Role of Pulse Crops in Achieving Food and Nutritional Security

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Dry Grain Pulses CRSP
GLOBAL PULSE RESEARCHERS MEETING
February 13 – 17, 2012; Kigali, Rwanda

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
Goals of Grain Legume (Pulse) Improvement

Centers of Domestication of Crop Plants

- Wheat, barley, pea, lentil, chickpea, pistachio, almond
- Maize, bean, squash, pepper, cotton, cacao
- Potato, cassava, bean, peanut, lupin, cotton, pepper, pineapple
- Sorghum, pearl millet, cowpea, bambara groundnut, melon, coffee, oil palm
- Rice, banana, mung bean, rice bean, sugarcane, coconut, cucumber, jute

Modified from Gepts 2004
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

Photos: D. Zizumbo

Role of Farmers?

Location of Michoacán-Guanajuato experiments

<table>
<thead>
<tr>
<th>Site</th>
<th>Distance* (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jéruco</td>
<td>10</td>
</tr>
<tr>
<td>Cepio</td>
<td>15</td>
</tr>
<tr>
<td>Pifícuaro</td>
<td>20</td>
</tr>
<tr>
<td>Santa Ana Maya</td>
<td>20</td>
</tr>
<tr>
<td>Tupáitaro</td>
<td>25</td>
</tr>
<tr>
<td>Yuriria</td>
<td>60</td>
</tr>
<tr>
<td>San Agustín del Púlque</td>
<td>110</td>
</tr>
</tbody>
</table>

* 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

<table>
<thead>
<tr>
<th></th>
<th>Average seed weight (g/100)</th>
</tr>
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<tbody>
<tr>
<td>Wild</td>
<td>6</td>
</tr>
<tr>
<td>Weedy</td>
<td>20</td>
</tr>
<tr>
<td>Domesticated</td>
<td>39</td>
</tr>
</tbody>
</table>

Average seed weight (g/100)

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

Different Genetic Structure in W & D

<table>
<thead>
<tr>
<th></th>
<th>$H$</th>
<th>$h$</th>
<th>$G_{ST}$</th>
<th>$Nm$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wild</td>
<td>0.24</td>
<td>0.13-0.18</td>
<td>0.40</td>
<td>0.78</td>
</tr>
<tr>
<td>Landraces</td>
<td>0.26</td>
<td>0.22-0.29</td>
<td>0.26</td>
<td>1.40</td>
</tr>
<tr>
<td>Breeding lines</td>
<td>--</td>
<td>0.03-0.06</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

Zizumbo-Villarreal et al. 2005

S. Barber & P. Gepts, unpubl. results

Study in Yuriria

- 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
  - cacahuate
  - cafe
  - higuerillo
  - higuerillo delgado
  - higuerillo grueso
  - huamuchil
  - morado
  - morado bola
  - morado grueso
  - guindo (rojo)
  - palacio
  - pinto
  - viudo

  - amapola delgada
  - color de rata
  - flor de mayo
  - flor de mayo gruesa
  - flor de mayo delgada
  - flor de junio
  - flor de junio - Marcela
  - japonés de bola
  - morada (Rosita)
  - ojo de cabra
  - ojo de liebre
  - peruano
  - de castilla

S. Barber & P. Gepts, unpubl. results

Environs of Yuriria, Guanajuato-Michoacán, Mexico
Study in Santa María Jaltianguis, OAX, MEX

<table>
<thead>
<tr>
<th>Sample</th>
<th>Elevation (max)</th>
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</thead>
<tbody>
<tr>
<td>FM3-1</td>
<td>2110</td>
</tr>
<tr>
<td>FM3-2</td>
<td>2146</td>
</tr>
<tr>
<td>RM92</td>
<td>2146</td>
</tr>
<tr>
<td>FM3-3</td>
<td>1779</td>
</tr>
<tr>
<td>FM3-4</td>
<td>2040</td>
</tr>
<tr>
<td>FM3-5</td>
<td>2081</td>
</tr>
<tr>
<td>FM3-6</td>
<td>2112</td>
</tr>
<tr>
<td>FM3-14</td>
<td>2084</td>
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<tr>
<td>FM3-16</td>
<td>2084</td>
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<tr>
<td>FM3-17</td>
<td>2302</td>
</tr>
<tr>
<td>FM3-20</td>
<td>2262</td>
</tr>
</tbody>
</table>

Farmer selection according to species & adaptation

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

Ecological Genomics

The Suggested Domestication Center of Common Bean in Mexico

THE SUGGESTED DOMESTICATION CENTER OF COMMON BEAN IN MEXICO

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

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°: 23°C
  - Average rainfall growing season: 549 mm

Differences among K = 5 STRUCTURE groups and market classes

<table>
<thead>
<tr>
<th>Eco-geographic variables</th>
<th>Prob&gt;ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biome</td>
<td>0.0086</td>
</tr>
<tr>
<td>Geomorphology</td>
<td>0.0639</td>
</tr>
<tr>
<td>Soil slope</td>
<td>0.0009</td>
</tr>
<tr>
<td>Soil fertility</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

ANOVA: ‘Mulatinho’
market class: lower altitudes, precipitation; higher temperature
Significant* Contrasts between Mulatinhos and Other Commercial Types

* Tukey test (α = 0.05)

**Mulatinho**
- Amarelo: 756
- Roxo: 742

**Others**
- 18.0
  - Pardo: 19.6
  - Preto: 18.6
  - Roxo: 20.1

**Temperature range (BIO2) (°C, weekly)**
- Preta: 114
- Rosinha: 120
- Roxo: 121

**Annual Precipitation (mm)**
- 430
- 22.4
- 497
- 1067

**Precipitation Cultivation Period (mm)**
- Manteigão: 598
- Pardo: 612
- Roxo: 687

**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

- Marker-assisted selection
Progress in CBB resistance breeding

Miklas et al. 2006

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; Mkwaia 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

PhaseolusGenes is a web resource for identifying and exploring markers, quantitative trait loci (QTL), and simple sequence repeats (SSR) in Phaseolus vulgaris (black eye pea). Explore the database to find marker information and access the PhaseolusGenes Genome Browser and Crop implications.

PhaseolusGenes: QTLs

QTL trait list

- Trait name
- Trait type
- Molecular marker
- Description
- Genomic location
- Link to sequence

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

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

Why “do” participatory breeding?

<table>
<thead>
<tr>
<th>Trait</th>
<th>Top 6 ranking traits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earliness</td>
<td>Men 1</td>
</tr>
<tr>
<td>Fast-to-cook</td>
<td></td>
</tr>
<tr>
<td>Marketability</td>
<td>2</td>
</tr>
<tr>
<td>Drought tolerance</td>
<td>4</td>
</tr>
<tr>
<td>Grain yield</td>
<td>3</td>
</tr>
<tr>
<td>Germination</td>
<td>5</td>
</tr>
<tr>
<td>Taste</td>
<td></td>
</tr>
<tr>
<td>Specific adaptation</td>
<td>6</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>CRP 3 (Number of Species)</th>
<th>Years</th>
<th>Amount (M USD)</th>
<th>Total Amounts (M USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legumes (8)</td>
<td>2011-13</td>
<td>138</td>
<td>138</td>
</tr>
<tr>
<td>Dryland Cereals (5)</td>
<td>3</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>Maize (1)</td>
<td>3</td>
<td>238</td>
<td></td>
</tr>
<tr>
<td>Rice (1 or 2)</td>
<td>5</td>
<td>593</td>
<td></td>
</tr>
<tr>
<td>Wheat (1)</td>
<td>3</td>
<td>228</td>
<td></td>
</tr>
</tbody>
</table>

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

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

From Dalrymple 2008
See also: Feed the Future: http://www.feedthefuture.gov/sites/default/files/resource/files/FTF_research_strategy.pdf