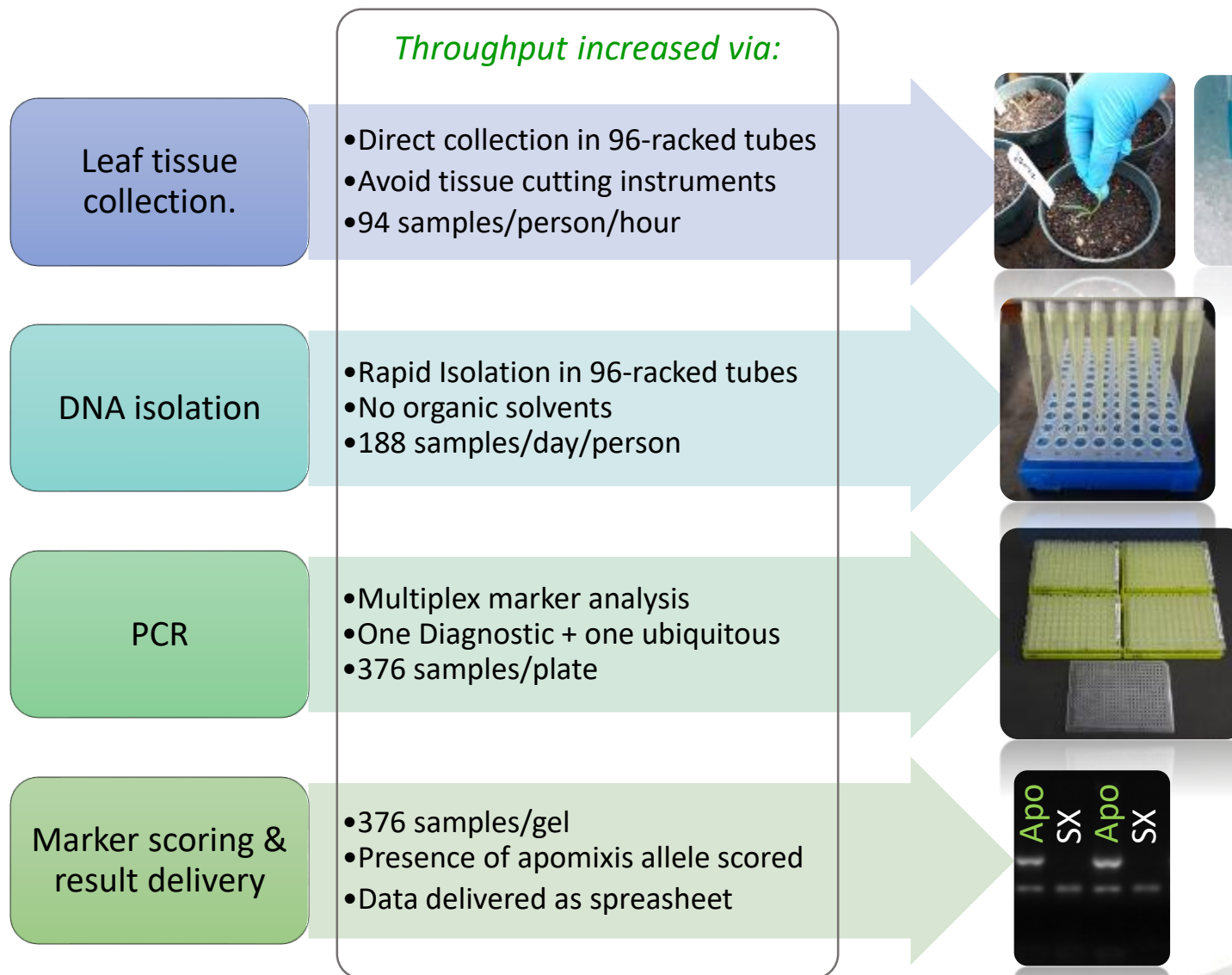
Building a sustainable future





Breeding Strategy & Optimization

Genotyping workflow for M.A.S. of apomixis

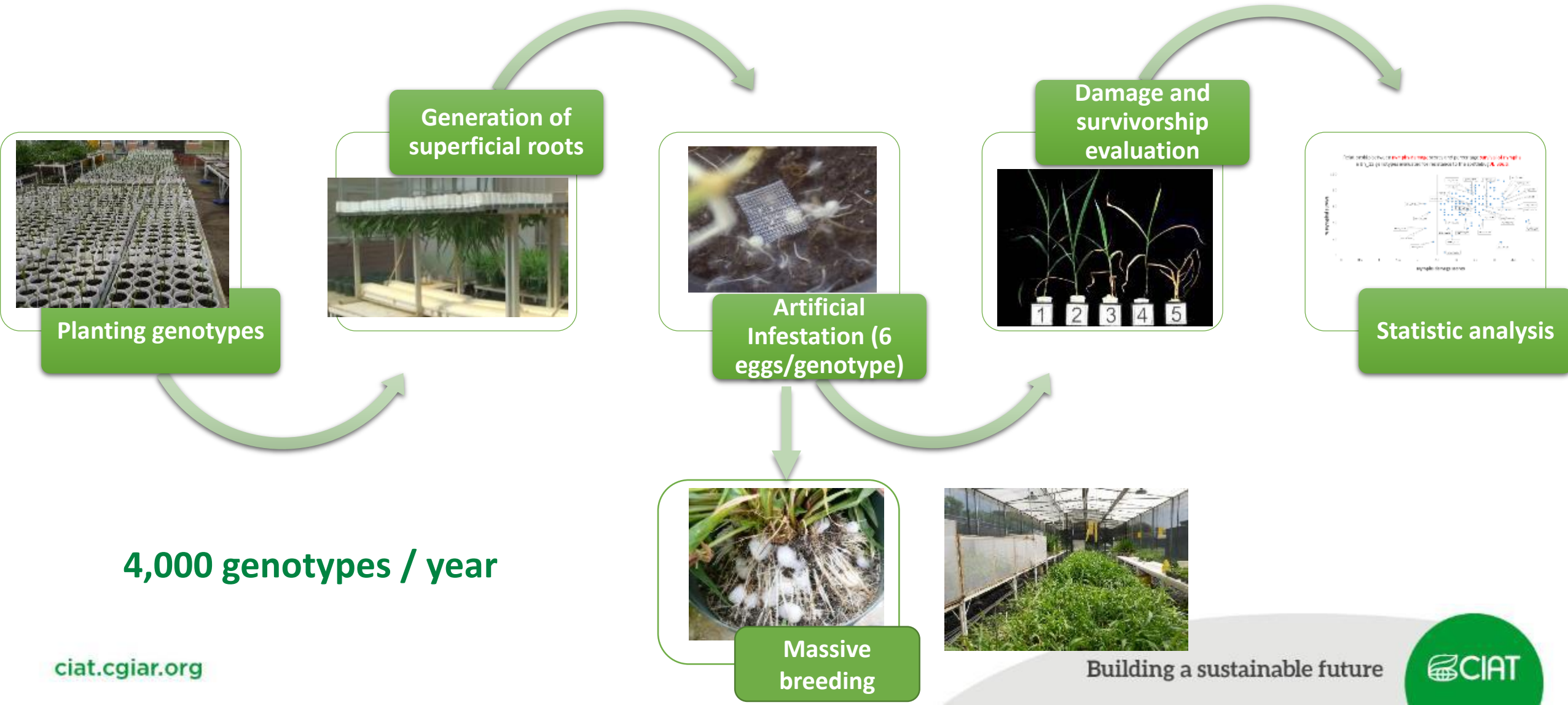


*Minimum turnaround time for 376 samples/3persons is 3days
Cost per data point: 0.723USD
(personnel cost not included)*



Breeding Strategy & Optimization

Phenotyping against spittlebugs (Nimphal stage)





Breeding Strategy & Optimization

Characteristics of the phenotyping process

High-throughput

1000 EU

High-speed

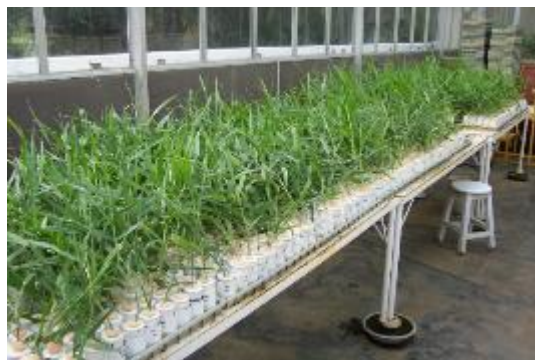
50-80 days

Short-space

12 m²

Accuracy

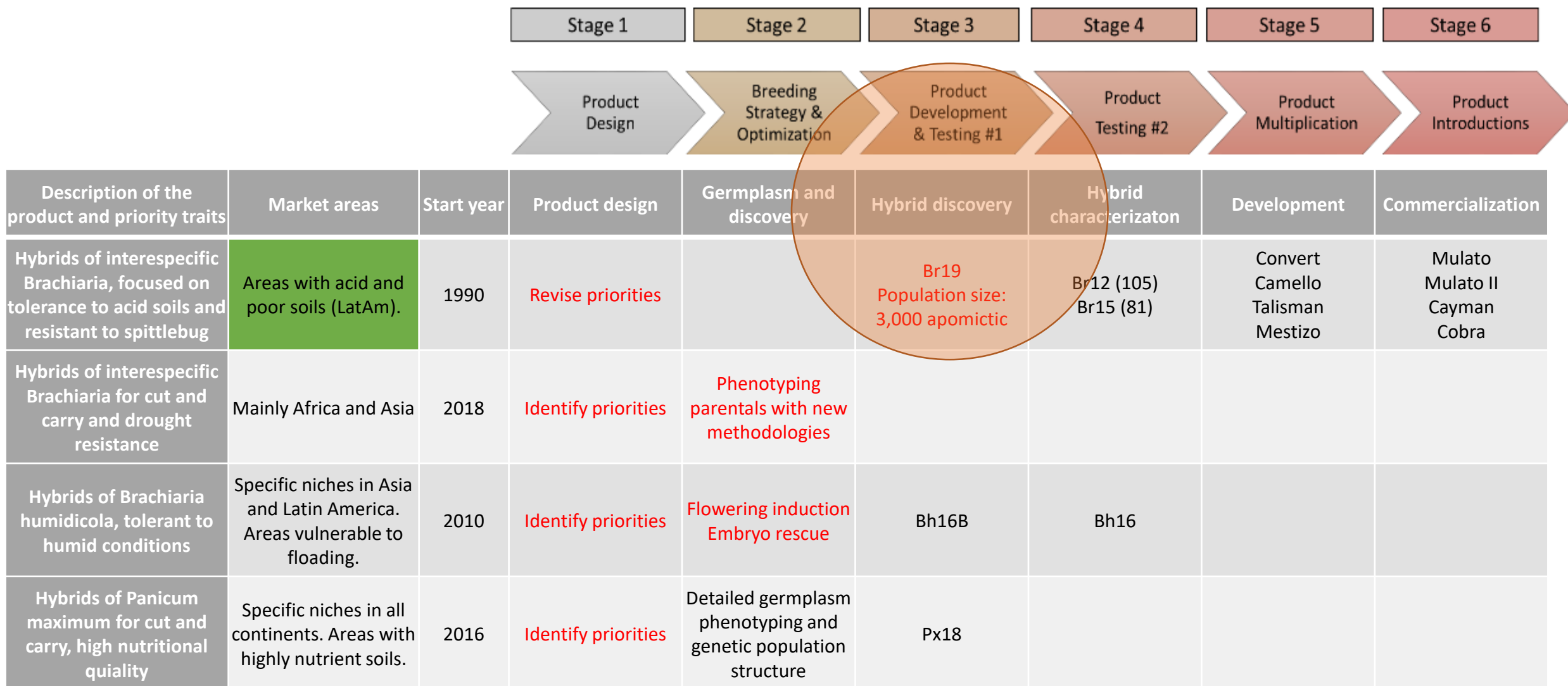
$\overline{CV} = 23.3\%$



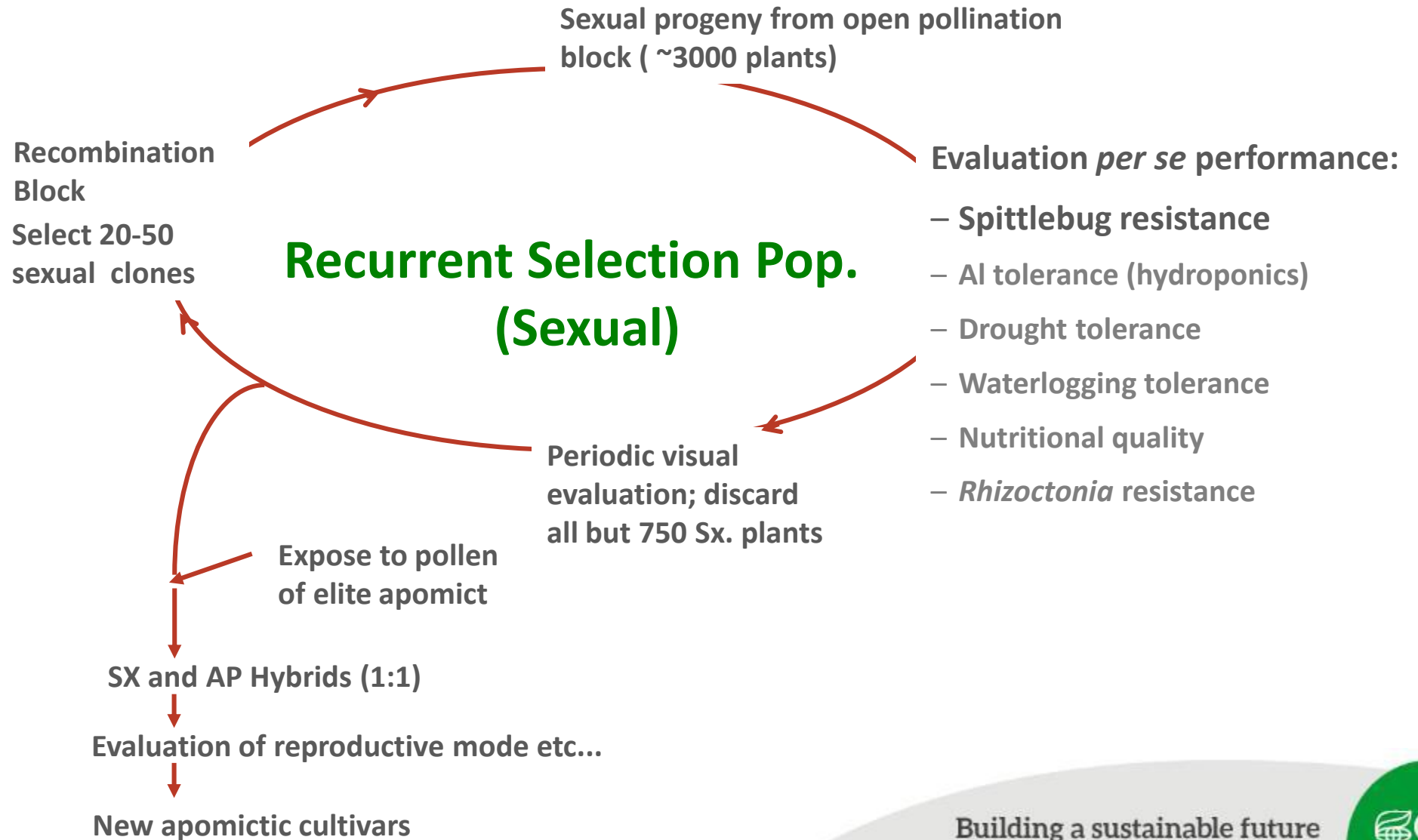
Building a sustainable future



Products and stages of development



*Activities that are about to be done for each product at each stage.





Product Development & Testing #1

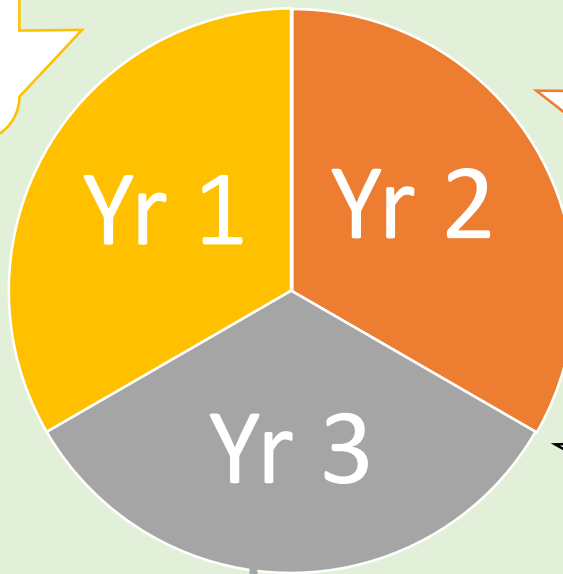
Interspecific Breeding scheme in *Brachiaria* (Miles, 2007)

VDP Stage 3: Product Development & Testing #1

Popayan

Recombination of sexual clones:

30 sexual clones in 2 plots (LAM & AF)



Formation of testcross progenies

SX x AP tester:



4000 to be analyzed by molecular markers for **apomixes**

Popayan

CIAT

Evaluation of testcross progenies:

RCDB – 2 reps with 2000 **apomictic clones**



Llanos

Multi-environment

Private Sector
+
NARS

Year 4
Year 5
Years 6-7
Years 8-10
Years 11-14

CULTIVAR RELEASE

VDP Stage 4:
Product testing 2



Product Development & Testing #1

Interspecific Breeding scheme in *Brachiaria* (Miles, 2007)

VDP Stage 3: Product Development & Testing #1

Popayan

Recombination of sexual clones:

30 sexual clones in 2 plots (LAM & AF)

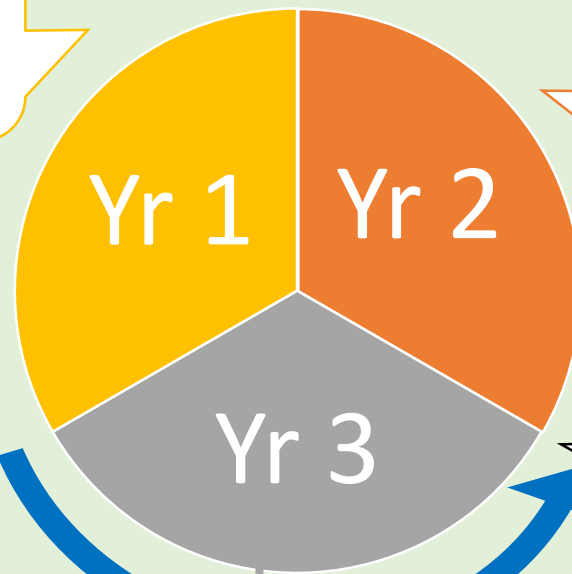


Year 4: Evaluation of testcross progenies:

Apomictic individuals derived from the best families are evaluated. AugD – 1 reps with 3000 apomictic clones



Llanos +
Palmira



Formation of testcross progenies
SX x AP tester:



7000 to be analyzed by molecular markers for apomixes

Popayan

CIAT

Evaluation of testcross progenies:

AugD – 1 reps with 3000 apomictic clones



Llanos +
Palmira

Year 4
Year 5
Years 6-7
Years 8-10
Years 11-14

Year 5
Year 6
Years 7-8
Years 9-11
Years 12-15

CULTIVAR RELEASE

Multi-
environment

Private
Sector
+
NARS

VDP Stage 4:
Product testing 2

Breeding stations in Colombia

● C.I. Turipaná

Palmira: CIAT headquarters.
All lab and glasshouse tests,
plus progeny tests.

● C.I. Nataima

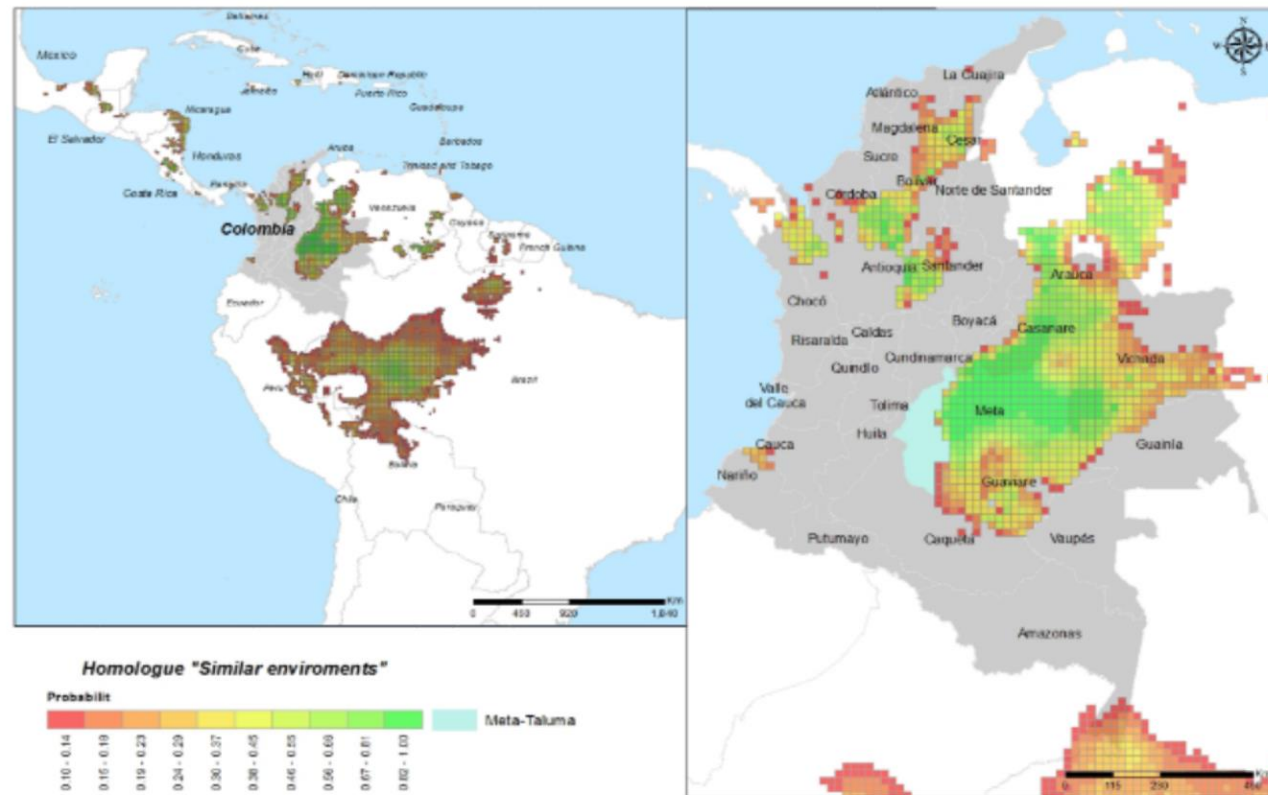
● El Porvenir

● La Florida

Patía: Strong dry season

Popayan: Dedicated to open
pollinated and test cross formation.
This location promotes flowering.

Llanos: Colombian most
similar environment to the
most important market in
Latin-America in the
tropical savannas of Brazil.



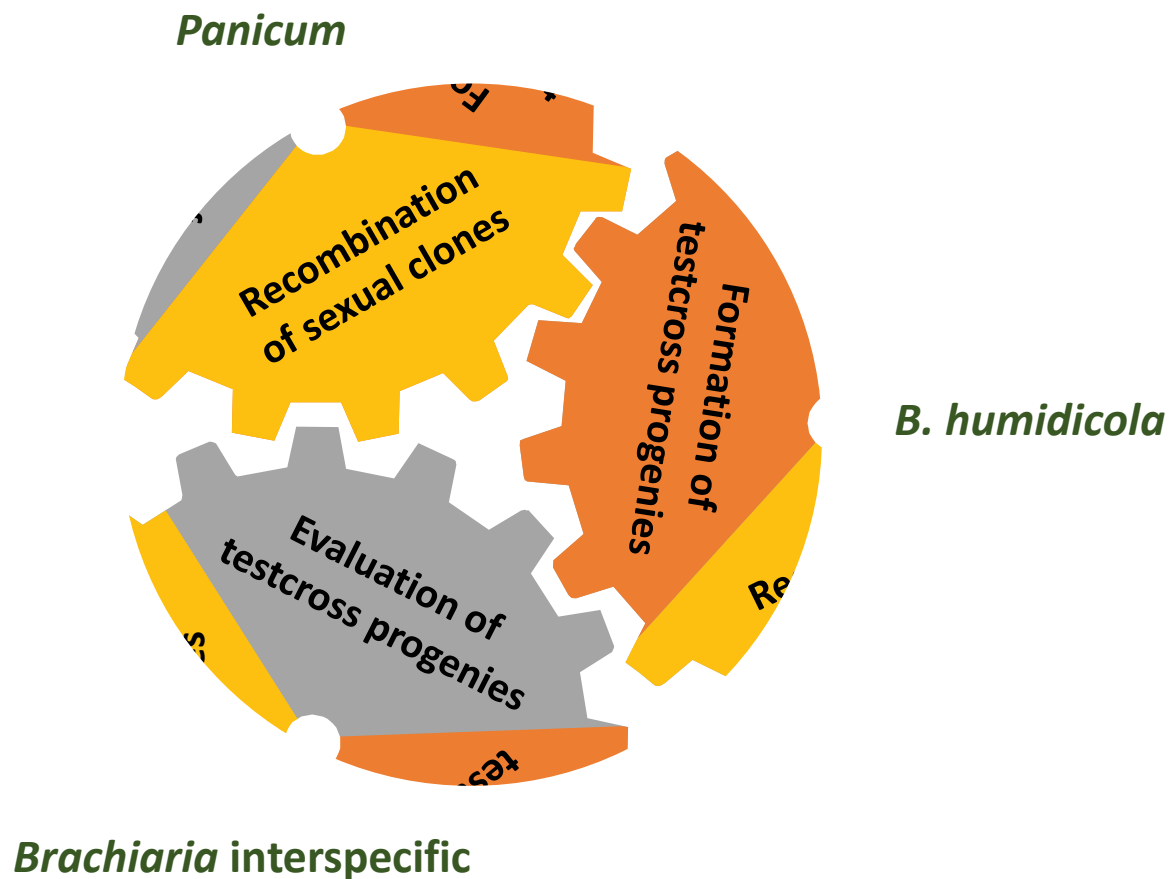
Identification of most representative environments from the main target environment, based on probability estimated by the program Homologue.



Year 1

Year 2

Year 3





Product Development & Testing #1

Future plans



Testcrosses

First evaluation

Second evaluation

Release



Marker Assisted Selection (MAS)
for Apomixes



3000 **Apomictic** clones in 3 locations
10% best – biomass

Testcrosses



Best parents, remanent seed
MAS: Apomixes



2018

2019

Best 100

Progeny test

Abiotic stress

Nutritional quality

Stage 1 Biomass (tonMS/ha/year)

Ideotype	<i>B. brizantha</i> cv. Toledo	<i>B. brizantha</i> cv. Marandú	<i>B. decumbens</i> cv. Basilisk	Híbrido interespecífico: Mulato II
Worst value accepted	CIAT 26110	CIAT 6780	CIAT 606	
> 20	25-35	15 - 20	15-20	20-25

Third evaluation

Fourth evaluation

Release

Final Evaluation			Priority	Ideotype	<i>B. brizantha</i> cv. Toledo	<i>B. brizantha</i> cv. Marandú	<i>B. decumbens</i> cv. Basilisk	Híbrido interespecífico
				Worst value accepted	CIAT 26110	CIAT 6780	CIAT 606	Mulato II
Stage 2	Quality	Protein Content	2	> 11.0	8-13	9-12	6-8	12-16
		% NDF		</= 60	63 - 72	65 – 75	65 – 75	56 – 65
		% ADF		</= 40	34 – 40	35 - 45	35 - 45	28 – 38
		% DIVMS (rumiantes)		> 72	55 - 60	55 - 65	55-65	60 - 65
	Biotic stress	Spittlebug Resistance - Visual damage score	3	< 2	Susceptible	Resistant	Susceptible	Resistant - antibiosis
		Rhizoctonia solani	5	< 2		Suceptible		
	Abiotic stress	Al tolerance	4	4.0-8.0 pH			3.9-7.5 pH	
		Waterlogging 15-21 days (%reduction compared to drained plants)	7	> 50	40-30 (moderately sensitive)	30-20 (sensitive)	50-40 (moderately tolerant)	20-10 (extremely sensitive)
		Waterlogging 15-21 days (SPAD values)	7	> 25	25-20	25-15	28-20	25-15
		Drought (soil kept at 50% field capacity) (%reduction of foliar area compared to plants kept at 80-100 %)	6	> 50	40-50	40-50	40-50	40-50
		Drought (soil kept at 50% field capacity) (Leaf rolling scores) Scale 0: no wilting; Scale 6: wilted, symptoms of senescence	6	< 2	3-4	3-4	2-3	2-3



Past

Today

Realized
selection
gain

$$\Delta G = \mu' - \mu$$

- Genotypic means of the selected fraction and the entire population.



Product Development & Testing #1

Realized genetic gain

The genetic gain achieved by the *Brachiaria* breeding program was first reported in

2006

(J. W. Miles, Cardona, & Sotelo, 2006)

Where it was demonstrated that

Synthetic
tetraploid
sexual breeding

was far superior
to the original

Tetraploidized
ruzigrass

And it was also
explained how

Recurrent
selection

in the synthetic
population
promoted such
improvement



Recurrent Selection in a Synthetic Brachiariagrass Population Improves Resistance to Three Spittlebug Species

J. W. Miles,* C. Cardona, and G. Sotelo

ABSTRACT

Spittlebugs (Homoptera: Cercopidae) are important pests of forage grasses in the genus *Brachiaria* (Trin.) Griseb. throughout the neotropics. Results of recurrent selection on resistance to spittlebugs in a synthetic brachiariagrass population are reported. The population was synthesized by recombining sexual hybrids obtained from crosses between a tetraploidized sexual ruzigrass (*B. ruzickensis* Germain & Evrard) biotype and nine natural apomictic tetraploid accessions of signalgrass (*B. decumbens* Stapf) and palisadegrass (*B. trizantha* (A. Rich.) Stapf). The first three selection cycles were on resistance to a single Colombian spittlebug species [*Aeneolamia varia* (F.)], and the final two cycles simultaneously on resistance to *A. varia* and to two additional Colombian spittlebug species [*A. reducta* (Lallemand) and *Zulia carbonaria* (Lallemand)]. Selection was based on survival of spittlebug nymphs feeding on artificially infested, greenhouse-grown plants. From C₂ to C₆, mean survival of *A. varia* nymphs on selected genotypes dropped from 55.6 to 7.0%. Tetraploid sexual clones with combined high levels of resistance to all three spittlebug species have been obtained. The effectiveness of this resistance against spittlebug species not occurring in Colombia needs to be determined, and its expression in crosses with spittlebug-susceptible, apomictic genotypes needs to be assessed.

THE FOUR commercial brachiariagrass species [signalgrass, palisadegrass, ruzigrass, and koroniviagrass (*B. humidicola* (Rendle) Schweick.)] together constitute by far the most important sown forage grasses in tropical America (Miles et al., 2004; Santos Filho, 1996). All four species are perennials of African origin. Three of them (signalgrass, palisadegrass, and ruzigrass) are closely related (Renvoize et al., 1996) but differ in their agronomic characters, so that each tends to occupy a distinct agronomic niche. Ruzigrass is a diploid sexual species, while accessions of signalgrass and palisadegrass are mostly tetraploid apomicts (Miles et al., 2004; Valle and Savidan, 1996). The currently available cultivars, except for the recently released cv. Mulato, which is a result of intentional interspecific hybridization, are apomictic selections from natural germplasm (Miles et al., 2004).

Commercialization of brachiariagrasses in Latin America began in the early 1970s with the importation to Brazil of Australian seed of 'Basilisk' signalgrass (Santos Filho, 1996), a cultivar derived directly from a Ugandan germplasm accession introduced to Australia in 1930 (Oram, 1990). Adoption of cv. Basilisk was very

rapid in Brazil and more widely throughout tropical America as it proved to be well adapted to extensive areas of savanna with low fertility and low pH soils (Santos Filho, 1996).

The greatest biotic limitation on brachiariagrass pasture productivity in the neotropics are the many native genera and species of grassland spittlebugs (Homoptera: Cercopidae) (Valério et al., 1996; Holmann and Peck, 2002). Basilisk signalgrass and common commercial ruzigrass are particularly susceptible. 'Marandu' palisadegrass was released by the Brazilian Agricultural Research Corporation (EMBRAPA, its Portuguese acronym) in the mid-1980s owing mainly to its resistance to spittlebugs (Nunes et al., 1984). Marandu is now extensively sown, though its adaptation does not extend to the very low fertility soils where cv. Basilisk is so well adapted, nor is it used in parts of the tropics (e.g., Thailand or tropical Australia) where spittlebug attack is not a threat. Ruzigrass, though of high nutritional quality (Valle et al., 1988; Lascano and Euclides, 1996), is only a minor commercial species in tropical America owing to its poor adaptation to low fertility soils and particularly to its extreme susceptibility to spittlebugs (Keller-Grein et al., 1996). Ruzigrass is an important commercial forage grass in southeast Asia, e.g., in Thailand, where locally produced seed is abundant and cheap (Hare and Phaikaw, 1999).

A small collection of brachiariagrass germplasm maintained by the International Center for Tropical Agriculture (CIAT, its Spanish acronym) was augmented during 1984 and 1985 through direct collection in Africa (Keller-Grein et al., 1996) with the objective of obtaining genotypes with broad edaphic adaptation combined with resistance to spittlebugs. Agronomic evaluation of the new germplasm collection suggested that none of the accessions offered the needed combination of attributes. Following the development of a fully sexual, tetraploid ruzigrass biotype (Svenne et al., 1981) and confirmation of its cross compatibility with apomictic tetraploid signalgrass and palisadegrass accessions (Ndikumana, 1985), applied brachiariagrass breeding programs quickly ensued, both at EMBRAPA and at CIAT (Miles and Valle, 1996; Miles et al., 2004).

Inheritance studies indicated a single-locus model of genetic control of apomixis in the signalgrass-palisadegrass-ruzigrass agamic complex (Ndikumana, 1985; Valle et al., 1994; Valle and Savidan, 1996): tetraploid apomicts are simplex for a dominant allele (Aaaa) at the putative "apomixis locus," sexuals being homozygous recessive at the locus and either diploid (aa) or tetraploid (aaaa). Hence, tetraploid, sexual × apomictic hybrid progenies segregate approx. 1:1 for reproductive mode and sexual × sexual progenies are uniformly sexual (Valle and Savidan, 1996).

Tropical Forages Project, International Center for Tropical Agriculture, A.A. 6713, Cali, Colombia. Received 3 June 2005. *Corresponding author (j.miles@cgiar.org).

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Crop Breeding & Genetics

doi:10.2135/cropsci2005.06-0101

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677 S. Segoe Rd., Madison, WI 53711 USA



Evidence of realized selection gain: Resistance of *Brachiaria* population against spittlebug



1998

Resist. Intermediate Susceptible



2004

Resistant

Intermediate

Susceptible



Product Development & Testing #1

Percentage nymphal survival and damage scores of final selections compared with cv. Marandu, by cycle.



Numerous sexual clones have now been isolated that combine resistance to each of the **three spittlebug species**

Cycle	No. of final selections	<i>Aeneolamia varia</i>		<i>Aeneolamia reducta</i>		<i>Zulia carbonaria</i>	
		Selections	Marandu	Selections	Marandu	Selections	Marandu
Percentage nymphal survival							
C ₂	11	55.6	32.5**	—	—	—	—
C ₃	11	45.0	40.0NS†	—	—	—	—
C ₄	41	25.9	23.0NS	—	—	—	—
C ₅	32	16.8	33.3*	17.2	33.3NS	38.2	69.4*
C ₆	42	7.0	36.7**	1.4	52.4**	4.9	50.0**
Damage scores‡							
C ₂	11¶	—	—	—	—	—	—
C ₃	11	2.4	1.7NS	—	—	—	—
C ₄	41	1.7	2.2NS	—	—	—	—
C ₅	32	2.0	2.1NS	1.6	2.8**	2.1	3.6**
C ₆	42	1.3	1.9*	1.1	3.1**	1.2	2.4**

* Mean of selections differs (by *t* test) from mean of cv. Marandu at the $\alpha = 0.05$ probability level.

** Mean of selections differs (by *t* test) from mean of cv. Marandu at the $\alpha = 0.01$ probability level.

† NS, Means do not differ at the $\alpha = 0.05$ probability level.

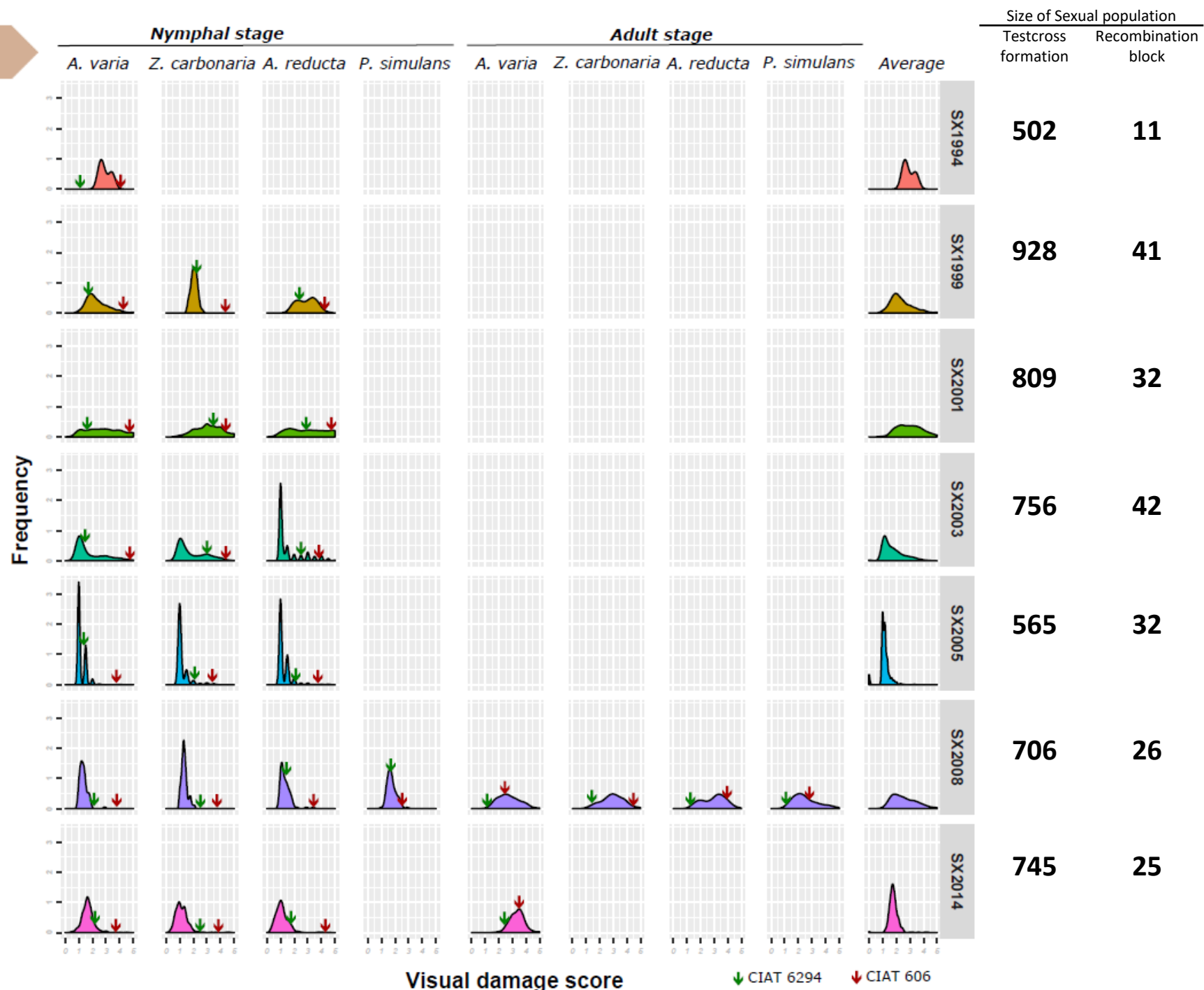
‡ Visual damage score on a scale of 1 (= no damage) to 5 (= dead plant).

¶ Damage scores not recorded in C₂.



Product Development & Testing #1

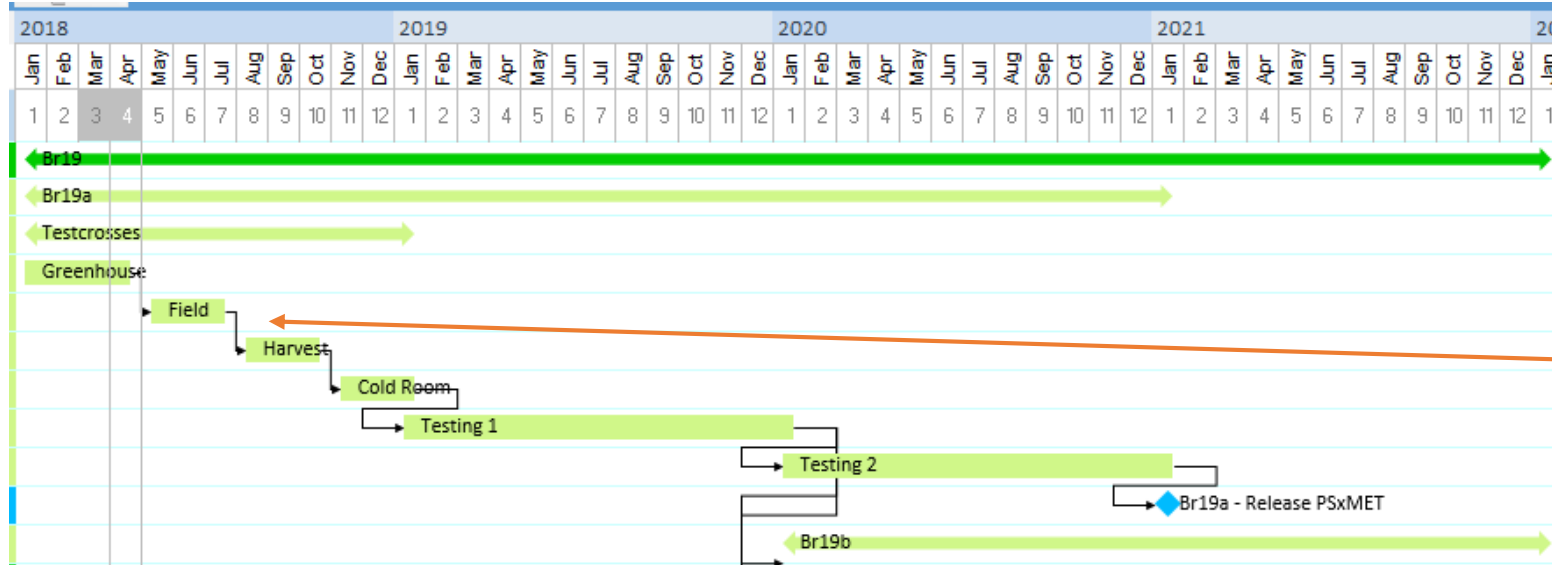
Genetic gain achieved by the population of recurrent selection in terms of resistance against several species of spittlebug.



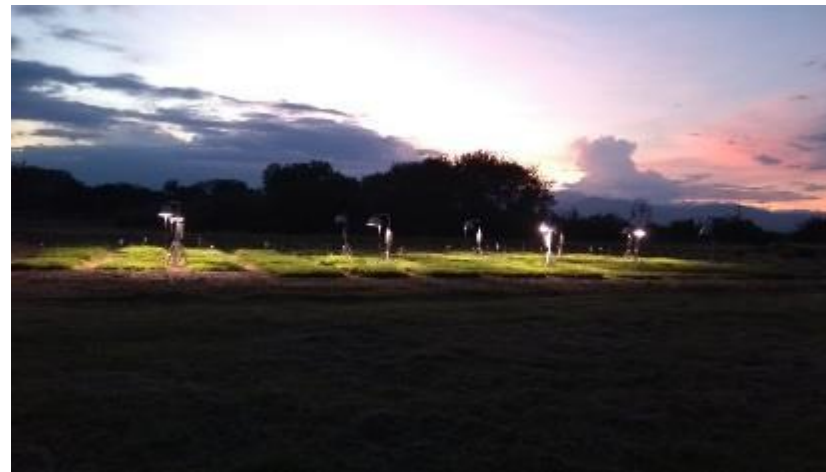


Product Development & Testing #1

Alternatives to increase expected genetic gain:
Rapid breeding



$$\Delta G = \frac{ih\sigma_g}{Y}$$

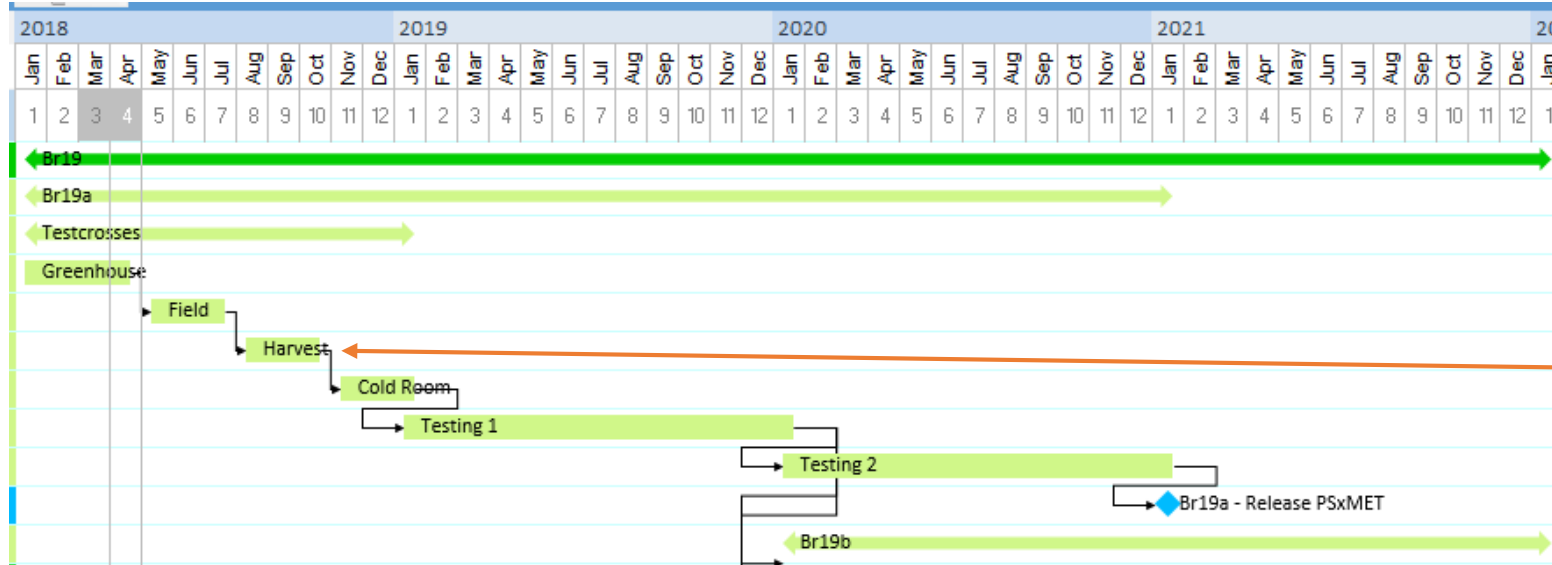


Flowering
control

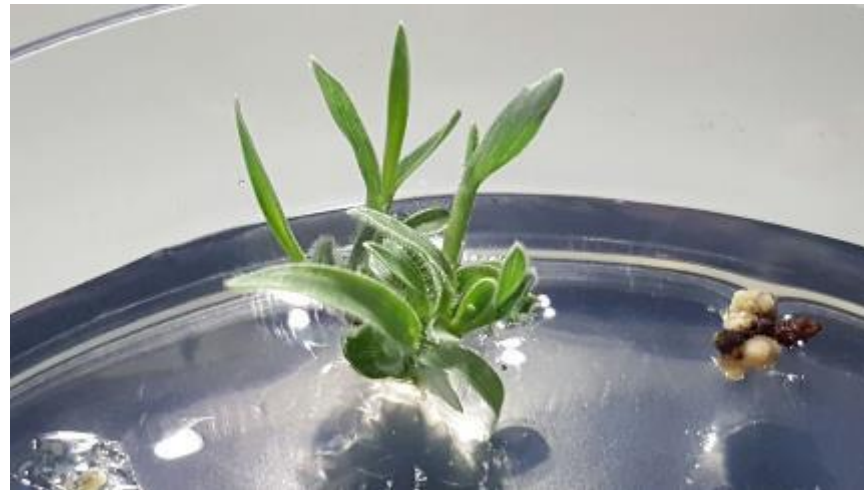


Product Development & Testing #1

Alternatives to increase expected genetic gain:
Rapid breeding



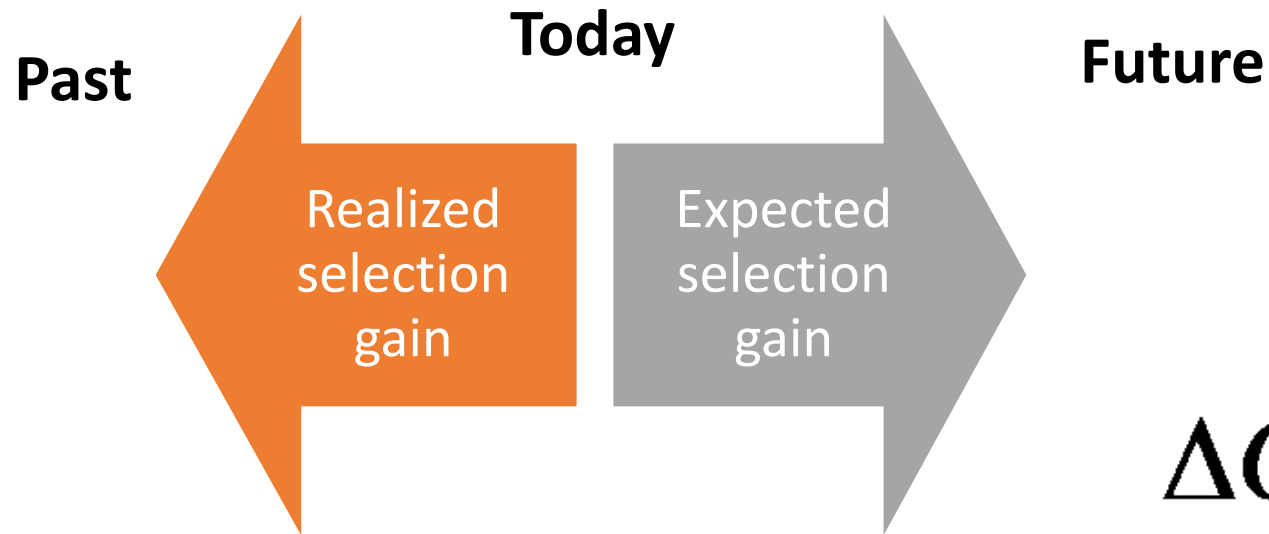
$$\Delta G = \frac{ih\sigma_g}{Y}$$



Embryo Rescue

Courtesy of Didier Marin. Transformation Platform

Special projects



$$\Delta G = \mu' - \mu$$

- Genotypic means of the selected fraction and the entire population.

$$\Delta G = \frac{ih\sigma_g}{Y}$$

- *a priori* analysis used in quantitative traits (Cochran, 1951 – Utz 1969 – Longin 2015)
- Apply R package SelectionGain

Optimum allocation of resources with simulations using the package Selection Gain

Package 'selectiongain'

October 9, 2016

Type Package

Title A Tool for Calculation and Optimization of the Expected Gain from Multi-Stage Selection

Version 2.0.591

Date 2016-10-09

Author Xuefei Mi, Jose Marulanda, H. Friedrich Utz, Albrecht E. Melchinger (Project contact person: Melchinger@uni-hohenheim.de)

Maintainer Xuefei Mi <mi_xue_fei@hotmail.com>

Depends R (>= 3.0.0), mvtnorm, parallel

Description Multi-stage selection is practiced in numerous fields of life and social sciences and particularly in breeding. A special characteristic of multi-stage selection is that candidates are evaluated in successive stages with increasing intensity and effort, and only a fraction of the superior candidates is selected and promoted to the next stage. For the optimum design of such selection programs, the selection gain plays a crucial role. It can be calculated by integration of a truncated multivariate normal (MVN) distribution. While mathematical formulas for calculating the selection gain and the variance among selected candidates were developed long time ago, solutions for numerical calculation were not available. This package can also be used for optimizing multi-stage selection programs for a given total budget and different costs of evaluating the candidates in each stage.

License GPL-2

NeedsCompilation no

Repository CRAN

Date/Publication 2016-10-09 17:54:53

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DOI 10.1007/s00122-016-2748-5



ORIGINAL ARTICLE

Optimum breeding strategies using genomic selection for hybrid breeding in wheat, maize, rye, barley, rice and triticale

Jose J. Marulanda¹ · Xuefei Mi² · Albrecht E. Melchinger³ · Jian-Long Xu³ · T. Würschum² · C. Friedrich H. Longin²

Received: 5 April 2016 / Accepted: 25 June 2016 / Published online: 7 July 2016
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Abstract

Key message A breeding strategy with moderate nursery selection followed by genomic selection and one-stage phenotypic selection maximizes annual selection gain for grain yield across a wide range of hybrid breeding scenarios.

Abstract Genomic selection (GS) is a promising method for the selection of quantitatively inherited traits but its most effective implementation in routine hybrid breeding schemes requires further research. We compared five breeding strategies and varied their available budget, the costs for doubled haploid (DH) line and hybrid seed production as well as variance components for grain yield in a wide range. In contrast to previous studies, we included a nursery selection for disease resistance just before GS on grain yield. The breeding strategy *GSrapid* with moderate nursery selection followed by one stage GS and one final stage with phenotypic selection on grain yield had the highest annual selection gain across all strategies, budgets, costs and variance components considered and we, therefore, highly recommend its use in hybrid breeding of cereals. Although selecting on traits not correlated with grain yield in the observation nursery, this selection reduced

the selection gain of grain yield, especially in the breeding schemes with GS and for selected fractions smaller than 0.3. Owing to the very high number of test candidates entering breeding strategies with GS, the costs for DH line production had a larger impact on the annual selection gain than the hybrid seed production costs. The optimum allocation of test resources maximizing annual selection gain in classical two-stage phenotypic selection on grain yield and for the recommended breeding strategy *GSrapid* is finally explored for maize, wheat, rye, barley, rice and triticale.

Introduction

Genomic selection (GS) is a promising method with high potential to improve selection of complex traits like grain yield (He et al. 2016). Most research on GS has focused on prediction models and prediction accuracies in different crops (Bernardo and Yu 2007; Jannink et al. 2010; Heslot et al. 2012; Windhausen et al. 2012; Lorenz 2013; Technow et al. 2014; Lehermeier et al. 2014; Zhang et al. 2015; Zhao et al. 2015). Although different prediction models were applied, they achieved very similar prediction accuracies. In hybrid breeding, three prediction scenarios must be distinguished: prediction of hybrids for which no (T0), one (T1) or both parents (T2) have been phenotyped for their general combining ability (GCA) of grain yield (Technow et al. 2014; Zhao et al. 2015). Thereby, T0 represents the prediction of new DH lines based on calibrations developed in previous cycles of selection (Longin et al. 2015). Current studies in hybrid wheat, maize, rice and rye report average T0—prediction accuracies of GS for grain yield varying from 0.2 to 0.4 (Zhao et al. 2013; Albrecht et al. 2014; Bernal-Vasquez et al. 2014; Xu et al. 2014). For hybrid barley

Communicated by H. Iwata.

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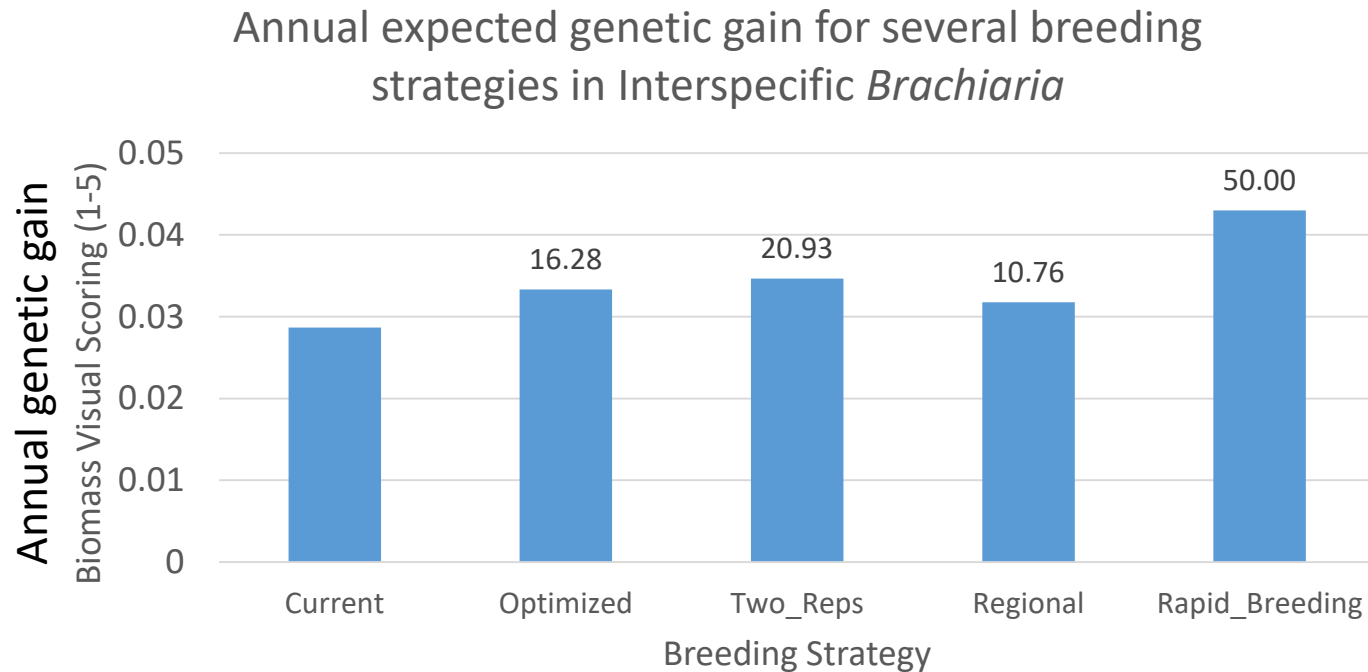
² State Plant Breeding Institute, University of Hohenheim, 70599 Stuttgart, Germany

³ Agricultural Genomics Institute, Chinese Academy of Agricultural Sciences, Shenzhen 518120, China



Product Development & Testing #1

Annual expected genetic gain for several breeding strategies in Interspecific *Brachiaria*

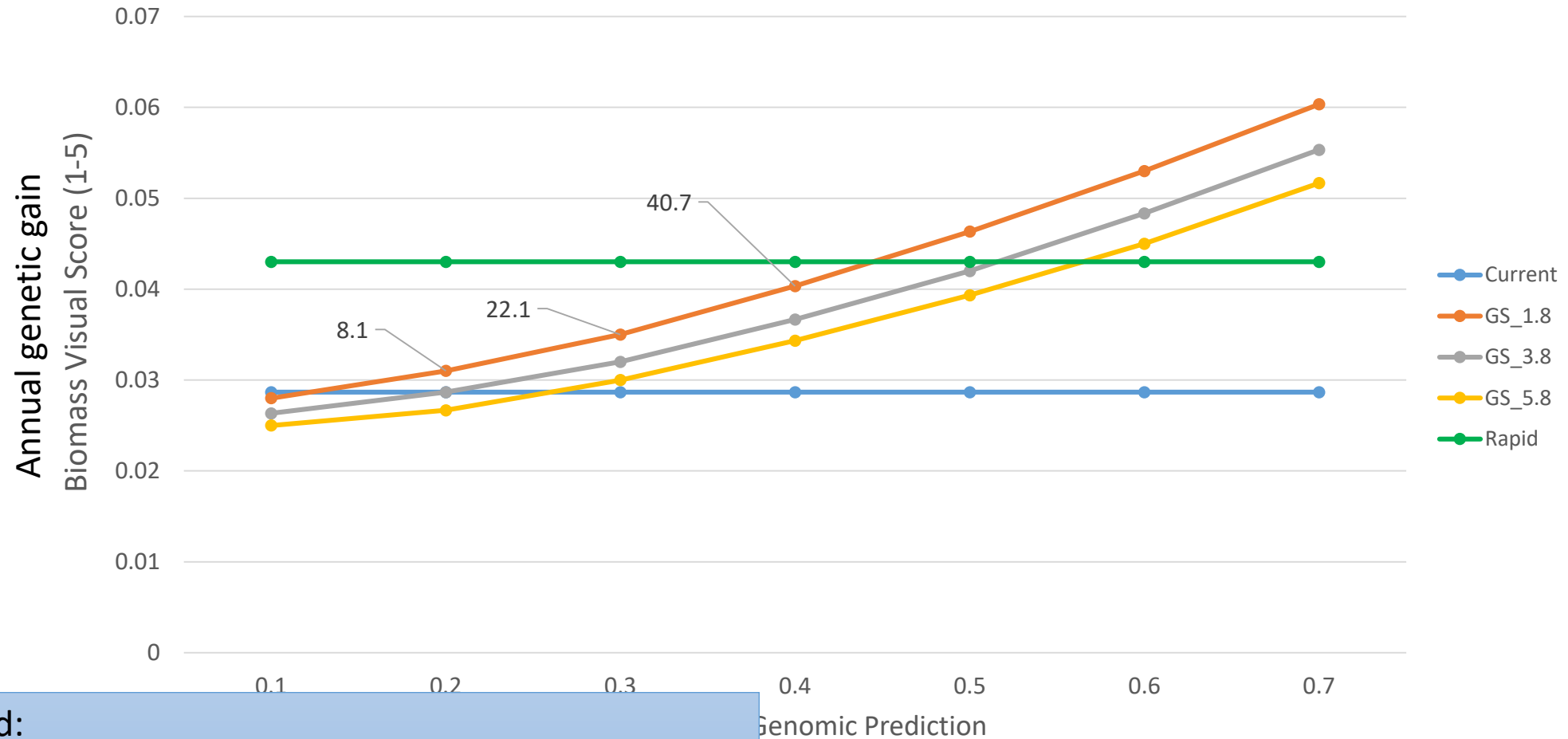


- **Current**
- **Optimized:** Reducing population size (-27%) while increasing locations (3 to 5).
- **Two-Reps:** Reducing population size (-36%) increasing reps (1 to 2).
- **Regional:** Reducing PopSize (Year 1: -32%; Year 2: 25% of year 1), increasing one year to include information of regional trials (5P + 5C= 10Loc) into recurrent selection.
- **Rapid_Breeding:** Reducing breeding cycle from 3 to 2 years.



Product Development & Testing #1

Potential of Genomic Selection for *Brachiaria* Interspecific Breeding



To be tested:

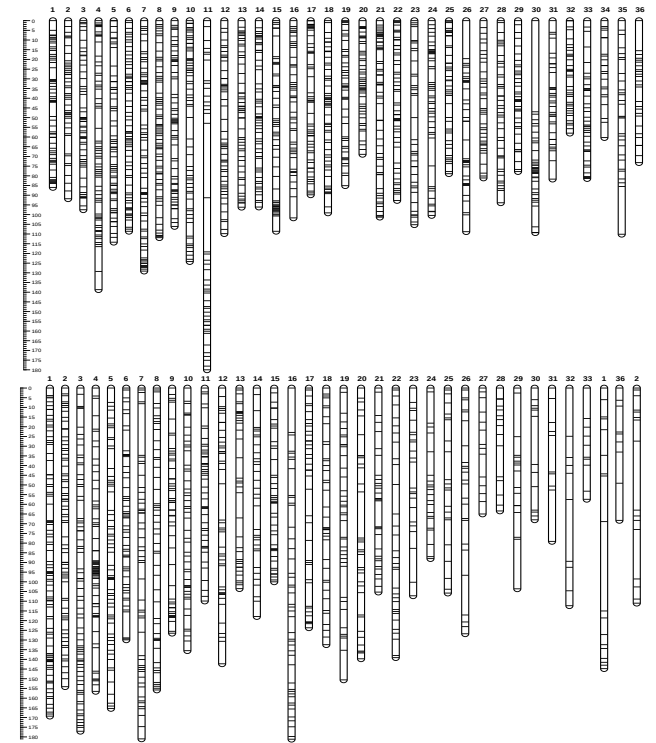
- RS-SCA vs. RRS. Challenge: Collect GCA field info
- Scenario Africa: Split the program in two ideotypes
- Tandem Selection: Challenge in programming



- Genomics complicated by: Large genome size, polyploidy, heterozygous parents, and multisomic segregation ratios
BUT modern tools and low-cost sequencing => rapid progress

First saturated genetic maps (GBS based)

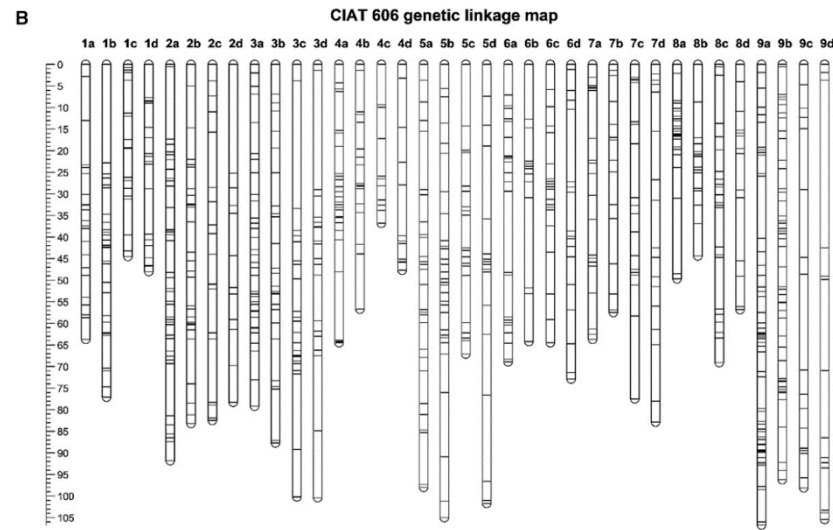
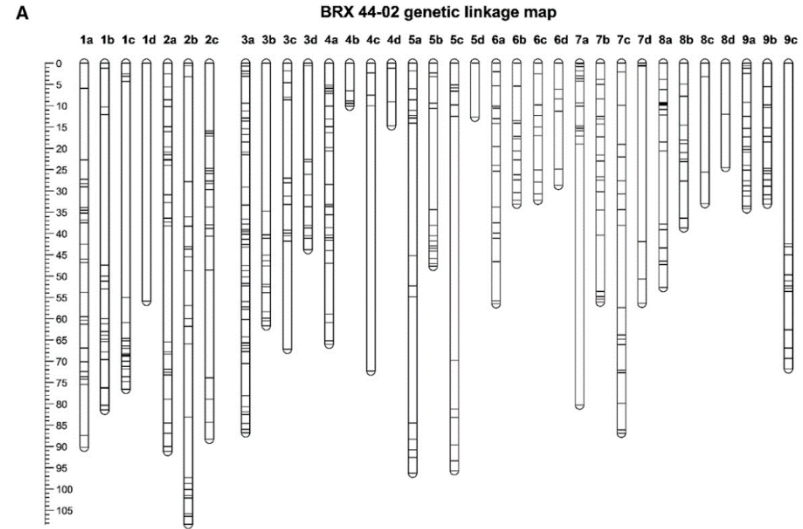
- *B. ruziziensis* x *B. decumbens*
 - $2n=4x=36$ (segmental allotetraploid)
 - Aluminum resistance QTL – On going
 - Flanking markers for apomixis
- *B. humidicola*
 - $2n=6x=36$ (autohexaploid)
 - QTL for biological nitrification inhibition
 - Flanking markers for apomixes
- Diploid *B. ruziziensis* reference genome (with TGAC)
30x Illumina PE reads, assembly by Platanus.
(https://www.ncbi.nlm.nih.gov/assembly/GCA_003016355.1/)





Product Development & Testing #1

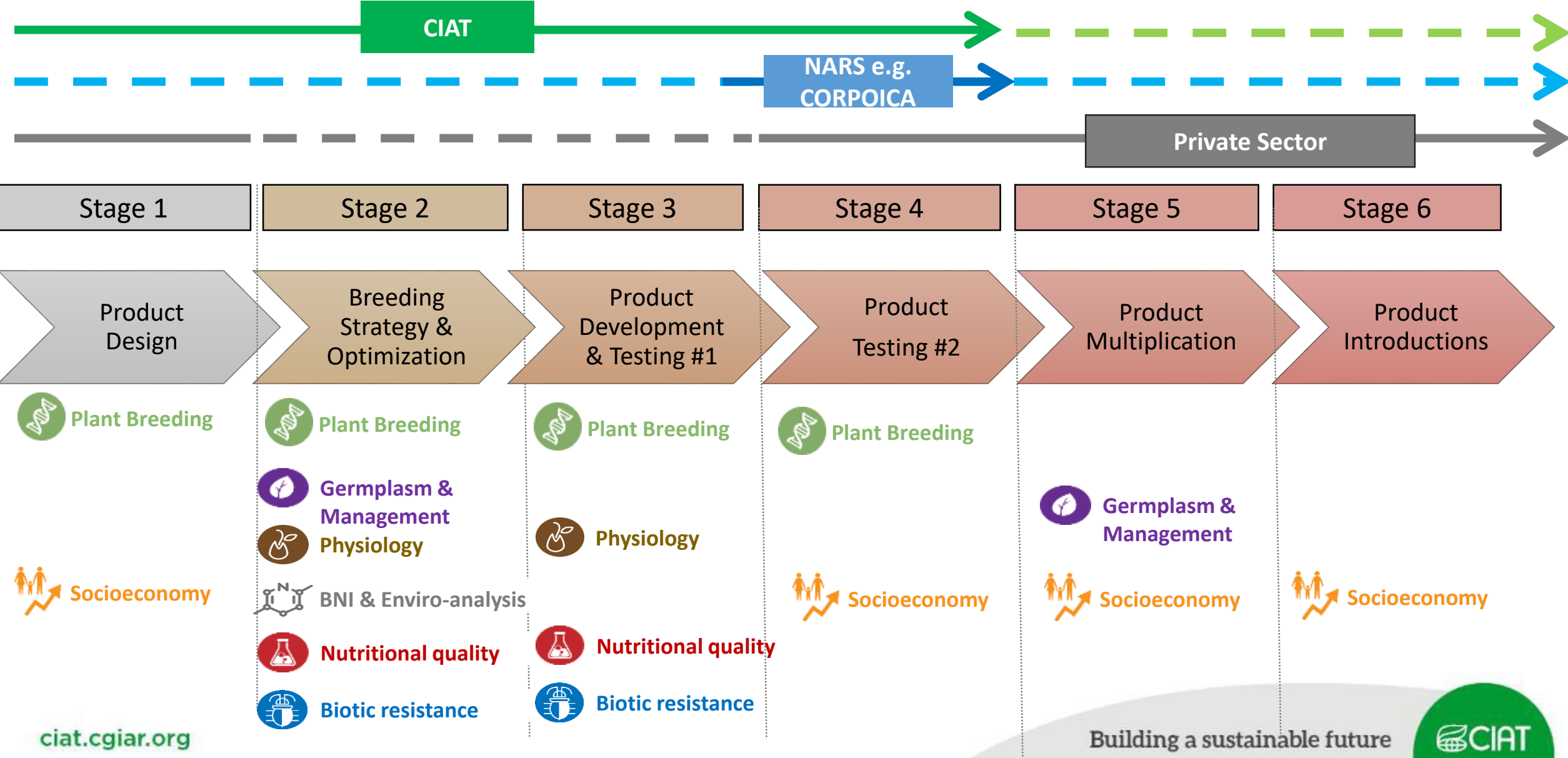
Genetic linkage maps *B. ruziziensis* and *B. decumbens* constructed Worthington et.al., 2016 (CIAT, YALE, TGAC)



- GBS of F_1 populations and parents.
- The apospory-specific genomic region (ASGR) was mapped to a region of reduced recombination on *B. decumbens* chromosome 5.



Team, partners and VDP





Product Multiplication

Delivery and dissemination

Massive seed production for *Brachiaria* seems to be stimulated by

Vernalization



Long
photoperiods

Therefore, seed production should be ideally localized in **higher latitudes**



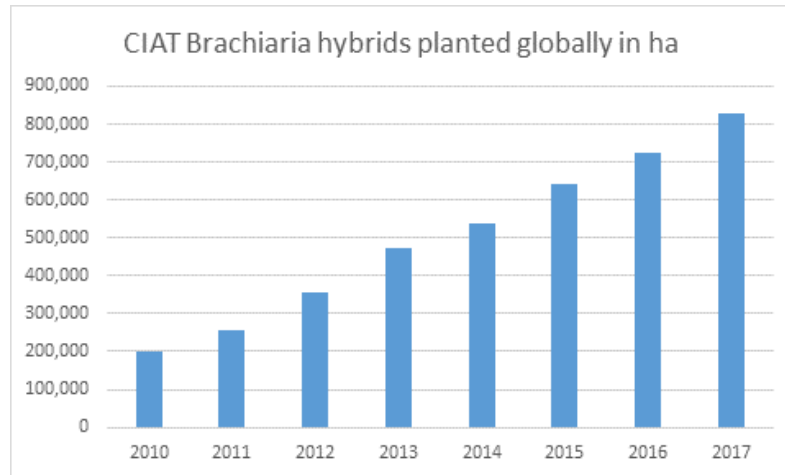
Private seed producers multiply successfully hybrid seed at the **Cerrado** in Brazil and the **North of Mexico**.

Interaction with a solid seed company is critical for successful delivery and dissemination of hybrid *Brachiaria* seed.



Product Introductions

Commercial releases



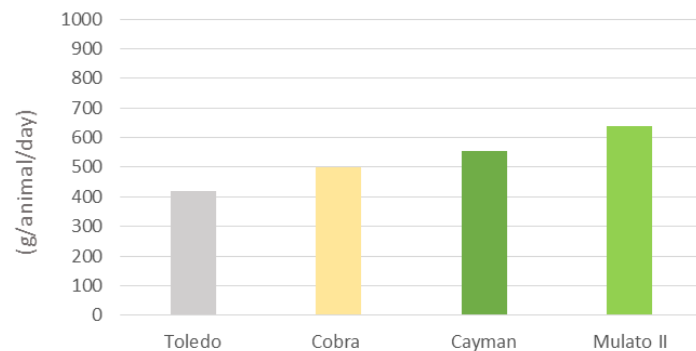
Mulato, the first commercial hybrid (released in **2001**) was bred by CIAT.



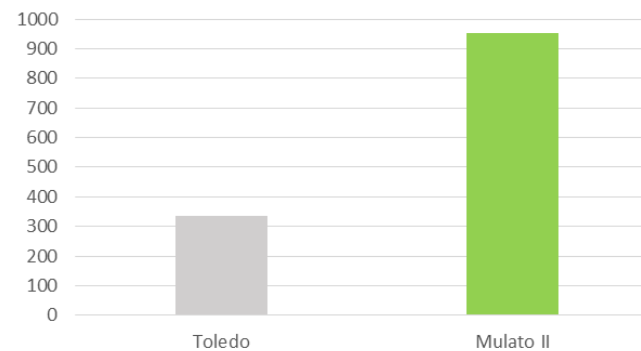
Hybrids has been a success in the market, reaching a estimated total area of **828,638** Ha*

Hybrids released have been proven that increase productivity in animal weight

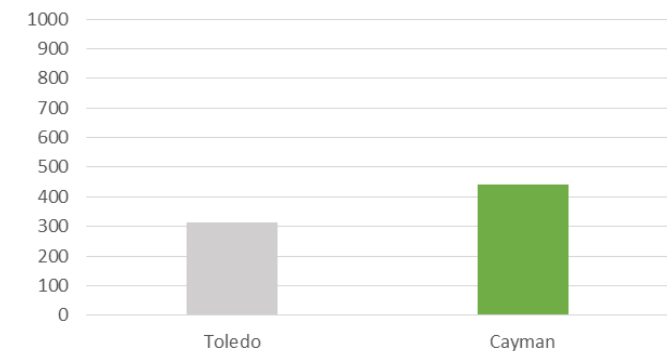
Daily weight gain



Villavicencio station



Cauca station



CIAT Headquarters



Product Introductions

Hybrids research in Africa: Mulato and Mulato-II

**Intercropping forages
in dairy systems**

(Uganda, Madagascar)

**Drought and acidic
soil tolerance**

(Rwanda)

**Integration in
conservation
agriculture systems**

(Madagascar)

Seed sales to African countries, from 2011-2017, suggest that an area of at least **4300 ha** has been sown so far.

Over **20,000** smallholder farmers in **Kenya, Uganda, Tanzania, Nigeria and Ethiopia** have already planted CIAT-bred *Brachiaria* hybrids. (Maas et al 2015)

Brachiaria breeding program POST-BPAT ADVANCES

November 2018

Valheria Castiblanco

Plant breeder | Tropical forages

v.castiblanco@cigar.org

ciat.cgiar.org



Content

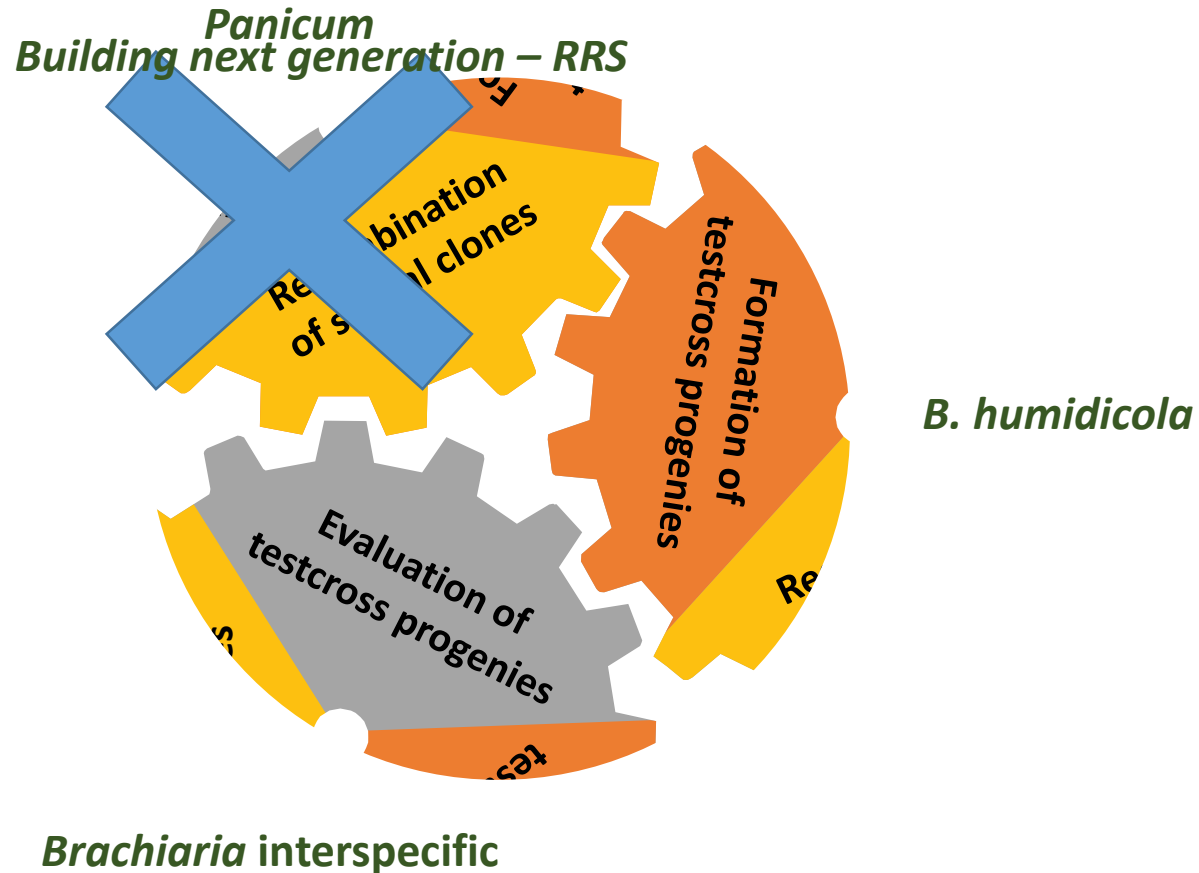
1. Prioritization of Product Pipelines – *Panicum maximum* (*Megathyrsus*) reduced to minimum investments.
2. Spatial analysis, GxE, BLUPs – TPE (Proposal) + Agrosavia experiments + BMZ
3. Measuring Biomass Yield and measuring Genetic Gain - Agrosavia Experiment
4. Quantitative Genetics Plant Breeding approach, Genomic Prediction, Breeding and Testing strategy and Optimization using Simulation – Advanced coding in the package “Selection Gain”, waiting for data Br19. 
5. Breeding Strategy for Africa and BMZ project
6. Breeding Cycle Time – Advances in flowering induction
7. Reciprocal Recurrent Selection – Building heterotic pools
8. Data Management – BMS training and updated
9. Mechanization – Tractor plus implements and bar coding 
10. Seed Systems and Production – Agreement with Papalotla

1. Prioritization of Product Pipelines – *Panicum maximum* (*Megathyrsus*) reduced to minimum investments.

Year 1

Year 2

Year 3



2. Spatial analysis, GxE, BLUPs – TPE (Proposal)

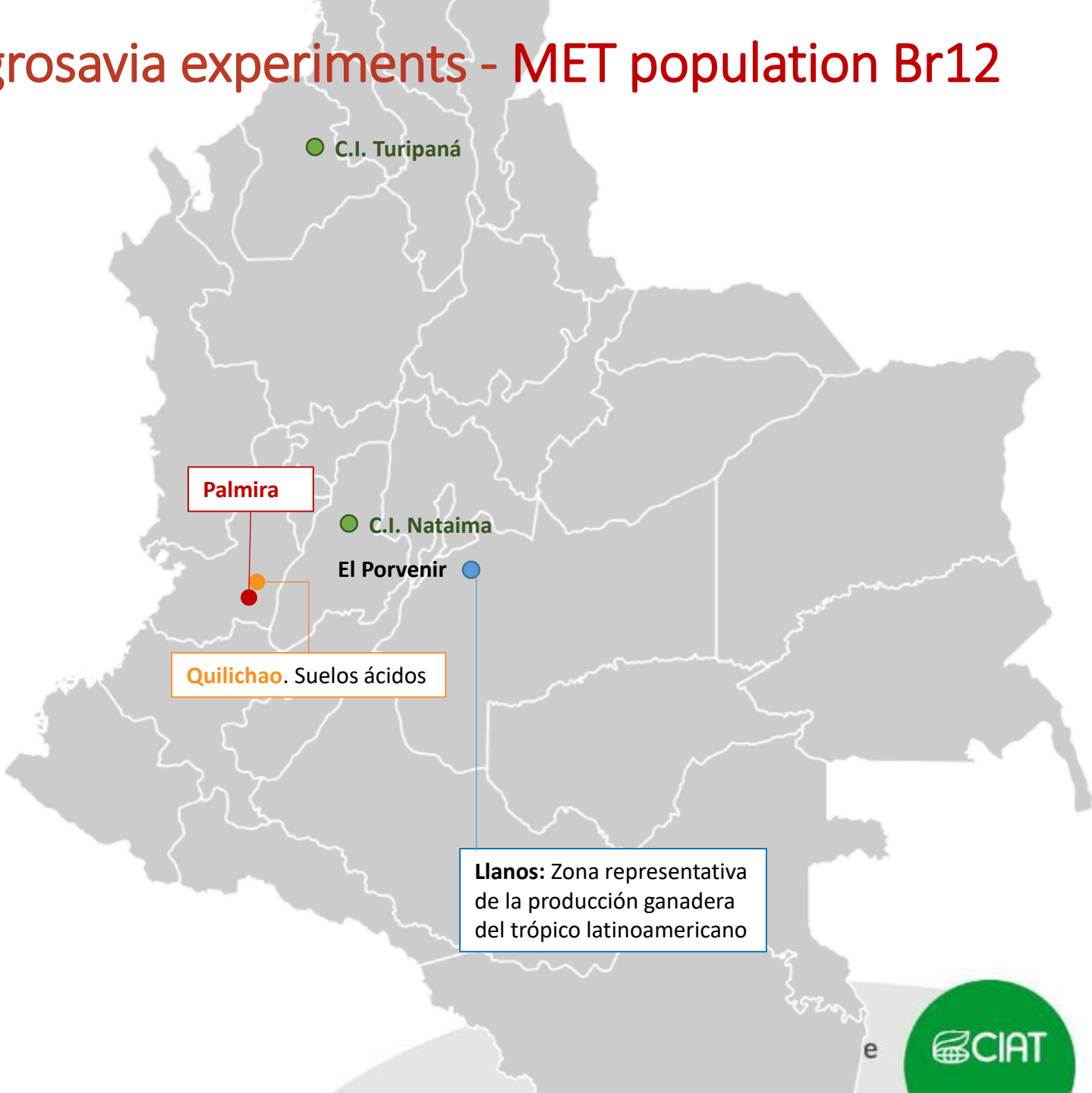
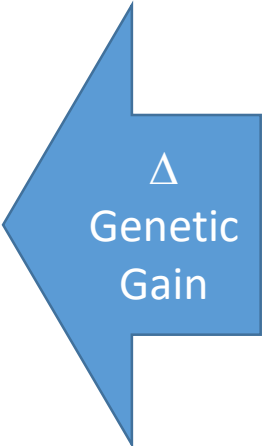


- GIS analysis
- Economic/Market review

2. Spatial analysis, GxE, BLUPs – Agrosavia experiments - MET population Br12

- **Methodology:**
 - 5 locations.
 - Alpha-lattice (10x11), two reps, 4 plants/plot.
 - 103 hybrids + 7 controls
 - Traits:
 1. Biomass
 2. Quality

Genotype	Common Name
CIAT/606	Basilisk
CIAT/36087	Mulato II
CIAT/6294	Marandu
CIAT/26110	Toledo 
CIAT/26646	La Libertad
BR02/1794	Cobra 
BR02/1752	Cayman



2. Spatial analysis, GxE, BLUPs – BMZ

Challenges: Regulatory
constrains

Panicum or *Brachiaria* for
WA?

Control 1	Napier
Control 2	Mombasa
Control 3	Toledo
Control 4	Cobra

Δ
Genetic
Gain

Methodology:

- Split-plot design.
- 4 counties – 2 groups each, reps within group.
- Each group of 12 farmers – Main plot
- Each farmer receives 6 genotypes
- 24 new genotypes + 4 controls
- Traits:
 1. Biomass
 2. Quality

Western Kenya

Administrative county 1	Group 1	Farmer 1	Control 1	Control 2	Control 3	Control 4	Genotype 1	Genotype 2
		Farmer 2	Control 1	Control 2	Control 3	Control 4	Genotype 3	Genotype 4
		Farmer 3	Control 1	Control 2	Control 3	Control 4	Genotype 5	Genotype 6
		Farmer 4	Control 1	Control 2	Control 3	Control 4	Genotype 7	Genotype 8
		Farmer 5	Control 1	Control 2	Control 3	Control 4	Genotype 9	Genotype 10
		Farmer 6	Control 1	Control 2	Control 3	Control 4	Genotype 11	Genotype 12
		Farmer 7	Control 1	Control 2	Control 3	Control 4	Genotype 13	Genotype 14
		Farmer 8	Control 1	Control 2	Control 3	Control 4	Genotype 15	Genotype 16
		Farmer 9	Control 1	Control 2	Control 3	Control 4	Genotype 17	Genotype 18
		Farmer 10	Control 1	Control 2	Control 3	Control 4	Genotype 19	Genotype 20
		Farmer 11	Control 1	Control 2	Control 3	Control 4	Genotype 21	Genotype 22
		Farmer 12	Control 1	Control 2	Control 3	Control 4	Genotype 23	Genotype 24
	Group 2	Farmer 13	Control 1	Control 2	Control 3	Control 4	Genotype 1	Genotype 2
		Farmer 14	Control 1	Control 2	Control 3	Control 4	Genotype 3	Genotype 4
		Farmer 15	Control 1	Control 2	Control 3	Control 4	Genotype 5	Genotype 6
		Farmer 16	Control 1	Control 2	Control 3	Control 4	Genotype 7	Genotype 8
		Farmer 17	Control 1	Control 2	Control 3	Control 4	Genotype 9	Genotype 10
		Farmer 18	Control 1	Control 2	Control 3	Control 4	Genotype 11	Genotype 12
		Farmer 19	Control 1	Control 2	Control 3	Control 4	Genotype 13	Genotype 14
		Farmer 20	Control 1	Control 2	Control 3	Control 4	Genotype 15	Genotype 16
		Farmer 21	Control 1	Control 2	Control 3	Control 4	Genotype 17	Genotype 18
		Farmer 22	Control 1	Control 2	Control 3	Control 4	Genotype 19	Genotype 20
		Farmer 23	Control 1	Control 2	Control 3	Control 4	Genotype 21	Genotype 22
		Farmer 24	Control 1	Control 2	Control 3	Control 4	Genotype 23	Genotype 24
Administrative county 2	Group 1	Farmer 1	Control 1	Control 2	Control 3	Control 4	Genotype 1	Genotype 2
		Farmer 2	Control 1	Control 2	Control 3	Control 4	Genotype 3	Genotype 4
		Farmer 3	Control 1	Control 2	Control 3	Control 4	Genotype 5	Genotype 6
		Farmer 4	Control 1	Control 2	Control 3	Control 4	Genotype 7	Genotype 8
		Farmer 5	Control 1	Control 2	Control 3	Control 4	Genotype 9	Genotype 10
		Farmer 6	Control 1	Control 2	Control 3	Control 4	Genotype 11	Genotype 12
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		Farmer 18	Control 1	Control 2	Control 3	Control 4	Genotype 11	Genotype 12
		Farmer 19	Control 1	Control 2	Control 3	Control 4	Genotype 13	Genotype 14
		Farmer 20	Control 1	Control 2	Control 3	Control 4	Genotype 15	Genotype 16
		Farmer 21	Control 1	Control 2	Control 3	Control 4	Genotype 17	Genotype 18
		Farmer 22	Control 1	Control 2	Control 3	Control 4	Genotype 19	Genotype 20
		Farmer 23	Control 1	Control 2	Control 3	Control 4	Genotype 21	Genotype 22
		Farmer 24	Control 1	Control 2	Control 3	Control 4	Genotype 23	Genotype 24

3. Measuring Biomass Yield



Orthomosaic

Measurements for each cutting each 6 weeks, visual and with the drone.
At least two cuttings in each rainy/dry season

Content

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9. Mechanization – Tractor plus implements
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Bias in heritability estimates when ignoring within family variation

Source	Variance
Block:	0.017
Genotype	0.10
Genotype x Loc	0.014
Error (average)	0.19

$$h^2 = \frac{\sigma_G^2}{\sigma_G^2 + \frac{\sigma_{G \times L}^2}{L} + \frac{\sigma_e^2}{L \times R}} \quad h^2 = \frac{0.1}{0.1 + \frac{0.014}{3} + \frac{0.19}{3}} \quad 0.60$$

Source	Variance
Block:	0.017
Families	0.012
Families x Loc	0.006
Error (average)	0.19
Within	0.093

Based on Piepho and Mohring 2007 and Holland, Nyquist and Cervantes-Martinez 2002

$$h^2 = \frac{\sigma_F^2}{\sigma_F^2 + \frac{\sigma_{F \times L}^2}{L} + \frac{\sigma_W^2}{I} + \frac{\sigma_e^2}{L \times I \times R}} \quad h^2 = \frac{0.012}{0.012 + \frac{0.006}{3} + \frac{0.093}{4} + \frac{0.19}{3 \times 4}} \quad 0.23$$

Current version of R package “*selectiongain*” **does not** allow to:

1. Declare within family variance
2. Optimize the number of families and individuals within families to maximize expected genetic gain

New functions for the package are under development to optimize Brachiaria breeding strategy

5. Breeding Strategy for Africa – BMZ project

2018

- Identify a place for first culling within Colombia using GIS and Modeling.
- Design a Strategy for Africa
- Send seed for BMZ project – Regulatory procedures

2019

- Panicum or Brachiaria? Test and compare in the field – BMZ Project
- Identify possible biotic challenges for the materials when coming back to the center of origin.
- Identify breeding priorities and build the product profile.

2020

- Diversity panel to identify potential parents for breeding crosses: Searching for sources of abiotic tolerance and biotic resistance

5. Breeding Strategy for Africa – BMZ project

2021

- First crosses focused on Eastern Africa market (Factorial design).

2022

- Test of first generation of hybrids in a field location within Colombia that mimics environmental conditions in EA (Culling from 8000 to 100 hybrids).

2023

- Open pollinated cross within promising parents.
- In-house testing of 100 hybrids for nutrition quality, biotic (África? How?) and abiotic resistances, progeny test and seed multiplication.
- Regulatory processes.

5. Breeding Strategy for Africa – BMZ project

2024

- Hybrid formation in factorial design.
- Shipment of seed for trials in EA (100 to 30 hybrids).

2025

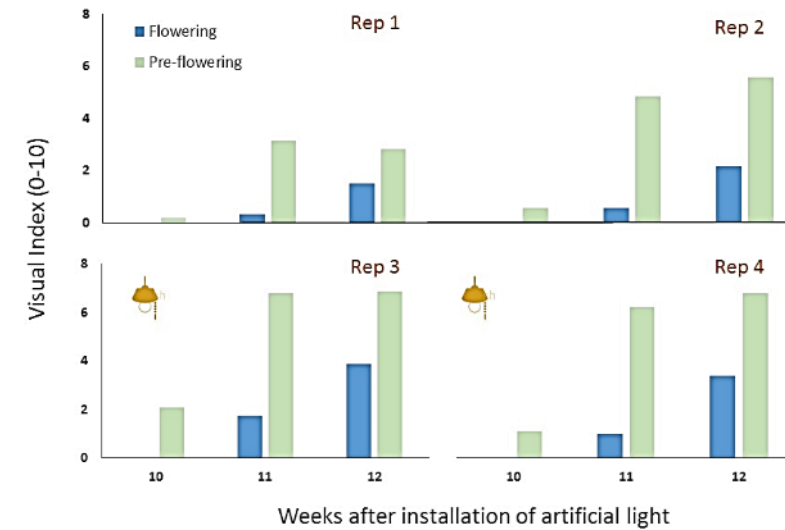
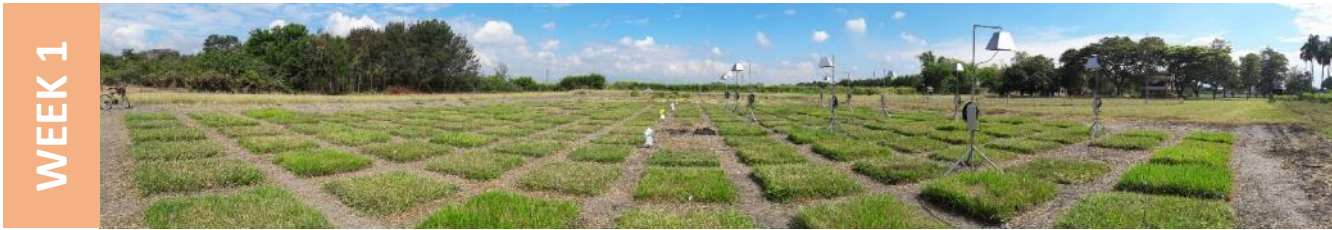
- Multilocation trials in EA, ideally participatory trials.
- Test of first generation of hybrids in a field location within Colombia that mimics environmental conditions in EA (Culling from 8000 to 100 hybrids).

2026

- Open pollinated cross within promising parents.
- In-house testing of 100 hybrids for nutrition quality, biotic (África? How?) and abiotic resistances, progeny test and seed multiplication.
- Shipment and regulatory processes.

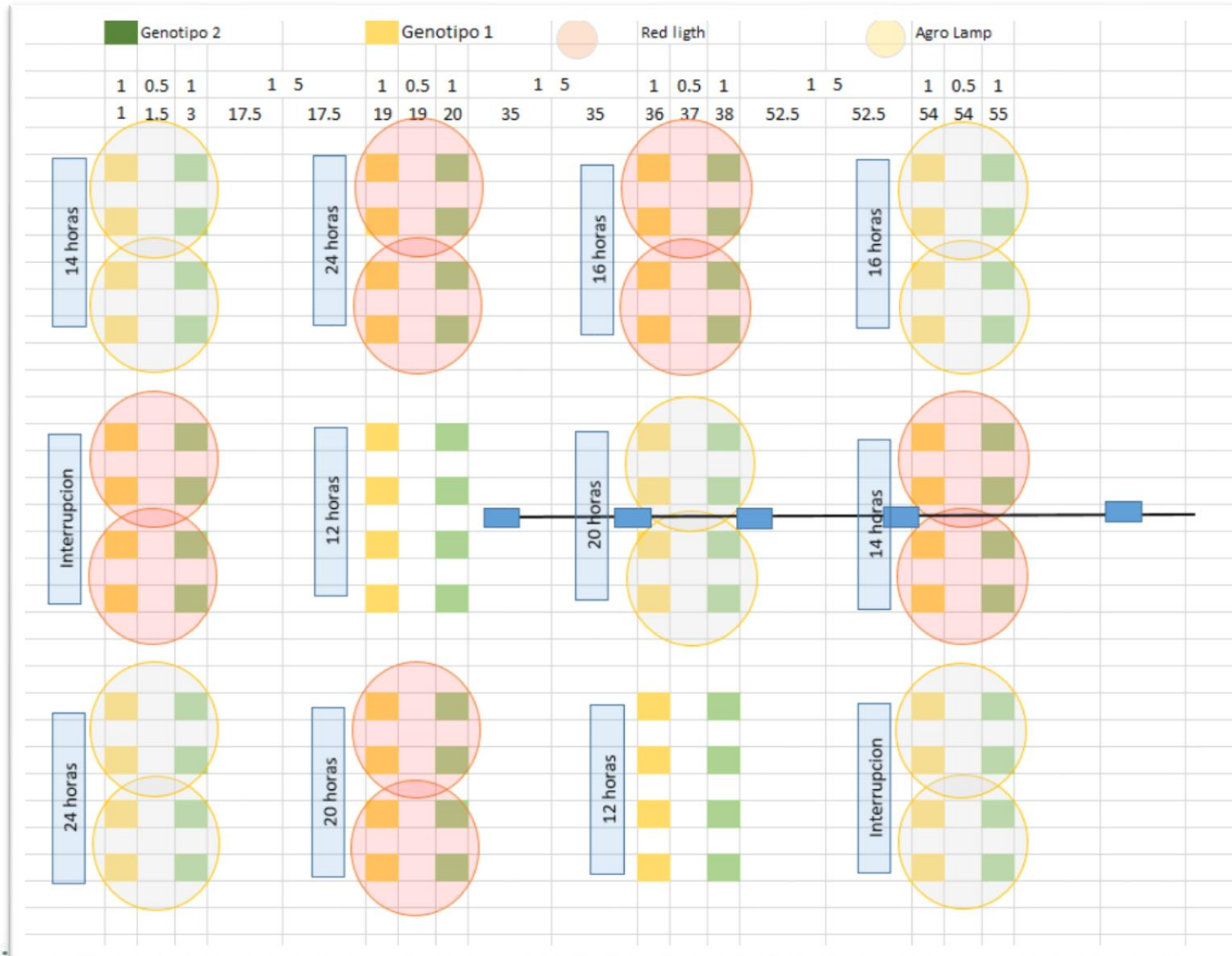
6. Breeding Cycle Time – Advances in flowering induction

Manage photoperiod to accelerate flowering



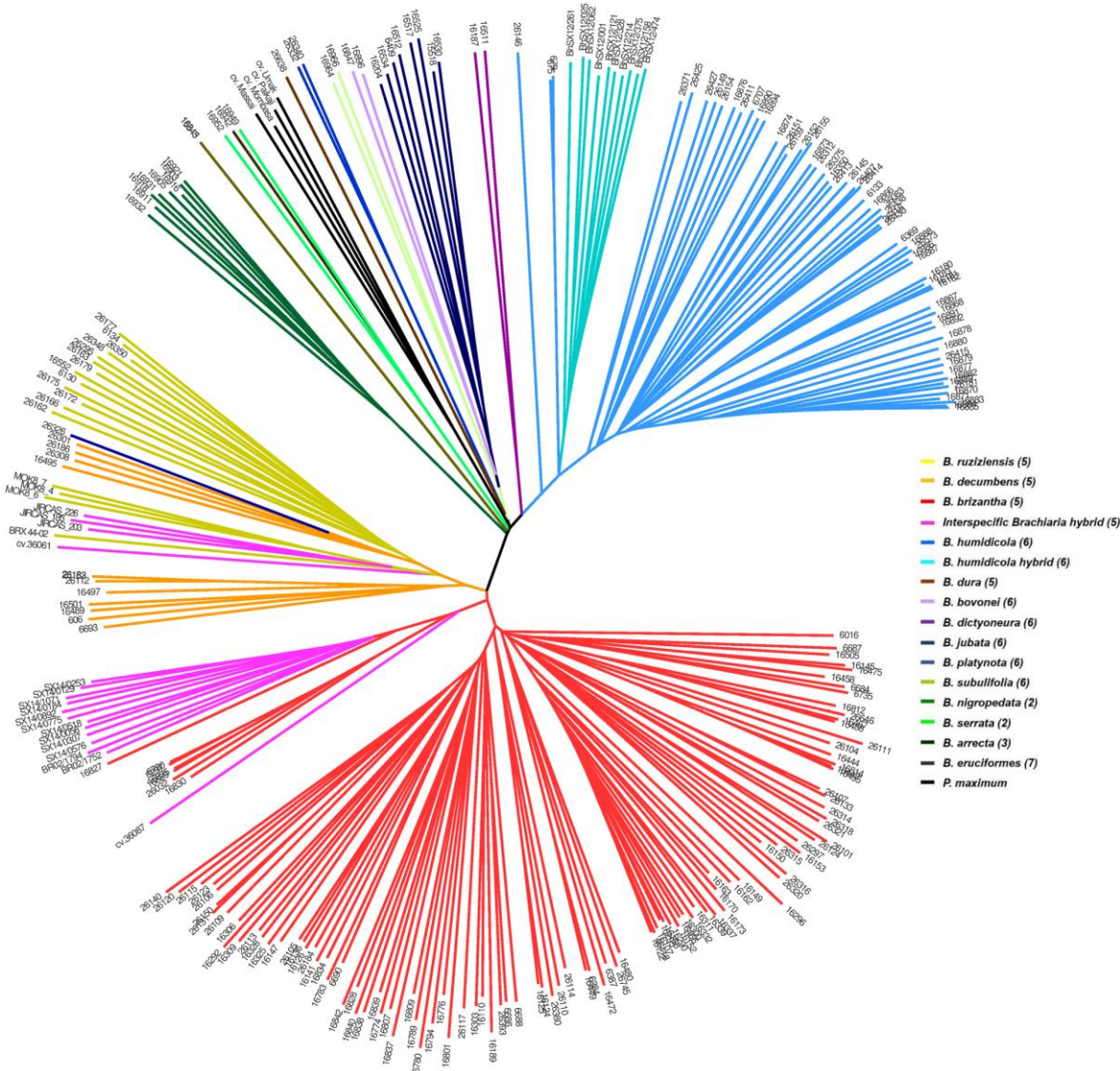
Building a sustainable future

6. Breeding Cycle Time – Advances in flowering induction



Research in dormancy management is still pending

7. Reciprocal Recurrent Selection – Building heterotic pools



B. ruziziensis
2x, sexual (aa)

Colchicine

B. ruziziensis
4x, sexual (aaaa)

X

B. brizantha
4x, apomictic (Aaaa)
(Various accessions)

F₁, sexuals
(aaaa)

F₁, apomicts
(Aaaa)

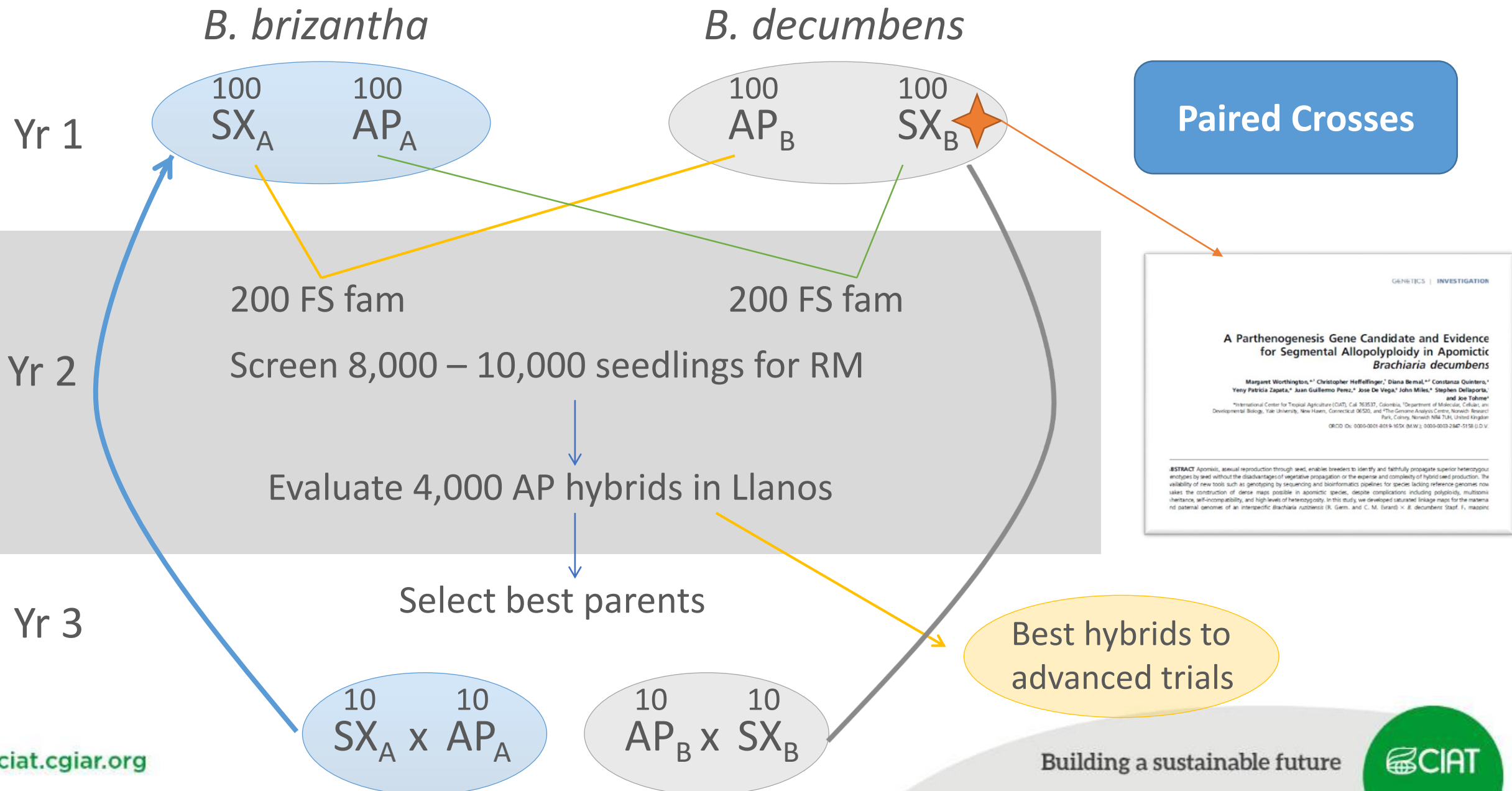
Open pollination

Synthetic population,
4x, sexual
(aaaa)

X

B. decumbens

7. Reciprocal Recurrent Selection – Building heterotic pools



7. Reciprocal Recurrent Selection – Building heterotic pools

Biparental mapping population for Apomixes

B. ruziziensis

4x, sexual (aaaa)

X

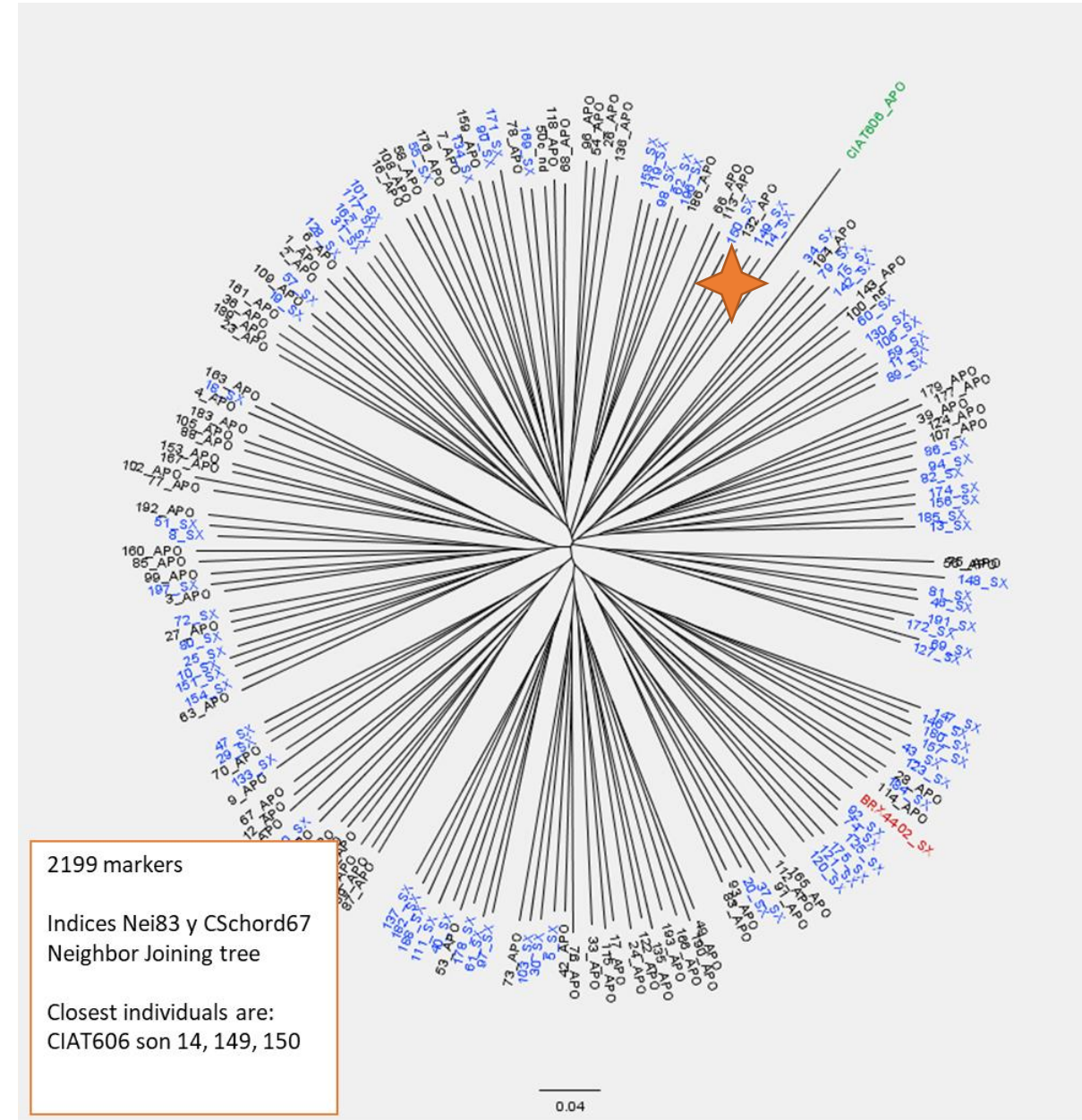
B. decumbens

4x, apomictic (Aaaa)
(Various accessions)

F₁, sexuals
(aaaa)

F₁, apomicts
(Aaaa)

BC 1



Content

1. Prioritization of Product Pipelines – *Panicum maximum* (*Megathyrsus*) reduced to minimum investments.
2. Spatial analysis, GxE, BLUPs – TPE (Proposal) + Agrosavia experiments + BMZ
3. Measuring Biomass Yield and measuring Genetic Gain - Agrosavia Experiment
4. Quantitative Genetics Plant Breeding approach, Genomic Prediction, Breeding and Testing strategy and Optimization using Simulation – Advanced coding in the package “Selection Gain”, waiting for data Br19. 
5. Breeding Strategy for Africa and BMZ project
6. Breeding Cycle Time – Advances in flowering induction
7. Reciprocal Recurrent Selection – Building heterotic pools
8. Data Management – BMS training and updated 
9. Mechanization – Tractor plus implements and bar coding
10. Seed Systems and Production – Agreement with Papalotla

9. Mechanization – Tractor plus implements and barcoding



9. Mechanization – Tractor plus implements and barcoding

Generador codigo de barras



Impresora codigo de barras



Lector codigo de barras



Terminal portatil TC75



Datalogic GD4430

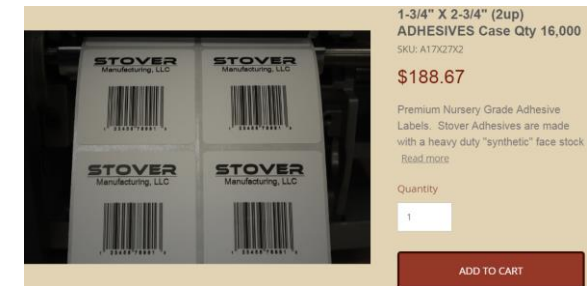
Customers looking for more than a few cases of product at a time ...
PLEASE CALL US for a Real-Time Tags "Program" Consultation & Deeper Discounts.



Item #	Size	Color	Qty./Roll	Wt./Roll	Qty./Case	Roll Price	Case Price
558X1	8"X1"	White	1,000	5.5 lb	5,000	\$32.73	\$27.66

Price Per Thousand Tags: 558X1, 558X07, 558X08, 558X1, 558X07, 558X06, 558X1, 558X07, 558X06, 558X05, 558X15, 558X15, 558X1

20mil Styrene Pot Stakes



9. Mechanization – Tractor plus implements and bar coding

Item	Ref	Costo (dolares)	Enlace
Impresora	SM425 WIDEBODY THERMAL TAG & LABEL PRINTER	\$ 3,295.00	https://www.realtimetags.com/product-page/sm425-widebody-thermal-tag-label-printer
Software impresora	NL17 pro	\$ 535.00	
Software generador de codigo de barras	ZebraDesigner™ Editions	\$ 345.00	https://www.zebra.com/la/es/support-downloads/printer-software/zebra-designer-downloads.html
Lector codigo de barras portatil	Terminal portatil Motorola TC75	\$ 1,350.00	https://www.lineatascan.com/productos/terminales-portatiles-zebra/tc75/
Lector codigo de barras estacionario	Datalogic GD4430	\$ 1,350.00	https://www.lineatascan.com/productos/lectores-de-codigo-de-barras-zebra/datalogic-gd4430/
Estacas	SS6X07 (6'x3/4')	\$ 187.80	https://www.realtimetags.com/potstakes
Estacas	SS6X1 (6'x1')	\$ 112.85	https://www.realtimetags.com/potstakes
ADHESIVES	1-3/4" X 2-3/4"	\$ 188.67	
Total		\$ 7,364.32	

10. Seed Systems and Production – Agreement with Papalotla

New partnership for a more sustainable forage production

by José Luis Urrea | Oct 4, 2018





Thank you!

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RESEARCH
PROGRAM ON
Livestock



WE'RE PROUD TO
HAVE CELEBRATED 50 YEARS
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