Role of Pulse Crops in Achieving Food and Nutritional Security

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Dry Grain Pulses CRSP
GLOBAL PULSE RESEARCHERS MEETING
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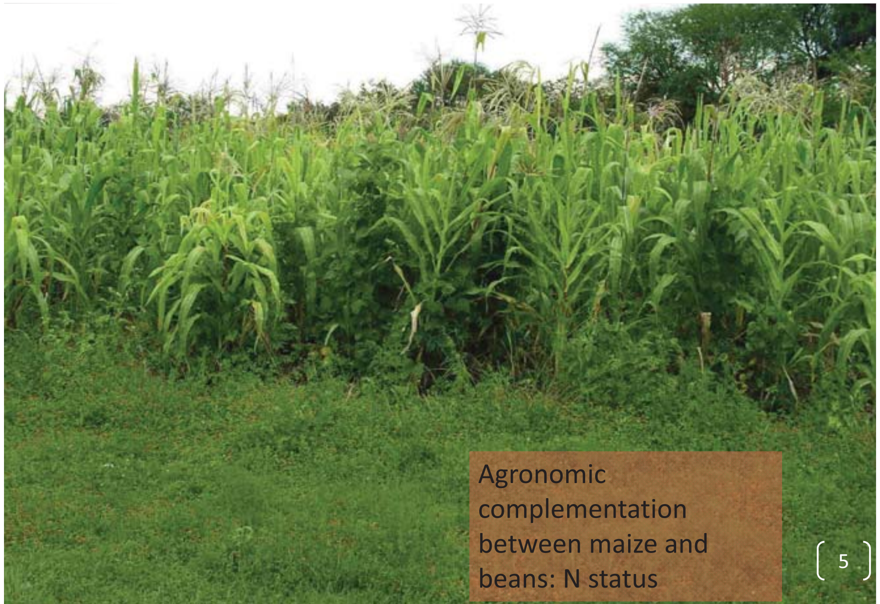
Outline

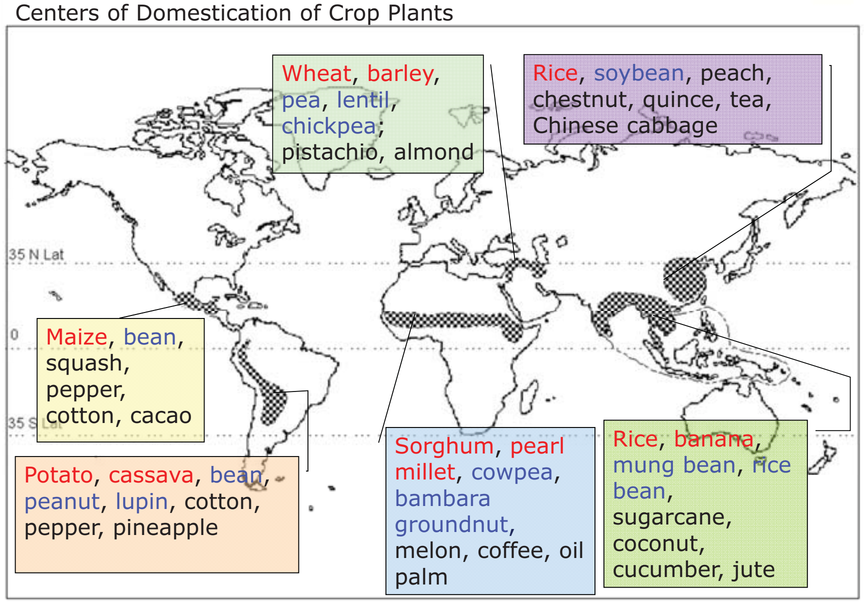
- Role of Grain Legumes
- Goals of Grain Legume Improvement
- Key Ingredients
  - Biodiversity:
    - Farmer role in conservation
    - Ecological genomics
  - Breeding methods & genomics
    - Marker-assisted selection
    - Participatory breeding
  - The role of phenotyping in breeding for abiotic stresses
  - Funding
- Conclusions

Role of Grain Legumes or Pulses



San Agustín del Pulque, MICH, MEX (2004)

Centers of Domestication of Crop Plants



Modified from Gepts 2004

Goals of Grain Legume (Pulse) Improvement

Goals

- Maximize yield within existing phenological constraints and for target environment
- Minimize inputs and maximize input use efficiency
- Improved human nutrition
- Farmer acceptance
- Consumer acceptance and marketability

- Any approach is fine, regardless of technology!

Key Ingredients: Biodiversity

❶Farmer Role in Conservation

Role of Farmers?

Photos: D. Zizumbo

Location of Michoacán-Guanajuato experiments

Site	Distance* (m)
Jéruco	10
Cepio	15
Piñicuaro	20
Santa Ana Maya	20
Tupátaro	25
Yuriria	60
San Agustín del Pulque	110

* Between wild and domesticated populations

Payró de la Cruz et al. Genet Res Crop Evol 2005

Wide range of diversity including improved cultivars and wild beans

	Average seed weight (g/100)
Wild	6
Weedy	20
Domesticated	39

Environs of Yuriria, Guanajuato-Michoacán, Mexico

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Different Genetic Structure in W & D

	H	*h*	G_{ST}	*Nm*
Wild	0.24	0.13-0.18	0.40	0.78
Landraces	0.26	0.22-0.29	0.26	1.40
Breeding lines	--	0.03-0.06	--	--

- Wild: less diversity within populations, more among populations compared to Domesticated
- Higher gene flow in Domesticated:
  - Diversity within landraces: outcrosses
  - Seed exchange among farmers

Zizumbo-Villarreal et al. 2005

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Study in Yuriria

S. Barber & P. Gepts, unpubl. results

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Distinguishing two groups in a single region (Yuriria, GUA, MEX)

Frijol late harvest in Nov-Dec/ thicker seedcoats – longer to cook/ longer storage time	*Frijola* early harvest in Sep-Oct/ thinner seedcoats – shorter to cook/ shorter storage time
apetito morado	amapola delgada
cacahuate	color de rata
cafe	flor de mayo
higuerillo	flor de mayo gruesa
higuerillo delgado	flor de mayo delgada
higuerillo grueso	flor de junio
huamuchil	flor de junio - *Marcela*
morado	japonés de bola
morado bola	morada (Rosita)
morado grueso	ojo de cabra
guindo (rojo)	ojo de liebre
palacio	peruano
pinto	de castilla
viudo	

S. Barber & P. Gepts, unpubl. results

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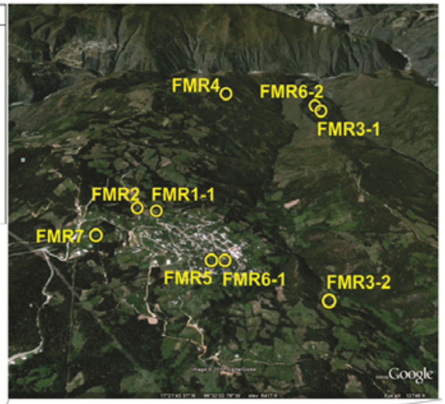
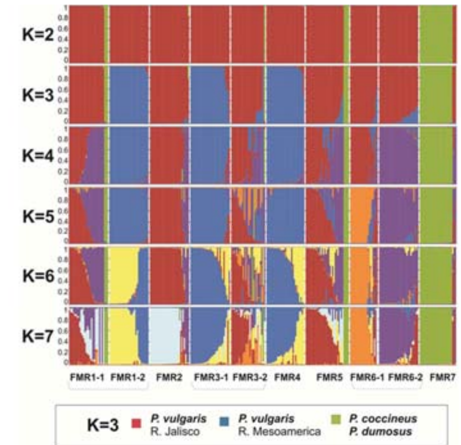
Study in Santa María Jaltianguis, OAX, MEX

Sample	Elevation (masl)
FMR1-1	2120
FMR1-2	N/A
FMR2	2145
FMR3-1	1779
FMR3-2	2040
FMR4	2051
FMR5	2112
FMR6-1	2084
FMR6-2	1802
FMR7	2262



M. Worthington, D. Soleri, & P. Gepts, submitted

Farmer selection according to species & adaptation



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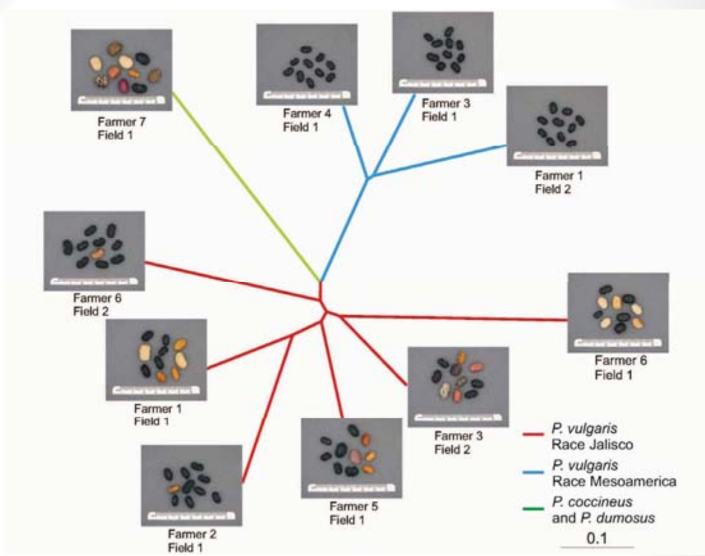
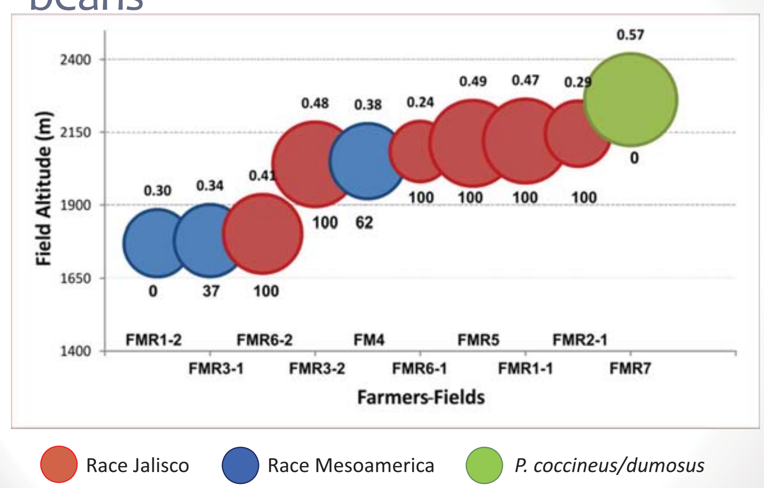


M. Worthington, D. Soleri, & P. Gepts, submitted

Altitude distribution of different beans



M. Worthington, D. Soleri, & P. Gepts, submitted

Conclusions: Farmer-Involvement in farm biodiversity management

- Awareness of adaptation of germplasm segments
  - Climate
  - Phenology
- What type of selection?
  - Stabilizing selection: Maintenance of type
  - Directional selection? Yield?
  - Maintain genetic diversity; Dynamic system: not a gene bank nor a museum
- Niche for intervention by participatory breeding
  - Improved germplasm
  - Selection procedure

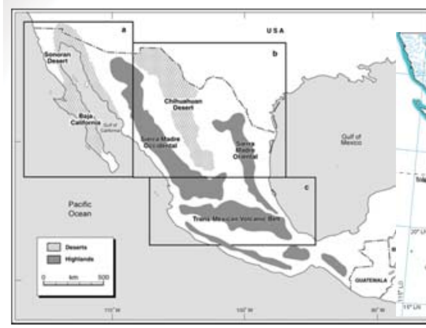
Key Ingredients: Biodiversity

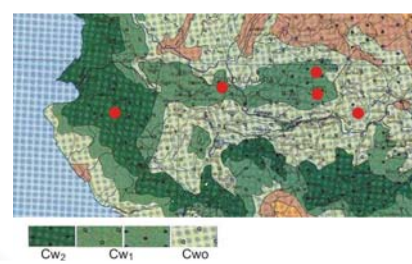
❷ Ecological Genomics

The Suggested Domestication Center of Common Bean in Mexico

M. Kwak, J. Kami & P. Gepts, Crop Sci., March 2009

Why the Lerma-Santiago Basin?





- Climate: Cwa
  - Subtropical: t° coldest month: 5-18 °C
  - Subhumid: 4-6 months of humidity in summer
  - Semi-warm: average annual t°: 18-22 °C
- Vegetation:
  - Dry deciduous forest to drier thorn forest

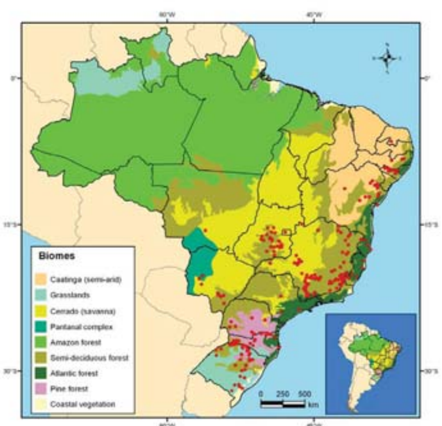
Westernmost putative domestication location, Mascota-Ameca Basin

Westernmost putative domestication location, Mascota-Ameca Basin

Dec. 5, 2008

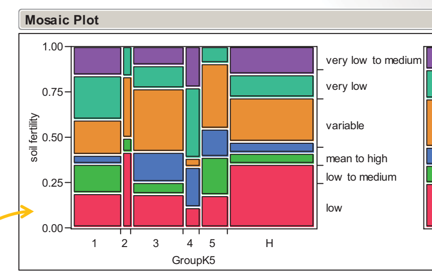
Eco-geographic variation of bean landraces in Brazil

- Biome: mainly semi-deciduous forest, pine forest
- Only difference between A and M?
  - Altitude: ~ 100m
  - Yearly average T°: 23C
  - Average rainfall growing season: 549 mm

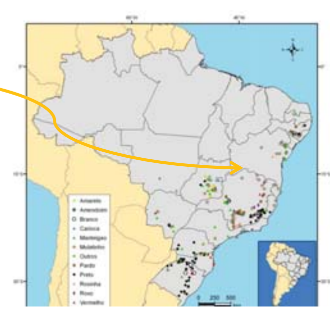


Differences among K = 5 STRUCTURE groups and market classes

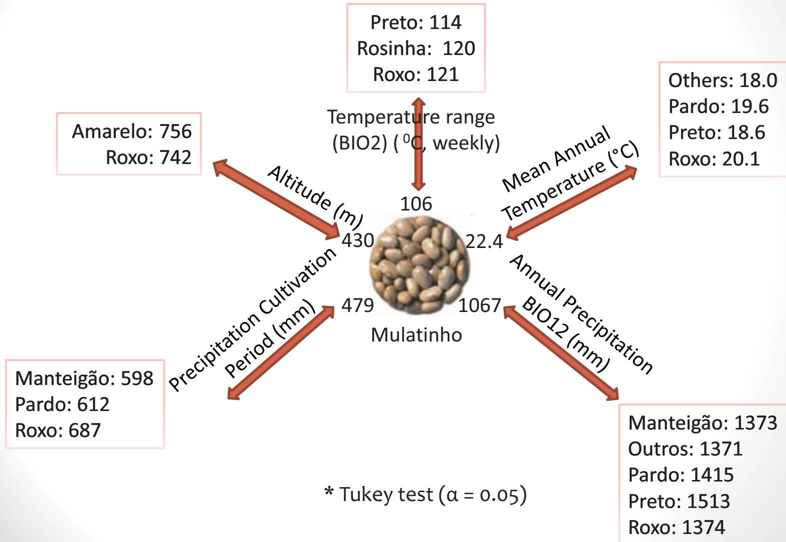
Eco-geographic variables	Prob>ChiSq
Biome	0.0086
Geomorpho-logy	0.0639
Soil slope	0.0009
Soil fertility	<0.0001



ANOVA: 'Mulatinho' market class: lower altitudes, precipitation; higher temperature

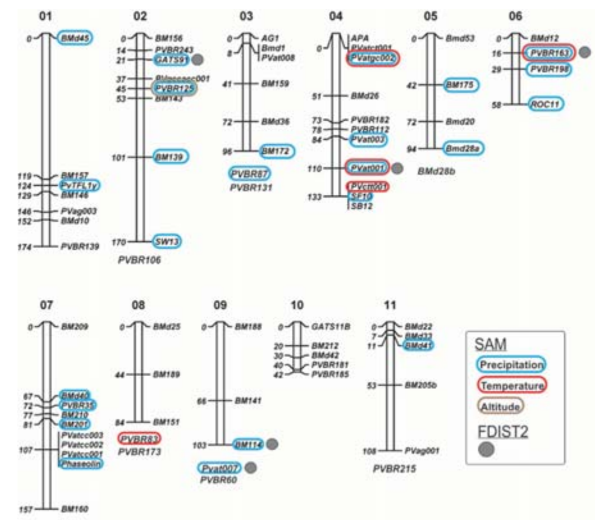


Significant* Contrasts between Mulatinhos and Other Commercial Types



* Tukey test (α = 0.05)

Molecular Linkage Map of Common Bean: Significant Correlations with T°, P, and Altitude



What is next?

- Evaluation of plant materials (a.k.a. phenotyping)
  - Yield and component traits
  - Germplasm
  - Locations/years
- High density of markers
  - Fragments (SSRs, indels), SNPs
  - Number: the more the better
- Other sources of genomic/genetic information
  - Transcriptomics
  - Metabolomics

Key Ingredients: Breeding Methods & Genomics

❶ Marker-assisted selection

Progress in CBB resistance breeding

Miklas et al. 2006

Table 1. Representative dry bean lines and cultivars with resistance to common bacterial blight (CBB) derived from individual or combined sources

Lines & cultivars	Sources: *P. vulgaris* Montana No. 5	*P. vulgaris* PI 207262	*P. coccineus*	*P. acutifolius* (Tepary markers)	Disease score (1–9)[a]
Jules, Chase, Montcalm	×				6, 7, 8
XAN 112, BAT 93	×	×			4, 5, 6
XR 235-1-1			×		5, 6
USPT-CBB-1	×		×		4, 5, 6
OAC 88-1				× (SU91)	4, 5, 6
HR 67				× (BC420)	3, 4, 5
XAN 159, CBB-Teebus				× (SU91 and BC420)	2, 3, 4
ABCP-8, USDK-CBB-15	×			× (SU91)	3, 4, 5
Wilkinson 2	×		×	× (SU91 and BC420)	2, 3, 4
XAN 309, VAX lines 3–6	×	×		× (SU91)	1, 2

[a]Relative average disease scores (1–9, where 1 is no visible symptoms and 9 is completely diseased) compiled from published and unpublished data.

1970, 1994, 1973

1999

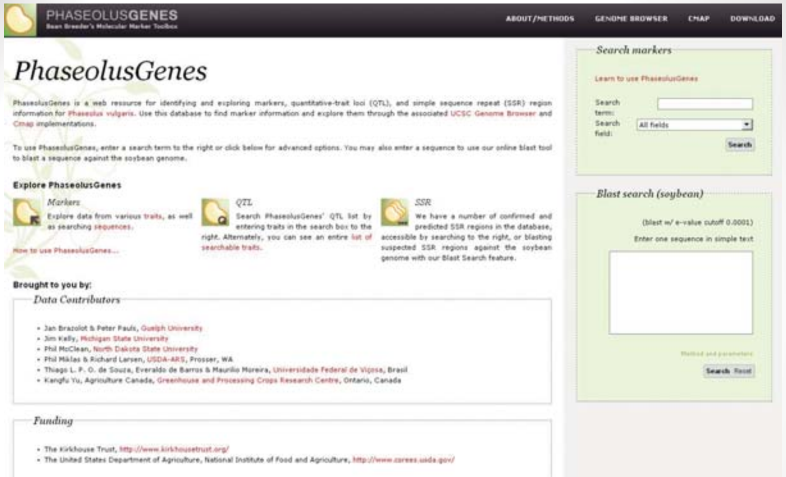
1) improved screening methods;
2) identified resistant *P. vulgaris*, *P. coccineus*, and *P. acutifolius* germplasm; e.g., Miklas et al. 2003; Singh & Nuñez 1999; etc.
3) molecular mapping to tag resistance loci (Nodari et al. 1993; Miklas et al. 1996; Jung et al. 1997; Miklas et al. 2000); and
4) pyramided resistance genes (Miklas et al. 2006b; Mutulu et al. 2005).

Where do we go from here?

- Other diseases?
  - White mold (Miklas et al. 2009; Soule et al. 2011; Mkwaila et al. 2011; Pérez-Vega et al. 2012)
  - Web blight (Godoy-Lutz et al. 2003; Takegami et al. 2004; Beaver et al. 2012)
- Generalize use of MAS?
  - Remains a tool and not a goal
  - Under what conditions is MAS applicable or not as a tool?
  - Other traits and genetic architecture (QTLs)
- Coordination among "players": Kirkhouse Trust ABC and WAC project, CIAT
  - Development of new markers: whole-genome sequencing and PhaseolusGenes database
- Other species: e.g., *P. lunatus*

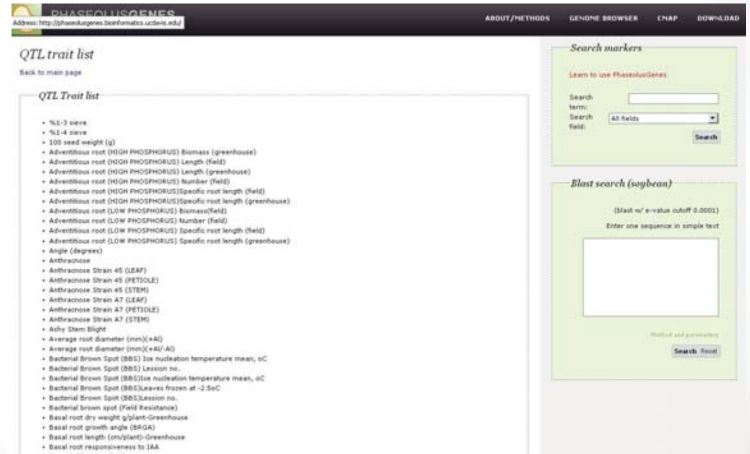
Kirkhouse Trust: African Bean Consortium (ABC) Project

- Main Goal: Introduce MAS capability in East African bean breeding programs
  - Focused on BCMV, ALS, ANT, CBB, Pythium RR → Preferred variety + 2-3 resistances
- Institutional improvement focused on Africa
  - National programs; education within Africa
- Main strategic elements
  - Human infrastructure: markers, plant pathology (CIAT-Kawanda)
  - Physical infrastructure: DNA fragment analysis; SNPs?
- At UC Davis:
  - 1x methyl-filtrated BAT93 sequencing
  - PhaseolusGenes database
  - Training of African students (applied bioinformatics, lab analysis, PhaseolusGenes)

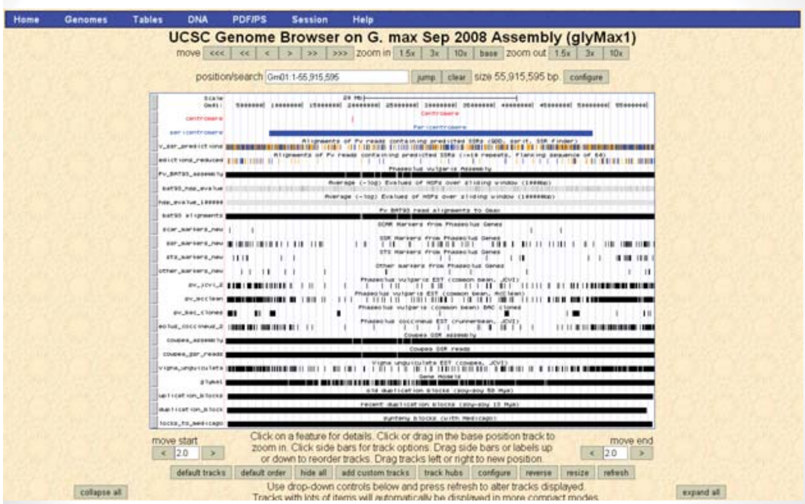


Phaseolusgenes.bioinformatics.ucdavis.edu

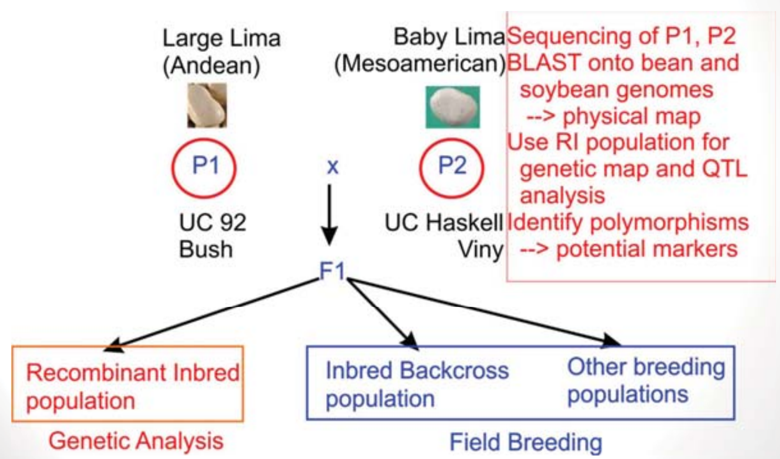
PhaseolusGenes: QTLs



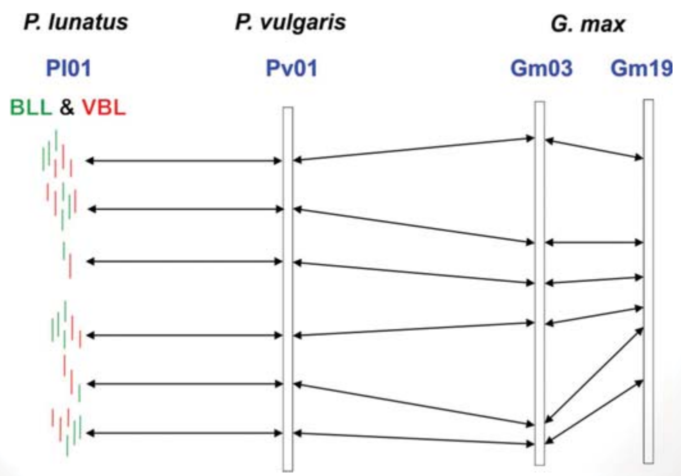
PhaseolusGenes: Genome Browser



Population-specific Genomics in Plant Breeding & Genotyping by Sequencing



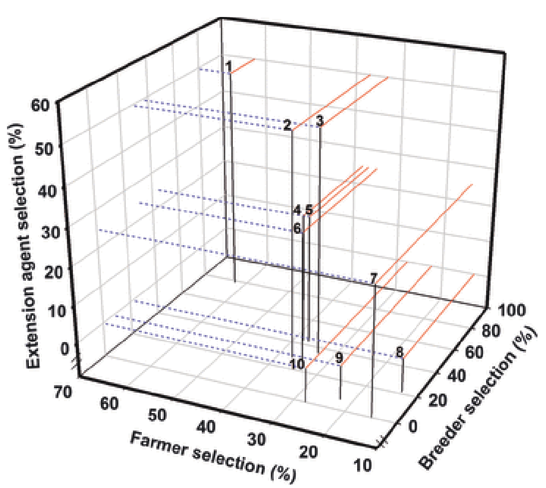
“Instant” Mapping in Lima Bean through Synteny With Common Bean and Soybean



Key Ingredients: Breeding Methods & Genomics

❷ Participatory Breeding

Participatory approach in common bean (*Phaseolus vulgaris* L.) breeding for drought tolerance for southern Ethiopia



Asfaw et al. Plant Breeding
Volume 131, Issue 1, pages 125-134, 7 DEC 2011 DOI: 10.1111/j.1439-0523.2011.01921.x
http://onlinelibrary.wiley.com/doi/10.1111/j.1439-0523.2011.01921.x/full#f1

Why “do” participatory breeding?

Gender Differences

Trait	Top 6 ranking traits	
	Men	Women
Earliness	1	1
Fast-to-cook		2
Marketability	2	5
Drought tolerance	4	3
Grain yield	3	4
Germination	5	
Taste		6
Specific adaptation	6	

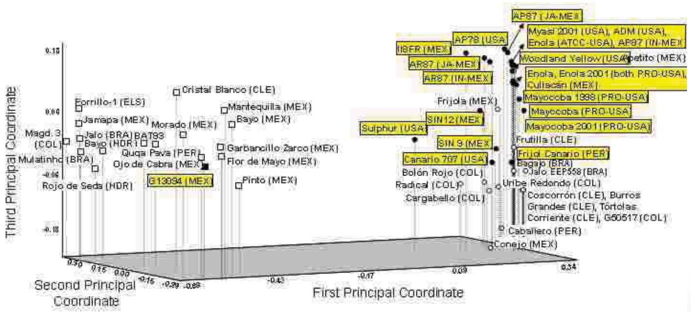
- Cultural and gender differences
- Environmental differences: broad vs. narrow adaptation
- G x E
- Novelties & flexibility

Asfaw et al. 2011

Results of Breeding for a "New" Bean Type: Azufrado Peruano: Azufrado (M) x Canario (A)

Effect of selection on organization of genetic diversity in breeding gene pools

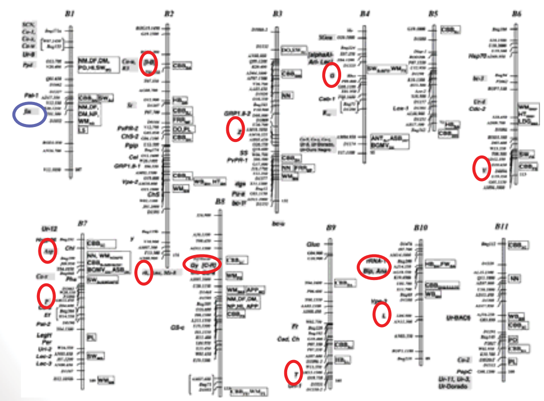
- Distribution of recombinants in genome
- "Haplotype blocks" in relation to agronomically important genes



Principal Coordinate Analysis

Pallottini et al. 2004

Some Help from Genetic Features of Common Bean



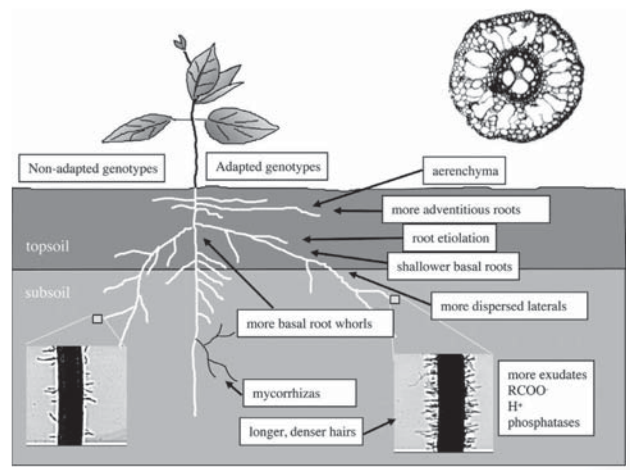
- Predominant selfing
- Seed color and growth habit gene distribution

- Markers
- Panel of pedigreed accessions
- Gene pool or race panels

Freyre et al. 1998; Kelly et al. 2003

Key Ingredients: The Role of Phenotyping in Breeding for Abiotic Stresses

Phenological traits enhancing P acquisition



Lynch 2011

Drought (Beebe et al. 2008)

- Breeding for drought tolerance in Mesoamerican market classes (red, black, carioca, mulatinho)
- Contrasting selection environments
- **Visual selection for well-filled pods (effective partitioning of photosynthates into seeds), in addition to yield *per se***
- Under drought stress: substantial improvement (~ 20-100%-> controls) in all color classes
- Under well-watered conditions: some classes and locations: up to ~15-20% > control
- Some lines **also had tolerance to low soil P** → can combine two important stresses

Biological nitrogen fixation

- Legume-Rhizobium specificity (or lack thereof) vs. N fixing ability
- Progress has been made towards understanding the initial steps of symbiosis at the molecular level:
  - initial recognition of Rhizobium by host ~ functionally conserved among legumes
- Limited progress towards understanding subsequent molecular steps:
  - Bacterial effector proteins and molecular targets in host cells; evolutionary diverged
- Supra-molecular processes: Rhizobial adaptation, especially to low fertility

Den Herder & Parniske 2009

Key Ingredients: Funding

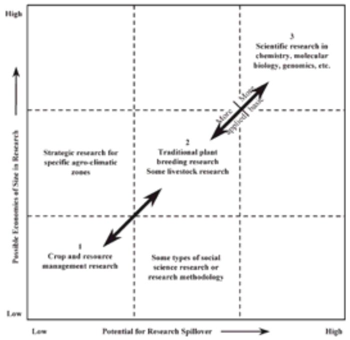
Funding deficit for grain legume research

Comparison of Funding among Legume and Cereal CRP3s[a]

CRP 3 (Number of Species)	Years	Amount (M USD)	Total Amounts (M USD)
Legumes (8)	2011-13	138	138
Dryland Cereals (5)	3	79	1138
Maize (1)	3	238	
Rice (1 or 2)	5	593	
Wheat (1)	3	228	

[a] Information from various documents or web pages on http://www.cgiarfund.org/cgiarfund/research_portfolio

Coordination among different players



- Transition between breeding and genetics/genomics
- Breeding on station and participatory breeding, including social sciences
- Trait-based breeding and physiology

From Dalrymple 2008

See also: Feed the Future:
http://www.feedthefuture.gov/sites/default/files/resource/files/FTF_research_strategy.pdf

Conclusions

- Improved management and utilization of germplasm:
  - Joint analysis of agronomic, molecular, and GIS information (ecological genomics and germplasm conservation and utilization)
  - Farmers play a role in maintenance of diversity and practice "stabilizing selection"
- Molecular markers
  - Understanding of inheritance of traits
  - Marker-assisted selection? Subordinated to phenotypic selection
    - Species, crop, markers (high-throughput), technology
- Participatory or distributed breeding
- Specific phenotypic traits informed by physiology with overall yield becomes critically limiting (in contrast with DNA sequence)
- Nitrogen fixation:
  - Combine selectivity and high BNF
- Funding:
  - Take into account nitrogen, rotational, and nutritional contributions of legumes