Reflections on four years of research aimed to improve the lives of smallholder farmers
PHASE 1
2012-2016

REVIEW MEETING
03 to 07 October 2016

PRESENTATION & POSTER ABSTRACTS

Reflections on four years of research aimed to improve the lives of smallholder farmers
Reflections on science that's improving the lives of smallholder farmers

As part of the Review Meeting, a poster exhibition is being organized highlighting key research outputs of Grain Legumes and Dryland Cereals. This book is a compilation of the abstracts of posters presented during the exhibition. All the posters presented in the exhibition are available on the program websites and the links to the same are available through a unique QR code alongside each abstract. Scanning the QR code with any QR Code scanner application from a smartphone with internet connection will take you to the webpage of that particular poster.
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Dear colleagues,

The two CGIAR Research Programs (CRPs), Grain Legumes, and Dryland Cereals, were launched in mid-2012, responding to the global challenges of hunger, malnutrition, poverty and climate change. With a strong global partnership, these two Programs brought together knowledge, expertise, and experience from stakeholders in the public and private sector, governments and farmers worldwide. The two programs completed their first phase in Dec 2014 and are currently in a two-year extension phase.

Outcomes and impact from the two programs has been significant during the four years since their inception. A Review Meeting during 3-6 Oct 2016 will highlight achievements of the program during 2012-2016 through a scientific review including presentations and poster sessions, followed by a celebration of the International Year of Pulses. This Review Meeting will be held at the ICRISAT Headquarters in Patancheru, Hyderabad, India.

The Organizing Committee of this Review Meeting and I take great pleasure in welcoming you to this meeting and look forward to insightful discussions on the accomplishments to date and the path forward.

Sincerely,

Dr Sobhana (Shoba) Sivasankar
Director
CGIAR Research Program on Grain Legumes &
CGIAR Research Program on Dryland Cereals

Organizing Committee

Director: Shoba Sivasankar
Committee Chair: Michael Baum, ICARDA
Co-Chairs:
- Grain Legumes: Pooran Gaur, ICRISAT-Patancheru, India
- Dryland Cereals: SK Gupta, ICRISAT-Patancheru, India

Committee
- Shiv Kumar Agrawal, ICARDA-Rabat, Morocco
- Malick Ba, ICRISAT-Niamey, Niger
- Steve Beebe, CIAT-Cali, Colombia
- S Gopalakrishnan, ICRISAT-Patancheru, India
- P Janila, ICRISAT-Patancheru, India
- Sameer Kumar CV, ICRISAT-Patancheru, India
- Esther Njuguna-Mungai, ICRISAT-Nairobi, Kenya
- Henry Ojulong, ICRISAT-Nairobi, Kenya
- Kiran Sharma, ICRISAT-Patancheru, India
- Manuele Tamo, IITA-Cotonou, Republic of Benin
**Program Schedule**

<table>
<thead>
<tr>
<th>Day</th>
<th>Date</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 AM</td>
<td>4 OCT 2016</td>
<td>Review Meeting Dryland Cereals (contd.)</td>
</tr>
<tr>
<td>2 PM</td>
<td>4 OCT 2016</td>
<td>Review Meeting Grain Legumes (contd.)</td>
</tr>
<tr>
<td>3 AM</td>
<td>5 OCT 2016</td>
<td>Review Meeting Grain Legumes (contd.)</td>
</tr>
<tr>
<td>4</td>
<td>6 OCT 2016</td>
<td>Celebrating International Year of Pulses</td>
</tr>
<tr>
<td>5</td>
<td>7 OCT 2016</td>
<td>Governance Meetings SAC &amp; RMC (DC, GL)</td>
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**DRYLAND CEREALS**

**DAY 1: 03 October 2016**

**OPENING SESSION (Chair: Dr Michael Baum)**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
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<tbody>
<tr>
<td>09:00</td>
<td>Welcome (Shoba Sivasankar)</td>
</tr>
<tr>
<td>09:10</td>
<td>Key Messages: Dr JS Sandhu</td>
</tr>
<tr>
<td>09:30</td>
<td>Opening Remarks: Drs Jill Findeis, Peter Langridge, Ylva Hillbur, Michael Baum</td>
</tr>
<tr>
<td>10:00</td>
<td>Message from Lead Centre DG (Dr David Bergvinson)</td>
</tr>
<tr>
<td>10:10</td>
<td>Photo &amp; Break</td>
</tr>
<tr>
<td>10:40</td>
<td>Dryland Cereals: Highlights (Dr Shoba Sivasankar)</td>
</tr>
<tr>
<td>11:20</td>
<td>Gender Research in Dryland Cereals: Highlights (Dr Esther Njuguna-Mungai)</td>
</tr>
<tr>
<td>12:00</td>
<td>Lunch</td>
</tr>
</tbody>
</table>
### DAY 2: 04 October 2016

#### SESSION 2:  Continued – Review of Product Lines (Chair: Dr Jayalekha AK)

<table>
<thead>
<tr>
<th>Time</th>
<th>Product Line</th>
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</thead>
<tbody>
<tr>
<td>09:00</td>
<td>Product Line 6: Pearl millet for East Africa and South Asia (Dr SK Gupta)</td>
</tr>
<tr>
<td>09:40</td>
<td>Product Line 7: Post-rainy sorghum for South Asia (Dr Ashok Kumar)</td>
</tr>
<tr>
<td>10:20</td>
<td><strong>Break</strong></td>
</tr>
<tr>
<td>15:00</td>
<td>Product Line 4: Finger millet for Eastern/Southern Africa (Dr Henry Ojulong)</td>
</tr>
<tr>
<td>16:00</td>
<td>Product Line 5: Barley for Africa and Asia (Dr Ramesh Verma)</td>
</tr>
<tr>
<td>16:40</td>
<td>Wrap-up of Day 1 (Dr SK Gupta)</td>
</tr>
<tr>
<td>17:00</td>
<td>POSTER SESSION (Dryland Cereals)</td>
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</table>

<table>
<thead>
<tr>
<th>Time</th>
<th><strong>Dinner</strong></th>
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</table>

### SESSION 4: Strategic Topics for Phase II (Chair: Dr Margaret Smith)

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
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</thead>
<tbody>
<tr>
<td>10:40</td>
<td>DC and GL eATLAS (Dr Glenn Hyman; Dr Chandra Biradar*)</td>
</tr>
<tr>
<td>11:20</td>
<td>Innovation and Varietal Improvement in West Africa - IAVAO (Prof Abdourahamane Sangare)</td>
</tr>
<tr>
<td>12:00</td>
<td><strong>Lunch</strong></td>
</tr>
</tbody>
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*Update for Day 1:*

- **SESSION 1: Review of Product Lines (Chair – Dr Yilma Kebede)**
  - 13:00 – 13:40 Product Line 1: Sorghum for West Africa (Dr Aboucar Toure)
  - 13:40 – 14:20 Product Line 2: Pearl millet for West Africa (Dr Malick Ba)
  - 14:20 – 15:00 Product Line 3: Sorghum for East Africa (Dr Eric Manyasa)
  - **Break**
  - 15:00 – 15:20 Product Line 4: Finger millet for Eastern/Southern Africa (Dr Henry Ojulong)
  - 15:20 – 16:00 Product Line 5: Barley for Africa and Asia (Dr Ramesh Verma)
  - 16:00 – 17:00 Wrap-up of Day 1 (Dr SK Gupta)
  - 17:00 – 19:00 POSTER SESSION (Dryland Cereals)
  - 19:00 – 21:00 **Dinner**
## DAY 2: 04 October 2016

### SESSION 1: Overview of Grain Legumes (Chair: Dr Asnake Fikre)

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>13:00 – 13:20</td>
<td>Key Messages: Dr Jill Findeis</td>
</tr>
<tr>
<td>13:20 – 14:00</td>
<td>Grain Legumes: Highlights (Shoba Sivasankar)</td>
</tr>
<tr>
<td>14:00 – 14:40</td>
<td>Gender Research in Grain Legumes: Highlights (Dr Esther Njuguna-Mungai)</td>
</tr>
<tr>
<td>14:40 – 15:20</td>
<td>Break</td>
</tr>
<tr>
<td>15:20 – 16:00</td>
<td>The PABRA Model (Dr JC Rubyogo)</td>
</tr>
<tr>
<td>16:00 – 16:40</td>
<td>Priority Setting – Current Efforts and Future Perspectives (Drs Tom Walker, Arega Alene*, Kai Mausch)</td>
</tr>
<tr>
<td>16:40 – 17:00</td>
<td>Wrap up of Day 2 (Dr Pooran Gaur)</td>
</tr>
<tr>
<td>17:00 – 19:00</td>
<td>POSTER SESSION (Grain Legumes)</td>
</tr>
</tbody>
</table>

## DAY 3: 05 October 2016

### SESSION 2: Review of Product Lines (Chair: Dr Ylva Hillbur)

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:00 – 09:40</td>
<td>Product Line 1: Drought and low-phosphorus tolerant common bean, cowpea and soybean (Dr Steve Beebe)</td>
</tr>
<tr>
<td>09:40 – 10:20</td>
<td>Product Line 2: Heat-tolerant chickpea, common bean, faba bean and lentil (Dr Michel Ghanem)</td>
</tr>
<tr>
<td>10:20 – 10:40</td>
<td>Break</td>
</tr>
<tr>
<td>10:40 – 11:20</td>
<td>Product Line 3: Short-duration, drought-tolerant and aflatoxin-free groundnut (Dr Patrick Okori)</td>
</tr>
<tr>
<td>11:20 – 12:00</td>
<td>Product Line 4: High nitrogen-fixing chickpea, common bean, faba bean, and soybean (Dr Sushil Chaturvedi)</td>
</tr>
<tr>
<td>12:00 – 13:00</td>
<td>Lunch</td>
</tr>
</tbody>
</table>

### SESSION 3: Continued Review of Product Lines (Chair: Dr Jeff Ehlers)

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
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</thead>
<tbody>
<tr>
<td>13:00 – 13:40</td>
<td>Product Line 5: Insect-smart chickpea, cowpea, and pigeonpea production systems (Dr Manuele Tamo)</td>
</tr>
<tr>
<td>13:40 – 14:20</td>
<td>Product Line 6: Extra-early maturing chickpea and lentil varieties (Dr Shiv Agrawal)</td>
</tr>
<tr>
<td>14:20 – 15:00</td>
<td>Product Line 7: Herbicide-tolerant, machine-harvestable chickpea, faba bean and lentil varieties (Dr Pooran Gaur)</td>
</tr>
<tr>
<td>15:00 – 15:20</td>
<td>Break</td>
</tr>
<tr>
<td>15:20 – 16:00</td>
<td>Product Line 8: Pigeonpea hybrid and management practices (Dr Sameerkumar)</td>
</tr>
<tr>
<td>16:00 – 16:30</td>
<td>Update on Phase II CRP (Dr Shoba Sivasankar)</td>
</tr>
<tr>
<td>17:00 – 19:00</td>
<td>Poster Session Open (No Presenters); Coffee and snacks</td>
</tr>
</tbody>
</table>
About Grain Legumes

Vision

Improved health, food and nutritional security, environmental sustainability and income for smallholder farmers through increased legume productivity, production and consumption to combat poverty, hunger, malnutrition and environmental degradation.

The CGIAR Research Program on Grain Legumes (Grain Legumes) is as a collaborative research program that aims to improve eight priority grain legumes crops – chickpea, cowpea, common bean, faba bean, groundnut, lentil, pigeonpea and soybean – grown by poor smallholder farmers in South and Southeast Asia, Sub-Saharan Africa, Central and Western Asia, North Africa, Latin America and the Caribbean to combat poverty, hunger, malnutrition and environmental degradation.

A global research partnership including public and private institutes and organizations, governments and farmers in the target regions will develop, adopt, disseminate and promote research for development aimed at

- An integrated approach to legumes research-for-development in each region
- improved knowledge generation and sharing by learning across target legume crops and systems in their distinctive regional settings; and
- shared research-for-development facilities and expertise to increase operational efficiency and effectiveness.

During the Extension Phase, Grain Legumes was restructured to place the key outputs of the Program into the context of the R4D process leading to outcomes, rather than emphasizing the specific technical innovations. The realigned Program structure is represented below.

- PL 1: Drought & Low-P tolerance
- PL 2: Heat tolerance
- PL 3: Short duration, drought tolerance & aflatoxin - free groundnut
- PL 4: High nitrogen-fixing
- PL 5: Insect smart
- PL 6: Extra early maturing
- PL 7: Herbicide tolerant mec-harvest
- PL 8: Hybrid pigeonpea

Adding Value / Mitigating Loss

Market Opportunity
The new structure encompasses seven major Flagship Projects (FPs) that describe the processes and activities by which Grain Legumes develops technological interventions. The seven Product Lines (PLs) from Phase 1 remain intact and run through the FPs to provide the outcome focus in this perspective.

**The Seven Flagship Projects include**

|-----------------------------------|---------------------------------|-------------------------------|--------------------------------------------------|------------------------------------------|--------------------------------------------------|--------------------------------------------------|

**Product Lines**

The on-farm impacts of Grain Legumes will be through eight Product Lines (PLs), grouped into four key priority areas.

**Addressing abiotic stresses and climate-change effects**

**Product Line 1:** Drought and low-phosphorus tolerant common bean, cowpea and soybean

**Product Line 2:** Heat-tolerant chickpea, common bean, faba bean and lentil

**Product Line 3:** Short-duration, drought-tolerant and aflatoxin-free groundnut

**Capturing unique legume ability to fix nitrogen**

**Product Line 4:** High nitrogen-fixing chickpea, common bean, faba bean, and soybean

**Managing key biotic stresses**

**Product Line 5:** Insect-smart chickpea, cowpea, and pigeonpea production systems

**Generating new opportunities to intensify cropping systems**

**Product Line 6:** Extra-early maturing chickpea and lentil varieties

**Product Line 7:** Herbicide-tolerant, machine-harvestable chickpea, faba bean and lentil varieties

**Product Line 8:** Pigeonpea hybrid and management practices
**About Dryland Cereals**

**Vision**

Improved food security, nutrition, income and resilience of smallholder agriculture in the dryland regions of Africa and Asia, through the collaborative development and deployment of solutions for crop improvement, crop management, post-harvest technologies and market access to dryland cereal crops.

The CGIAR Research Program on Dryland Cereals (Dryland Cereals) aims at improving food security, nutrition, income and resilience of smallholder agriculture in the dryland regions of Africa and Asia, through collaborative development and deployment of solutions for crop improvement, crop management, post-harvest technologies and market access to dryland cereal crops including barley, finger millet, pearl millet and sorghum. These are highly resilient, climate-hardy, micronutrient-dense crops that are the mainstay of agricultural systems in the dryland regions, where they are primarily used for food, feed and fodder.

The objectives of the program are to:

- Achieve critical mass of expertise and resources focused on the major cereal crops in dryland agriculture and provide a unified channel for separate and fragmented efforts;
- Utilize the comparative advantage of CGIAR Centers and other partner agencies, particularly in the areas of genomics, phenomics and bioinformatics applied via modern breeding methods and platforms;
- Raise awareness of the lesser-known facts about dryland cereals such as their resilience and climate hardiness and their nutritional value, thus supporting the development of internal infrastructure and human capacity critical for lasting benefits.

In the Extension Phase, Dryland Cereals follows an Impact Pathway that will enable integrated, streamlined implementation across the delivery pipeline from demand analysis to product/technology delivery to scaling up and out.

**The Delivery Pipeline**

**Priority setting & Adaption**
- Baseline data, decision making
- Value - chain analyses, priority setting
- Adaptation tracking, Impact analysis

**Improved Varieties & Hybrids**
- Pre-breeding
- Testing Locations, TPEs
- Tools for breeding selections
- Yield
- Food, feed quality
- Resistance to biotic, abiotic stress

**Integrated Crop Management**
- Soil crop Water management
- Integrated pest, disease, weed management
- Integrated crop-livestock management
- Mechanization for crop production

**Seed System & Input Services**
- Seed supply models
- Seed policy interventions
- Functional seed units
- Commercial hybrid seed production
- Access to inputs

**Post-harvest value & output Markets**
- Grain processing characteristics
- Post - harvest loss reduction
- Bulk sale of grain
- Storage processing & Nutrition
- Value - chain incubators

**Gender Delivery Pipeline**

<table>
<thead>
<tr>
<th>Research Partnerships</th>
<th>Development Partnerships</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1-3 years</strong></td>
<td><strong>3-6 years</strong></td>
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<tr>
<td>Farmers 000s</td>
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<tr>
<td><strong>6-9 years</strong></td>
<td><strong>9-12 years</strong></td>
</tr>
<tr>
<td>Farmers 000s</td>
<td>Farmers 000s</td>
</tr>
</tbody>
</table>
The five Flagship Projects include

Flagship 1: Priority Setting & Adoption
Flagship 2: Improved Varieties & Hybrids
Flagship 3: Integrated Crop Management
Flagship 4: Seed Systems & Input Services
Flagship 5: Post-harvest Value & Output Markets

Product Lines

Dryland Cereals included seven Product Lines (PL), in its first phase, as shown below. These PLs remain intact as Cluster of Activities within each Flagship in the Extension phase.

**PL1:** Sorghum for West Africa: Supporting farmers’ transition from subsistence to market orientation with productive, nutritious, photoperiod-sensitive sorghum production packages for multiple uses in West Africa

**PL2:** Pearl millet for Africa: Improving food security for subsistence smallholder farmers in East and West Africa with productive and nutritious pearl millet food and fodder production technologies

**PL3:** Sorghum for East Africa: Drought tolerant, highly productive multi-use sorghum varieties for food and processing uses in the dry lowlands of East Africa

**PL4:** Finger millet for Eastern/Southern Africa: Improving nutritional security with productive and nutritious finger millet production technologies for East and Southern Africa

**PL5:** Barley for Africa and Asia: Multi-purpose barley production technologies to meet food, feed and fodder demands in the driest regions of Africa and Asia

**PL6:** Pearl millet hybrids for East Africa and South Asia: Improving food security and incomes with productive and nutritious multi-purpose pearl millet hybrid production technologies for East Africa and South Asia

**PL7:** Post-rainy sorghum for South Asia: Multi-purpose post-rainy season sorghum hybrid production technologies for improving food and fodder availability in the driest regions of South Asia
Progress in supporting sorghum farmers' transition from subsistence to market orientation in West & Central Africa: Burkina Faso, Mali and Nigeria

Aboubacar TOURE  
ICRISAT-Mali Bamako.  
ab.toure@cgiar.org

From 2012 to 2016 great progress has been made to support sorghum farmers' transition from subsistence to market orientation in West and Central Africa with improved crop productivity, natural resource management and economic growth of farming systems centered on the crop and livestock. Improved farmer-preferred varieties and hybrid were developed. Over 30A/B pairs were developed and more than 200 hybrids are tested to establish solid heterotic group for the region. 600 F2 families from biparental crosses were phenotyped and genotyped as well as 4740 BC1F5 families derived from 47 populations using a Back Cross-Nested Association Mapping. Several varieties were selected for high grain yield and high Stover quality with an average grain yield of 2t/ha, a biomass of 15 t/ha and a total sugar content of 10-16%Brix. A total of 26 varieties and 7 hybrids were released during the period and unscripted in the national / regional catalogue in Mali in 2016. In integrated crop management options, sorghum yields obtained from Integrated Striga management were 60% higher than those obtained from farmer with a marketable surplus estimated at 412 kg per hectare. Over 20,000 DVD’s Fighting Striga were distributed, containing 10 videos on improving sorghum production under Striga infested conditions in locale languages. Microdosing reached more than 30000 farmers’ fields in Mali, Burkina Faso and Nigeria. A locally developed motorized seeder in Mali is used as mechanization prospects to increase labor saving. Thus, seedling labor time decreases from 12 person days / ha for manual planting and 1 person day / ha for animal traction to 1/4 person day / ha for motorized seeder. Several activities were conducted on seed production techniques and distribution for sorghum in target zones. Information on commercial feasibility of hybrid seed production and delivery has been provided in farmer communities. A total of 4618 farmers including 28% women were trained in seed production techniques. Over 20 seed cooperatives are able to produce and sale seeds including hybrid parents. About 85% of certified seed produced in 2015 by Farmers’ seed cooperatives in Mali were sold locally in 2016. Mini-packages with key information were important tools for seed marketing in the target zones.

Pearl millet for West Africa

Improving food security for smallholder farmers in West and Central Africa with productive and nutritious pearl millet

Ba M; Gangashetty P; Fatondji D; Hakeem A; Angarawai I; Nzungize J; Singbo A; Badolo F; Hash CT; Okwach G and Tabo R.  
ICRISAT.  
b.malick@cgiar.org

Pearl millet is the staple cereal crop over the entire Sahelian zone of WCA. Although this crop is exceptionally adapted to the region, productivity is still very low due to several constraints. Priority setting and adoption studies showed that the rate of adoption of improved varieties varies between 13% and 35% across the region with higher rate of adoption in Nigeria. Among other things, the main reasons of the non-adoption are still seed unavailability, non-resistance to insects, and late maturity of varieties. Significant progresses are being made in Improved varieties and Hybrids to over come the low productivity. The breeding program preliminary yield tested single and top cross hybrids and identified 14 promising fertile and phenotypically distinct hybrids with yield grain of up to 2.7 t/ha (ICMH IS 14012) compare to 0.5 t/ha for the local land race. Similarly some progresses have been made in Integrated Crop management with the testing of combine hill applications of 300g of cow manure or 100 g of poultry manure combine with microdose of mineral fertilizer. Results showed grain yields increase of 113% to 321% in Niger and Nigeria respectively. Regarding the Seed Systems and Input Services a multi stakeholder consortium is being used innovatively to enhance awareness and access to new technologies for enhancing millet production.
In Mali a public private partnership (PPP) is being created with two institutions; one providing seed treatment chemical (Apron Star) and another specialized in micro-financing systems. Finally in the Postharvest Value and Output Markets sector, the analysis of the supply marketing show that only 25% to 30% of quantity produced by farmers. The marketing system is vertically integrated and consists of five categories of actors: farmers, collectors, wholesalers, retailers and consumers. This indicated that increase of productivity could only be reached when farmers had higher market gain.

**Sorghum for East Africa**

**Drought tolerant, highly productive multi-use sorghum varieties for food and processing uses in the dry lowlands of East Africa**

Eric Manyasa; Henry Ojulong; Samuel Njoroge; Patrick Sheunda; Daniel Ajaku; Joseph Kibuka

Sorghum research in ESA targets the entire value chain to increase productivity, production and profitability through development, promotion and uptake of new sorghum cultivars and management options, post harvest and value addition and improving farmer access to markets. Sorghum-based production systems were characterized to establish determinants of the differences in productivity parameters within and between target areas to help the design, implementation and monitoring of projects. Between 2012 and 2016, one OPV in Tanzania, two in South Sudan, 2 in Kenya; two hybrids in Ethiopia and one hybrid each in Kenya and Tanzania were released. New potential hybrids have been identified in Kenya, Tanzania, Malawi and Zimbabwe with 30-40% yield advantage over farmer / improved OPVs. To understand sorghum diseases prevalence a survey was conducted across different agro-ecologies of major sorghum production areas in Tanzania and Uganda. In Tanzania, 16 diseases were identified and the most prevalent (% of fields) were leaf blight (76%), anthracnose (56%), and rust (43%). In Uganda, 15 diseases were identified with leaf blight at 55%, anthracnose at 43% and ladder leaf spot, at 20%. In eastern Kenya, sorghum-cowpea/sorghum-green gram intercropping systems were more productive (35-60% more value) than maize-bean intercropping systems. Strengthening of Public-Private Partnerships (PPPs) enhanced the availability and affordability of the seed to resource-poor farmers. Over 10t of breeder and 380t of foundation seed was produced and availed to seed producers and farmers between 2012 and 2016. Public-Private Partnerships were also instrumental in sorghum grain marketing which and over 8000 farmers are marketing grain to the malting industry per year with grain prize improvement of about 40%. To increase sorghum consumption at household and commercial level training in value addition and product diversification was enhanced. A total of 17 charcoal ovens were distributed and TOTs trained in preparation of baked sorghum products.

**Finger millet for East and Southern Africa**

**Improving nutritional security with productive and nutritious finger millet production technologies for East and Southern Africa**

Henry Ojulong; Eric Manyasa; Chris Oduori; Elias Letayo; Nelson Wanyera; Taye Tadesse; Patrick Sheunda; Daniel Ajaku; Joseph Kibuka

Finger millet improvement program is geared to germplasm collection and characterization, validation and promotion of Good Agricultural Practices, improving post-harvest handling and value addition. Since 2012, 721 accessions were collected from Ethiopia, Kenya, Tanzania and Uganda, and more than 1000 accessions have been characterized. More than ten sources each for resistance/tolerance to blast, striga & drought; and high nutrient content have been identified. Emasculation technique was perfected and using the identify sources, populations were developed for the different traits. Nutrient profiling of the core collection, farmer-preferred varieties, elite and released varieties revealed that Local cultivars and varieties released in the region have significantly lower levels of the essential micro nutrients- Fe, Zn, Ca. High nutrient variability with values as high as 544 mg/100gm for Ca, 30.04 mg/100g for Fe and 3.73 mg/100g for Zn was recorded. To stratify testing sites, Multi-locational data was used to group countries into mega environments. Of the four countries, Uganda, Kenya and Tanzania were grouped as one mega-environment and Ethiopia as another.
NaSSARI site (Uganda) was found as an ideal test site for mega-environment one. A total of 13 varieties were released in the region (Ethiopia 6, Kenya 5 and Tanzania 2). Three management options micro-dosing, integrated striga management (resistant variety, micro-dosing and a trap crop) and tied ridges were validated for promotion. Plant spacing of 50 x 30 cm has yield not significantly different from the recommended 30 x 10 cm and is to be recommended and promoted. Improved varieties had an average yield advantage of 25% while a combination of improved variety with one management option had yield advantage of up to 60% over the farmer variety. Threshers were validated and are being promoted to improve grain quality and reduce drudgery.

Barley for Africa and Asia

Barley research for development under CGIAR Research Program on Dryland Cereals

R.P.S. Verma
Coordinator PL 5: Barley for Asia and Africa, CGIAR Research Program on Dryland Cereals
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Barley research for development was reorganized at ICARDA under the CGIAR Research Program on Dryland Cereals, to address the requirements of North and East Africa, Central, West and South Asia regions. The baseline survey, regional information workshops and focal countries review meeting were conducted to get the research prioritization for barley in extension and second phase of the CRP. Germplasm improvement and evaluation to address the feed, forage, food and malting successfully organized utilizing the complementing capabilities of focal countries. Improved germplasm in form of international trials & nurseries (>390 sets) was shared annually with more than 55 collaborators in 38 countries resulting in release of 23 varieties in last five years. In order to enhance genetic gains in the barley, MAS and doubled haploid technologies were integrated. Partnership were also supported under CRP Dryland Cereals with USDA, Institute de Genech, France, GRDC and several others in this regard. Disease surveillance, pathogen diversity, identification of diverse sources of resistance using FIGS (Focused Identification of Germplasm Strategy) approach have been the key activities for disease & pest management towards prevention of losses to the farmers. Through farmers’ field, on farm and experimental stations experiments the resource management technologies have been successful to reduce the yield gap with reduced input cost for the resource poor farmers. The major limiting factor has been observed the lack of timely seed availability in various surveys and increased seed production through formal and informal means has been promoted in Ethiopia and Morocco. The establishment of the micro-malting quality laboratory with support from Dryland Cereals at Morocco will help in identifying germplasm with desirable traits for target regions. Private-public partnership to meet rising demand for malting barley and increase the farmers’ income through contract farming in East Africa and South Asia, has been successful. Improvement for nutritional (Zn, Fe, and β-Glucan) and malting qualities are new initiatives in this period though post-harvest value addition aspects still need more collaboration with industry.

Pearl millet for East Africa and South Asia

Steps towards making Pearl Millet more Climate Smart and Nutrition Rich for South Asian (SA) and Eastern African (ESA) markets

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Following the strategy of demand-driven research, efforts were made through all the possible interventions viz. breeding, genomics, phenomics, crop management and processing linked technologies to increase the productivity of pearl millet crop in the SA and ESA region. This product line targets India in SA, and Tanzania and Uganda in ESA regions.
Through consultation process with partners, priority traits were identified, like disease resistance (DM and blast), heat tolerance, cytoplasmic diversification, exclusive forage type products, and drought tolerance and were addressed subsequently. The program primarily focuses on the development of a diverse range of hybrid parents (both seed and restorer parents) coupled with significant disease resistance for the potential to develop high yielding hybrids for adaptation to different ecologies. Many new sources for several traits, like high heat tolerance, blast resistance, high biomass traits were identified and utilized in a breeding program to generate new wave of breeding materials. **Mega-objective of sequencing genome of pearl millet** was accomplished and also sequencing some of important pathogens to add new dimensions to crop improvement research. Information was generated to reveal existing heterotic pools in pearl millet crop and attempts are on to standardize genomic selection model in the crop. Phenotyping protocols were standardized for blast disease and heat tolerance, while a 3-D LeasyScan system was developed and standardized to characterize materials for drought tolerance. Investigations revealed significant variability for flour shelf-life linked traits which will open new frontiers in next phase of market-linked research. Efforts are on to mainstream nutritional traits (high grain-Fe) in the breeding program after successful demonstration of development and deployment of first pearl millet bio-fortified cultivars, in any crop, at farmer’s field in India. The program conducted about 30,000 on-farm trials and identified hybrids for drought prone environments of north western India, and further sensitized seed chain to make these available to farmers. The program envisages to translate success story of hybrid technology in India to ESA region, hence based on multi-year and multi-country evaluation identified stable pearl millet hybrids having about 30-40 higher yield than local best checks, and attempts are underway to get them released in the region to make a new beginning.

**Post-rainy sorghum for South Asia**

**Improved breeding efficiency for enhanced productivity frontier of post rainy sorghum**

A Ashok Kumar; HC Sharma; Rajan Sharma; Vincent Vadez; Santosh Deshpande; Jana Kholova; Sunita Gorthy; Mohammad Riyazaddin; Kotla Anuradha; Prabhakar B; HS Talwar; R Madhusudhana; HV Kalpande; SR Gadakh; ST Kajjidi; Gowri Sajjanar; Belum VS Reddy and Michael Blummel

Post rainy sorghum grown on 4 m ha occupies ~10% of total global sorghum area and prized for its grain and stover quality. It is life line contributing for the food and fodder security of dryland farmers in Deccan Plateau of India but the productivity was low (0.6 t ha⁻¹). Therefore the reasons for low productivity were identified and research and technological interventions designed, developed and disseminated to farmers for enhancing the on-farm productivity. Improved sorghum varieties were developed and seed chain was strengthened with an innovative ‘Seed Consortium’ for supplying the seeds to 150000 farmers per year. The five point program adopted in target areas, viz., *in-situ* moisture conservation, adoption of improved variety seed, seed treatment for controlling shoot fly, adoption of recommended spacing, fertilizers and weed management methods helped in increasing the on-farm grain productivity by 40% and stover productivity by 30% in adopting farmers’ fields. To increase the genetic gain, improved varieties, hybrid parents and hybrids were developed and evaluated for adaptation and yield in multi location trials across the post rainy sorghum growing areas. Aphid screening methods standardized, inheritance of shoot fly resistance established, QTLs controlling components traits contributing for shoot fly resistance transferred to elite lines, QTLs controlling grain Fe and Zn concentration identified, drought patterns in post rainy sorghum areas established, high-throughput phenotyping of traits controlling plant water budget developed, stay-green QTLs introgressed in to elite lines and all the elite lines developed were assessed for invitro organic matter digestibility to identify most promising genotypes for feed use. The early adoption study showed that 70% of the farmers in target areas adopting the improved varieties and practices disseminated in the project, reduced the yield gaps by 35% and increased farmers’ incomes by close to 40%. With these the post rainy sorghum productivity increased to 800 kg ha⁻¹ and growing further.
The CGIAR Research Program on Dryland Cereals mainstreamed gender research through enhancing capacities for gender research by hiring a scientist, a scientific officer and allocating sufficient resources to support gender research in line with the approved Gender Strategy. Dryland Cereals was represented in the CGIAR Gender and Agriculture Network and focused on deriving common ‘gender and empowerment IDO’ that highlighted 2 indicators: women’s participation in decision making and women’s control over resources. We present research work in the CRP that contributes to understanding women’s participation in decision making [strategic research on social norms] and a cluster of studies that focus on women’s control over resources [training on business opportunities in sorghum and pearl millet value chain is being imparted to the Association of Lady Entrepreneurs of Andhra Pradesh, by ICRISAT’s Agri-Business and Innovation Platform, and two groups of women entrepreneurs (Ind-Millet and Mathesis) started their business in these value-chains and whole-grain consumption of sorghum and millets improves the intake of iron and zinc]. Identified research for future interventions included market surveys on food barley products and processing in Morocco and Ethiopia. Preliminary findings identified the need for focused inclusion of women in interventions related to value addition and market and in seed production and management. We also report progress on ‘gender voice’ in breeding process as part of a post doc fellowship between CRP DC and GL that is in progress.
Bean and cowpea are important nutritional components in the diets of eastern-southern Africa, and West Africa, respectively, and often are cited as a nutritious and inexpensive source of protein for the poor. However, analysis of consumption data of bean in Uganda and Tanzania, and cowpea in Nigeria, indicates that the rural poor only spend a third to half of what the well-to-do spend on these legumes. Urban areas show a similar but less dramatic difference.

Thus, productivity must increase to bring prices down and permit the poor to consume more of these legumes. Breeding of beans and cowpeas addressed basic yield limitations of drought and low soil phosphorus (P) availability. Root traits were investigated, and drought tolerance was enhanced. Lines of common bean were derived with multiple stress tolerance to both drought and low P, and some of these are advancing rapidly toward varietal release.

Reaching clients, especially among the poor, requires directed action. Seed systems to assure access to new materials face special challenges in dry areas, and several options are being implemented. Post-harvest processing of beans was developed within communities and with the private sector, with the goal to support nutrition and health outcomes of mothers and children. In Uganda, the private sector was engaged to promote cost-effective production and consumption of nutrient dense bean-based products that included a weaning porridge flour and bean flour for soups and sauces. In Burundi a similar product was developed as a cottage industry, and the female entrepreneur was unable to meet demand. An innovative and integrated approach to combine production, nutrition and policy led to beans being used widely in school feeding programs in Madagascar to supplement a rice-based diet.

**Addressing abiotic stresses and climate change effects**

**An overview of PL-1: Drought and Low P Tolerant Common Bean, Cowpeas, and Soybean**

Stephen Beebe

CIAT.

Bean and cowpea are important nutritional components in the diets of eastern-southern Africa, and West Africa, respectively, and often are cited as a nutritious and inexpensive source of protein for the poor. However, analysis of consumption data of bean in Uganda and Tanzania, and cowpea in Nigeria, indicates that the rural poor only spend a third to half of what the well-to-do spend on these legumes. Urban areas show a similar but less dramatic difference. Thus, productivity must increase to bring prices down and permit the poor to consume more of these legumes. Breeding of beans and cowpeas addressed basic yield limitations of drought and low soil phosphorus (P) availability. Root traits were investigated, and drought tolerance was enhanced. Lines of common bean were derived with multiple stress tolerance to both drought and low P, and some of these are advancing rapidly toward varietal release.

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**Heat-tolerant chickpea, common bean, faba bean and lentil**

**High-temperature tolerance in grain legumes: development and progress**

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High-temperature stress (or heat stress) is a serious constraint to the productivity of grain legumes as their cultivation is expanding to warmer environments and temperature variability is increasing due to climate change. Large genetic variations exist in grain legumes for heat tolerance which can be exploited for the development of locally adapted heat tolerant cultivars. Here we present examples of research progress on heat tolerance in ICRISAT, ICARDA, CIAT and IITA on chickpea, common bean, soybean, faba bean and lentil. Heat tolerant cultivars will be more resilient to the impacts of climate change, allow flexibility in sowing dates and enhance opportunities for expanding the area of grain legumes to new niches and cropping systems.
Leveraging legumes to combat poverty, hunger, malnutrition and environmental degradation

**Addressing abiotic stresses and climate change effects**

### Short-duration, drought tolerant and aflatoxin-free groundnut

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Product line 3(PL3) of the CGIAR Research Program on Grain Legumes (CRP) aims to catalyse competitiveness, production and productivity improvement of groundnut based cropping systems especially in Africa and Asia. The focus being short duration, drought tolerance and aflatoxin free groundnut varieties with elevated micro-nutrients and resilience to endemic biotic stresses. PL3 is underpinned by three assumptions i.e. (1) Modern groundnut varieties coupled with improved agronomy will increase productivity; (2) Investment imperatives for agricultural growth exist in Africa and South Asia exist; (3) Trade globalisation unlocks demand for agricultural produce, and pull for legume supply. Major achievements in phase I of the CRP include: (1) Development and deployment of genomic tools for groundnut breeding such as a: high throughput 58K single nucleotide polymorphisms array, development of dense genetic maps, marker-trait associations, molecular breeding and varietal identification, and multi-parent advanced generation inter-cross, training populations and nested-association mapping populations. Transgenic options for aflatoxin mitigation have been investigated; (2) Strengthened groundnut breeding pipelines among NARS and CGIAR programmes i.e. over 4000 new populations of short duration, low aflatoxin and drought tolerant generated; 867 elite lines entered into national performance trials and 15 new varieties released; (3) Seed systems strengthened i.e.: (i) WCA - produced 17.5 tons of breeder, 67 tons of foundation and 504 tons of certified seed; In ESA, 15 tons of breeder, 407 tons of foundation and 4000 tons of certified seed produced; In South Asia 26 tons of breeder and 16 tons of foundation seed produced; (4) Strengthened capacity among NARS in use of modern statistical, resource management and planning; Strategic partnerships were established with Peanut and Mycotoxin Innovation lab, CIRAD and EMBRAPA and gender main-steamed in research activities.PL3 leveraged CRP A4NH for aflatoxin mitigation. These and other results will be discussed.

### Capturing unique legume ability to fix nitrogen

#### High nitrogen-fixing chickpea, common bean, faba bean, and soybean

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Symbiotic nitrogen fixation (SNF) is a natural process that distinguishes legumes from other crops. The most important N₂-fixing agents in agricultural systems are the symbiotic associations between legumes and rhizobia. Past efforts to enhance SNF through inoculation with Rhizobium strains were partially successful in most of the developing or under developed countries due to suboptimal quality of inoculants and efficient delivery systems. A good quality rhizobial inoculant should be free of contaminants, contains a high number of rhizobia (8.0 X 10⁹ per g of product), besides longer shelf life so that inoculation can be purchased and stored for some time by farmers. Further, on-farm demonstration of the potential of SNF is absolutely essential in order to regain confidence of SNF technology among farmers. Rhizobia is highly specific not only to the crop it nodulates but also specific to soil type and environment and hence there is a need to identify specific high nodulating and nitrogen fixing rhizobia and the germplasm, by screening germplasm. SNF potential is severely limited by environmental factors including salinity, drought, heat, flooding and low soil phosphorous and hence there is a need to address the “SNF gap” by defining better the limiting factors in a given farming system. Mass multiplication protocols and the carrier materials that suits promising rhizobia also needs to be standardized.
Rhizobia are primarily considered for nitrogen fixation during the past but after the concept of plant growth-promoting (PGP) rhizobacteria (PGPR), rhizobia have also been looked for its PGP properties as rhizobial inoculum can provide additional plant and soil health benefits besides fixing nitrogen such as phosphate solubilization, iron mobilization, phytohormone production (such as indole acetic acid) and biocontrol. Hence, while selecting a rhizobia one needs to consider its other PGP traits. The activities of product line 4 (PL-4) were framed based on the above points.

## Managing key biotic stresses

### Insect-smart chickpea, cowpea, and pigeonpea production systems


1. IITA; 2. Michigan State University; 3. ICARDA; 4. ICRISAT.

The overall objective of PL5 is to use an IPM approach that will integrate the application of genetic engineering and genomic tools, wide hybridization, biological control, and rational application of biopesticides and synthetic pesticides to guide decision-making in pest management.

A study carried out on cowpea to understand factors influencing decisions making in pest control revealed that farmers are aware of health hazards from chemical pesticides but use them out of necessity; prefer pest control methods that reduce costs, labor, and yield losses; and social influences are important, hence mass education strategies could be leveraged to promote biocontrol in communities.

New pigeonpea transgenic events were engineered using stacked genes Cry1Ac1F and cry1Ac2Aa for higher and efficient expression. Over four independent transgenic events of ICPL88039 variety have been produced and transferred to contained greenhouse. In chickpea, two different gene constructs pBINcry2Aa and pMDC100 Cry1Ac1F have been used to develop ten new transgenics events for pod borers resistance.

Vertimec (Abamectin, 25 cc/hl) was effective against chickpea leaf miner, with a 60% reduction of infestation with the first application. The most effective biological insecticide was Radiant 120 SC (Spinetoram, 25 cc/hl), with a 40% reduction of infestation. Two promising chickpea lines for resistance to leaf miner (IG 6461, IG 70556) confirmed their good level of resistance in the field.

Of 119 varieties of cowpea tested for tolerance to flower thrips, 5 confirmed high levels of tolerance (Burkina Niébé, CIPEA82672, Suvita2, TVU7677 and Diaye).

Two parasitic wasps (parasitoids) where recently introduced at selected locations in Burkina Faso and Benin to control populations of Maruca vitrata in cowpea. Preliminary observations a few months after releases already indicate steady establishment of the parasitoids.

An insecticidal compound purified from the actinobacterium *Streptomyces bacillaris* CAI-155 was identified as N-(1-(2,2-dimethyl-5-undecyl-1,3-dioxolan-4-yl)-2-hydroxyethyl)stearamide for the first time. The purified metabolite showed 70-78% mortality in 2nd instar *Helicoverpa armigera*.

Some 12 PhD students (7 males five females) have participated in the program throughout the period under review.

## Generating new opportunities to intensify cropping systems

### Extra-early chickpea and lentil varieties for Southeast Asia and East Africa


1. ICARDA-Rabat, Morocco; 2. ICARDA-New Delhi, India; 3. ICARIS-Patancheru, India.

Development of extra-early varieties of chickpea and lentil offers opportunities for intensification and diversification of existing cropping systems in addition to introduction in new niches such as rice fallows in South Asia, two crops per season in Ethiopia, and spring planted legume crop in West Asia and North Africa. To achieve this goal, appropriate changes in phenology and plant type that can fit within the short-season windows available between major cereal crops are required. Under the Product Line 6, efforts were made to develop improved varieties through trait discovery and deployment in appropriate agronomic background, and their large-scale adoption through demonstrations, training and farmers’ participatory seed system.
This product line aims at developing and making available to farmers machine harvestable and herbicide tolerant chickpea, lentil and fababean varieties that are expected to reduce cost of cultivation through labor saving, enhance income of farmers, and reduce drudgery on farm women who are largely involved in manual harvesting and weeding of these crops. Accelerated breeding efforts led to release of several machine harvestable varieties, which include 10 kabuli chickpea varieties with resistance to ascochyta blight (3 in Turkey and one each in Lebanon, Tunisia, Georgia, Azerbaijan, Iran, Kazakhstan and Russia), two desi chickpea varieties with resistance to fusarium wilt (India), four lentil varieties with resistance to ascochyta blight (Turkey), and four fababean varieties (two in Syria and one each in Ethiopia and Mexico). Adoption of these varieties is being enhanced by conducting demonstrations on farmers’ fields, conducting field days and enhancing seed availability. Over 3400 genotypes (germplasm accessions, breeding lines and varieties) were screened for tolerance to herbicides in chickpea (949), lentil (771) and fababean (1703) and sources of tolerance to several herbicides (Metribuzin, Imazethapyr, Glyphosate, Pendimethalin, and Oxyflurfen) were identified. Efforts are also being made to induce herbicide tolerance through mutagenesis and development of transgenics using P450 gene from soybean (CYP71A10) and a xenobiotic inducible gene of Helianthus tuberosus. Two EMS-induced mutant lines of fababean were found tolerant to herbicide glyphosate. Parasitic weeds (Orobanche spp.) are also constraints to lentil and fababean production in some countries (e.g. Ethiopia, Morocco, Tunisia, Egypt). A large number of genotypes of lentil (516) and fababean (1924) were screened for Orobanche resistance and genotypes with high level of resistance to Orobanche were identified. Studies are in progress to identify molecular markers for quantitative trait loci (QTLs) controlling herbicide tolerance in chickpea and resistance to Orobanche in faba bean.

Herbicide-tolerant, machine-harvestable chickpea, faba bean and lentil varieties

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This has led to the release of 10 short duration varieties each of chickpea and lentil in target countries (India, Bangladesh, Ethiopia, Kenya) besides basic information on various components of crop duration and different early flowering genes, efl-1 (ICCV 2), efl-2 (ICC 5810), efl-3 (BGD 132) and efl-4 (ICC 16641) in chickpea. Identification of a new source of extra earliness in lentil from a wild accession, ILWL118 having less than 90 days maturity has resulted in development of new breeding lines which can fit in rice-lentil-boro rice system in South Asia. For accelerated adoption of improved cultivars, seed availability of improved varieties was enhanced by strengthening formal and informal seed systems. Over 161,882 metric tons of quality seed of improved cultivars of chickpea and 1005 metric tons of lentil was produced in South Asia and East Africa. Some of the success stories due to adoption of short duration varieties along with improved crop production practices are chickpea in Myanmar (5-fold increase in production 117,000 to 581,000 tons) and lentil in Bangladesh (126,000 to 210,000 tons). For small holder farmers, obtaining a harvest of chickpea and lentils from the same piece of land as a bonus has not only improved their livelihood but also nutrition for their families.

Generating new opportunities to intensify cropping systems

Pigeonpea hybrid and management practices

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Further researchers are being trained on new genomic tools and hybrid breeding approaches by imparting training and supply elite breeding material will lead to the development of location specific cultivars. Hybrid purity assessment kits, tagging of genes governing sterility and restoration, development of heterotic gene pools are some genomic interventions hastening the breeding process. A quantity of 705 tons of hybrid seed was produced during the year 2015 by ICRISAT in collaboration with public and private seed agencies, progressive farmers, NGOs and farmer cooperative societies. The area expected to be under hybrids during 2016 season will be around 1,50,000 ha. Significant progress has been made in identifying resistance sources, genetics and breeding for resistance to wilt, sterility mosaic and phytophthora diseases in pigeonpea.

Epidemiologically sound, effective, repeatable, sustainable field and greenhouse screening techniques are available for these diseases. In Eastern and Southern Africa during the last five years seven pigeonpea varieties were released for cultivation in Tanzania (4), Kenya (1), Malawi (1), Zambia (1) and several varieties are in the pipeline for release. Formal and informal seed systems are being strengthened, by production and delivery of 4250 t of seed during last eight years which could cover about 0.5 million ha. Sustainable intensification options through P-micro dosing, inter cropping with cereals and double up legumes had increased yields of both pigeonpea and associated crops. This led to productivity gains in the region up to 917 kg/ha and in Malawi, it has reached about 1309 kg/ha.

Gender research integration into Grain Legumes Research 2014 – 2016

Gender integration in grain legume research focused majorly on the operationalization of the gender strategy, developed and approved in 2013 The CGIAR Research Program on Grain Legumes capacities for gender research were enhanced through multiple pathways: hiring a scientist, a scientific officer, allocating sufficient resources to support gender, training workshops for product line teams of social and biological scientists on gender integration and analysis as well as a number of men and women students are being sponsored at MSc level to enhance gender analysis skills.

The CRP Grain Legumes was represented in the CGIAR Gender and Agriculture Network and involved in discussions of the common 'gender and empowerment IDO' that highlighted 2wo indicators: women's participation in decision making and women's control over resources.

We present research work in the CRP that contributes to understanding women's participation in decision-making [strategic research on social norms, cultural norms in women's participation in PVS training in Ethiopia] and a cluster of studies that investigate women's control over resources [e.g. impact of commercialization and small-scale mechanization on women's control of resources in Malawi and Zambia; disaggregated analysis of men &women ownership and control of grain legumes production and marketing decisions; empowering women to enhance nutrition through bean value chains and women's participation in cowpea marketing and the effect on poverty and food security] Progress on unpacking the ‘gender gaps’ in grain legumes value chains will be shared as work in progress implemented through a post-doctoral fellowship in the CRP GL and DC.

Long-term databases at the village level studies in India are presented. Designing of a bean breeding program responsive to women preferences for short cooking time is a highlight of gender transformative programming in the grain legumes value chain.
GRAIN LEGUMES
POSTER ABSTRACTS
Soil impoverishment, farmers' lack of access to inputs and climate change motivates rapid improvement of tolerance to drought and low soil fertility in bean and cowpea. Resources are stratified in most soils. Roots morphology has heritable genetic control and is measurable. Several examples illustrating the benefit of particular root phenes are presented for common bean. A similar variation is present in cowpea. Roots are important factors involved in soil resource acquisition and their targeted selection and deployment offers novel tools to breeders to increase tolerance to drought and low soil fertility. Collaboration between Pennsylvania State University, CIAT and IITA revealed ample variation of root traits in available germplasm of these species for further testing and use in breeding programs.

In the semi-arid regions cowpea and bean are important for poverty reduction, food and nutritional security and sustainable farming. The crops are grown by resource-poor farmers in marginal lands. Therefore, high-throughput phenotyping and breeding for improved varieties can be a low-input approach to enhancing the resilience and sustainability of agriculture in the tropics. Collaborative work conducted by IITA, CIAT and Pennsylvania State University to assess the genetic variability in plant traits for tolerance to low phosphorus (P) and drought was extended to breeding programs with the identification of elitelines with traits of interest. Germplasm of the two species were tested in both greenhouse and field conditions for their variation in yield, shoot and root traits that are associated with tolerance to individual and combined stresses. Overall, IT87D-941-1, IT89KD-288, IT90K-76, IT95K-1543, IT97K-499-38, IT07K-187-24, IT07K-188-49, IT07K-297-13, Danila and Iron-Bean were the most promising cowpea lines with the highest yields under low P. TVu-11982, IT98K-1111-1 and IT07K-318-33 with shallow root system and TVu-11986, IT97K-499-35 and IT98K 205-8 with steep root system were the most promising lines for adaptation to low P and terminal drought, respectively. Field evaluation of beans in Colombia under combined low P and drought conditions indicated that two BFS lines (95, 143) acquired greater amounts of P while ALB 91 was very efficient in using P for grain production. Further, 5 BFS lines adapted to both drought and low P were identified as superior in root hair length and density. Field testing in Nicaragua resulted in the identification of 3 BFS bean lines (81, 85 and 140; selected sequentially for yield under low P and drought) that doubled yields of the local elite check INTA Rojo under severe drought, with or without P application. These results validate the potential for improving the productivity of legumes in the face of multiple stresses.
Water use in bean and cowpea: efficiency or effective use of water?

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Common bean and Cowpea are two major food legumes cultivated by small farmers in Latin America and Africa, where unfavorable climatic conditions and minimum use of inputs frequently limit productivity. Drought is one of the major abiotic stress limitations for grain legume production in smallholder agricultural systems. Phenotypic characterization of water consumption by different species of legumes and genotypes within them plays a key role in adaptation to drought. Dynamics of water use may differ depending on the origin and evolution of the species of legume and the agro-climatic conditions faced by the legumes. In terms of water use two concepts have been formulated: Water use efficiency (WUE) defined as “more crop per drop”, and Effective use of water (EUW) that implies maximal soil moisture capture for transpiration. For common beans field studies were conducted at CIAT to determine the relationship between grain yield and parameters such as WUE and EUW in elite lines for drought resistance. A set of 36 bean genotypes were evaluated under two levels of water supply (irrigated and drought) over two seasons. Bean lines resistant to drought were classified into two groups: “water spenders” that showed effective use of water and “Water savers” that were efficient in water use. This classification of genotypes could help to target different type of bean genotypes to specific agroecological niches. Lysimetric studies were carried out at ICRISAT to compare sets of germplasm of cowpea and bean under a factorial of nitrogen (N) and water treatment and showed that beans were generally more sensitive to N stress than to water stress, in contrast to cowpea. High seed yield in both crops was associated with high early water extraction under low N conditions especially, which we interpret to be a consequence of an early onset of symbiotic nitrogen fixation allowing early plant growth and high N accumulation for later seed filling.

Breeding heat tolerant varieties of chickpea

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Heat stress at the reproductive stage has become a major constraint to chickpea production in India. This is mainly because chickpea area under late-sown conditions has considerably increased, particularly in the northern and the central India due to the inclusion of chickpea in new cropping systems and intense sequential cropping practices. Many farmers sow chickpea in the month of December after harvest of rice or potato. The late sown crop experiences heat stress at the reproductive stage and suffer heavy yield losses. Systematic efforts have been made to develop heat-tolerant varieties in chickpea. Screening for heat tolerance is carried out by growing the crop in the field under late sown conditions. Several breeding lines with improved heat tolerance have been developed. A heat tolerant desi chickpea breeding line ICCV 92944 was released as JG 14 in Madhya Pradesh state of India, specifically for late sown conditions. It was developed from a multiple cross [(GW 5/7 x P326) x ICCL 83149. It is an early maturing (95 to 105 days) variety with semi-erect growth habit, attractive grain of medium size (20 to 22 g 100-seed) and high resistance to Fusarium wilt. A Large number of demonstrations were conducted on JG 14 under late-sown conditions on farmers fields in Madhya Pradesh, Chhattisgarh, Uttar Pradesh, Bihar, Jharkhand and Odisha states of India. On an average JG, 14 gave 25% higher yield than the check varieties. There has been a rapid adoption of the heat tolerant variety JG 14 by the farmers. Among the 74 varieties under seed chain in India, JG 14 has become the fifth most indented variety for breeder seed production in India.
Rising temperatures or global warming will be detrimental for various crops. Chickpea and lentil are two vital winter-season legumes; their production has been found to be seriously constrained by an increase in temperature during the reproductive stage. Modern cultivars of chickpea and lentil are not resilient to changing climate, hence there is a need to develop heat-tolerance in these legumes. It is imperative to understand the mechanisms associated with heat tolerance. Considering this, we examined the effects of high temperature on both these legumes by growing them under late-sown environment to expose them to heat stress (>32/20°C) at the reproductive stage as well as under varying degrees of high temperatures in a controlled environment. In chickpea, we used genotypes contrasting for heat sensitivity, while in lentil, few released cultivars were examined for their response. The genotypes were assessed for damage by heat stress to the leaves and reproductive organs using various indicators of stress injury and reproductive function. In the heat-stressed plants, phenology accelerated as days to flowering and podding, and biomass decreased significantly. The significant reduction in pod set (%) was associated with reduced pollen viability, pollen load, pollen germination (in vivo and in-vitro) and stigma receptivity in all four genotypes. Heat stress inhibited pollen function more in the sensitive genotypes than in the tolerant ones and consequently showed significantly less pod set. Heat stress significantly inhibited leaf and anther function by adversely affecting the sucrose metabolism leading to reduced sucrose production. As a result, pollen had considerably lower sucrose levels, resulting in reduced germination, tube growth, impaired fertilisation and poor pod set in heat-sensitive genotypes. Controlled-environment studies, where the plants were subjected to high temperatures (33/15°C, 35/20°C) during reproductive growth, also validated the detrimental effects of heat stress on studied traits, similar to outdoor conditions.

Effects of heat stress on physiology and reproductive biology of chickpea and lentil

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Heat tolerance in common bean derived from interspecific crosses

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Many countries could experience unprecedented heat stress because of global climate change. Heat stress could affect negatively all stages of reproductive development in grain legumes. Common bean (Phaseolus vulgaris L.) is the most important food legume, cultivated by small farmers and usually exposed to unfavorable conditions. Based on climate models, with current varieties, the area suited for bean production will have shrunk up to 50% by about 2050. With heat-tolerant beans, the reduction will be only 5%, even assuming conservatively that the tolerant beans can handle a temperature rise of only three °C. In some parts of Africa and Latin America, farmers adopting the heat beaters will actually be able to expand production on land where it’s normally too hot for beans. Previous research indicated that tepary beans (Phaseolusacutifolius) are an important source of heat tolerance due to their evolution in dry and hot environments. Crossing them with P. vulgaris is not easy because of their genetic distance. Interspecific lines developed with crosses between P. vulgaris and P. acutifolius (SEF lines) were evaluated for their tolerance to heat stress under field (Armero, Colombia) and greenhouse (CIAT, Palmira, Colombia) conditions. Pollen viability, canopy biomass and grain yield were determined. Genomic analysis was made to validate the introgression of P. acutifolius genes into the interspecific lines.
Phenotypic differences were observed in heat tolerance of interspecific lines of common bean under field and greenhouse conditions. Pollen viability in some interspecific lines was more than 64% under severe heat stress, compared to less than 20% in checks of common bean, confirming the value of in trogression from *Phaseolus acutifolius* into common bean. Results from field and greenhouse evaluation confirmed that *Phaseolus acutifolius* is an important and useful genetic resource for improving heat tolerance in common bean. Results from genomic analysis indicated the introgression of *P. acutifolious* genes into inter specific INB line that was used as a parent for developing heat tolerant SEF lines.

**Groundnut integrated breeding: Superior performance of introgression lines developed using molecular and phenotyping tools**

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First ever National Testing trial for evaluating groundnut near-isogenic lines (NIL) is underway in India. Sixteen introgression lines (ILs) of groundnut with enhanced resistance to rust and late leaf spot (LLS), recorded up to 91% pod yield increase over the national check, were advanced to NIL trial. Genotyping and screening in disease nursery enabled selections in segregating populations, followed by multi-location trials (MLTs) to measure yield under disease pressure resulted in the selection of superior performing lines. The selected ILs recorded up to 75% increased pod yield over the Zone-V check and up to 43% increased pod yield over the recurrent parent in MLTs conducted at seven locations during rainy-2015. The rust score was at par with the donor parent, GPBD 4 and some of the ILs had LLS score of 1-5. Major effect QTL governing resistance to rust and LLS was introgressed into three mega-varieties, TAG 24, JL 24 and ICGV 91114. Background genotype, environment and genotype x environment interactions are important for expression of resistance governed by the QTL region.

‘High Oleic’ groundnut lines in the background of Spanish and Virginia bunch types were bred and 68ILs with enhanced oleic acid content, are under evaluation at five locations during rainy 2016 season. The oleic acid content in selected lines varied from 67 to 86% and oil content from 46 to 55%. Pod yield increase up to 80% was recorded over the recurrent parent. The ILs were developed using a marker-assisted selection (MAS) and marker-assisted backcross (MABC) approach to introgress the mutant genes *ahFAD2A* and *ahFAD2B* conferring the high oleic trait. Genotyping and robust phenotyping using near-infrared reflectance spectroscopy (NIRS) enables selection in segregating population. This is the first effort in India to develop and release disease resistant and high oleic groundnut genotypes using an integrated breeding approach.
New resilient varieties for unlocking groundnut production and productivity in semi-arid tropics

High yielding and resilient groundnut varieties are key to improving groundnut productivity, which is essential for combating poverty, hunger and malnutrition among smallholder families of semi-arid tropical agro-ecologies. The CGIAR has been instrumental in breeding and commercialization of new groundnut varieties in partnership with National Agricultural Research Systems (NARS). The development and deployment of short-duration, drought tolerant, nutrient dense and low aflatoxin contaminated groundnut is a major output of the Product line 3 of the CGIAR Research Programme (CRP) on Grain Legumes. A combination of genomic assisted breeding and conventional breeding methods have been deployed to breed a new generation of improved productive and resilient groundnut. Major achievements in the first phase of the CRP include strengthening of breeding pipelines with 1984 new populations for short duration, low aflatoxin and drought tolerance; 335 populations with novel traits (processing and confectionery) developed; 867 elite lines entered into national performance trials for release and 15 new varieties released. To address new market demand for groundnut, 77 new populations with high oleic acid and oil content developed by the Asia containing relatively higher levels of 65 to 83%, and O/L of 6.0 to 30.0%. In the Africa programs 952 populations for Africa high zinc, Fe, oleate and low aflatoxin contamination have been developed. These next generation varieties are underpinned by productivity traits such as – disease and pest resistance, short duration and drought tolerance as well as food safety traits such as low aflatoxin contamination. The large portfolio of new varieties will become ready for release in Phase II of the CRP. Capacity for research has been developed and seed systems strengthened for outcome delivery.

Scaling out improved technologies: Case studies from ESA, India, WCA

The current investments in scaling of improved groundnut seed are premised on the efficient supply of prioritized, highly productive varieties. Investments such as AGRA’s SSTP, W3/bilateral projects funded by USAID in West Africa and East and Southern Africa and India, Irish Aid, Bill and Melinda Gates Foundation supported Tropical Legumes III and McKnight Foundation supported collaborative research programs are underpinned by strategic CGIAR-NARS partnerships that involve formal and informal seed systems. Formal seed sector based models aim at improving the availability of early generations of seed (breeder and basic/foundation seed) and include programs such as the “Seed revolving fund scheme” in Malawi. Informal seed systems harness community seed production of Quality Declared Seed (QDS). In both formal and informal models, seed flows influence dynamics of varieties that farmers access, exchange and deploy.
During Phase I of the CGIAR Research Program on Grain Legumes, the highlights of achievements include: (i) Strengthening production and access to improved groundnut varieties with WCA- Nigeria producing 15 tons of breeder, 13 tons of foundation seed and 10 tons of certified seed; Ghana, Mali and Nigeria producing 2.5 tons of breeder and 54 tons of foundation seed and 494 tons of certified seed. In ESA15 tons of breeder, 407 tons of foundation seed and 4000 tons of certified seed was produced; in South Asia,26 tons of breeder and 16 tons of foundation seed was produced. Informal systems provided evidence for long distance movement of seed by up to 150 Km through farmer-led processes. Strengthening both formal and informal seed systems requires capacity strengthening for production, maintenance and quality assurance. For groundnut whose seed industry is not attractive for private sector led formal seed sector investment, improving seed flows from breeding to delivery and adoption requires leveraging informal systems to catalyze total factor productivity improvement and wider benefits in especially smallholder farmer livelihoods and farming system resilience.

Assessment of Chickpea Mesorhizobium Symbiosis for Biological Nitrogen Fixation and Yield Enhancement

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Concern for sustainable agricultural practices has intensified interests in eco-friendly sources of plant nutrients particularly BNF. Chickpea can derive 54-80% of its N demand by BNF. The present research findings were aimed: i) Screening of germplasm lines for inherent BNF traits, ii) Selection of effective Mesorhizobium strains with BNF and PGP traits, and iii) Evaluation of potential Mesorhizobium as biofertilizers and imparting training to the farmers. Of 376 germplasm lines 269 and 107 were screened at PAU, Ludhiana and GBPUAT, Pantnagar, respectively during winter seasons (2014-15 to 2015-16). Results revealed the superiority of 26 germplasm lines (GL10006, GL12007, GL13025, GL13001, GL13043, GLK10084, GL13024, GL13032, GL13037 and GL13041) at Ludhiana and 7 (ICCL10302, GL13029, BG362, GL13044, PG043, GL12020 and PG038) at Pantnagar in terms of BNF traits and grain yield. Of 243 Mesorhizobium isolates of chickpea 168 (Ludhiana) and 75 (Pantnagar) were collected from nodule and soil samples from diverse conditions. On the basis of cultural tests, 147 (Ludhiana) and 59 (Pantnagar) isolates were tentatively assigned Mesorhizobium genera. Few unidentified isolates were also noticed. Mesorhizobium isolates were subjected to P-solubilization, IAA, siderophore, ACC deaminase and HCN production, salt tolerance, fungal cell wall degrading enzymes and plant infectivity test. Three and five isolates from Ludhiana and Pantnagar respectively were found promising with PGP traits. Efforts needed to explore the role of unidentified isolates with Mesorhizobium within nodules. Molecular characterization and extensive field evaluation of these isolates is required for harnessing their potential for chickpea and chickpea based cropping systems. Training imparted and field demonstrations at farmers field on biofertilizer use enhanced chickpea productivity from 1.9 to 7.7% over the control providing an additional benefit of US$ 40-80 ha⁻¹. Dissemination of the knowledge on the promotion of biofertilizer technology in chickpea is extensively needed to provide full benefits to resource poor farmer.
Assessment of inherent nodulation potential among chickpea accessions belonging to minicore set

Karivaradharajan Swarnalakshmi; Subramaniam Gopalakrishnan; Mohan Singh; Sushil Kumar Chaturvedi; Abhishek Rathore; Vijay Pooniya; Hari Deo Upadhyaya and Partha Sarathi Basu.

The two main objectives of this study were to: (i) quantify the response of accessions to Mesorhizobium inoculation at IIPR and ICRI SAT. In field study, the chickpea lines were evaluated for their inherent nodulation ability with native Mesorhizobium under low P conditions. Stable genotypes showing similar (low and high) nodulation as well as plant growth pattern (at flowering stage) were identified at both IARI and IIPR locations. Further, 17 genotypes with low nodulation (211 nodules plant\(^{-1}\)), 18 genotypes (1032 nodules plant\(^{-1}\)) with intermediate nodulation and 39 genotypes (1185 nodules plant\(^{-1}\)) with high nodulation were found common at both locations. All these genotypes showed corresponding low and high shoot growth rate suggest that selection of genotypes with inherent symbiotic potential is essential for breeding cultivars for high SNF.

Evaluation of genotypic variation in symbiotic nitrogen fixation ability in climbing bean

Norma Barbosa; Elizabeth Portilla; Hector Fabio Buendia; Bodo Raatz; Idupulapati Rao; Stephen Beebe.

Nitrogen (N) deficiency affects about 40% of the common bean producing regions causing yield losses up to 60%. Symbiotic nitrogen fixation (SNF) – through association with root-nodulating rhizobia for the uptake of atmospheric N – contributes to improving grain yield. Climbing bean is known to be superior to the bush bean in its potential for SNF ability. One of the main factors determining the efficiency of SNF is the plant genotype. The two main objectives of this study were to: (i) quantify genotypic variability in SNF ability of climbing bean using 15N natural abundance method; and (ii) identify genotypes that combine high SNF ability with high yield potential that could serve as parents in the breeding program. A total of 100 genotypes of climbing bean including 89 ENF lines and 11 checks were evaluated for SNF ability. Field trials were conducted at two locations in Colombia. Both trials received Rhizobium inoculum and adequate nutrients except N fertilizer. Measurements included visual evaluation of root nodulation, \(^{15}\)N natural abundance (\(^{15}\)N) in shoot tissue and grain, %N derived from the atmosphere (%Ndfa), total Ndfa, canopy biomass, total N uptake, N use efficiency, N partitioning index and pod harvest index. Significant genotypic differences were observed in SNF ability. Good yielding lines fixed as much as 60% of their total N from the atmosphere which is equivalent to about 60 kg N/ha. Genotypic variation in SNF ability is usually estimated using \(^{15}\)N of shoot tissue rather than \(^{15}\)N of grain tissue. We tested the relationship between \(^{15}\)N of grain vs \(^{15}\)N of shoot at both locations. We found a positively significant relationship between the two methods. Thus using grain samples to determine SNF ability helps the breeding programs to select for genotypes with superior SNF ability. Based on evaluation from both locations, five lines (ENF 235, ENF 234, ENF 28, ENF 201 and CGA 10) were identified as promising for further testing and use as parents in the breeding program.

Chickpea (Cicer aritinum) has an inherent potential to fix atmospheric nitrogen through symbiotic association with rhizobia. To bridge large yield gaps in potential and actual grain yield of newly developed varieties of chickpea, a number of production technologies including inoculation with efficient strains of rhizobia have been recommended. However, soil nutrients deficiencies, especially phosphorus in soils of chickpea growing areas is a major limiting factor for N\(_2\) fixation and productivity enhancement. The assessment of chickpea accessions with better symbiotic potential under limited soil phosphorus is important for varietal improvement programme. Attempts were made to assess the inherent symbiotic potential and plant growth of chickpea minicore under pot as well as field conditions. The results of pot study demonstrated a direct correlation between nodule numbers and plant growth in its potential for SNF ability. One of the main factors determining the efficiency of SNF is the plant genotype. The two main objectives of this study were to: (i) quantify genotypic variation in SNF ability of climbing bean using 15N natural abundance method; and (ii) identify genotypes that combine high SNF ability with high yield potential that could serve as parents in the breeding program. A total of 100 genotypes of climbing bean including 89 ENF lines and 11 checks were evaluated for SNF ability. Field trials were conducted at two locations in Colombia. Both trials received Rhizobium inoculum and adequate nutrients except N fertilizer. Measurements included visual evaluation of root nodulation, 15N natural abundance (15N) in shoot tissue and grain, %N derived from the atmosphere (%Ndfa), total Ndfa, canopy biomass, total N uptake, N use efficiency, N partitioning index and pod harvest index. Significant genotypic differences were observed in SNF ability. Good yielding lines fixed as much as 60% of their total N from the atmosphere which is equivalent to about 60 kg N/ha. Genotypic variation in SNF ability is usually estimated using 15N of shoot tissue rather than 15N of grain tissue. We tested the relationship between 15N of grain vs 15N of shoot at both locations. We found a positively significant relationship between the two methods. Thus using grain samples to determine SNF ability helps the breeding programs to select for genotypes with superior SNF ability. Based on evaluation from both locations, five lines (ENF 235, ENF 234, ENF 28, ENF 201 and CGA 10) were identified as promising for further testing and use as parents in the breeding program.
Studies on influence of pink-pigmented facultative methylo trophic bacteria PPFMs and Rhizobium inoculation on BNF in Faba bean and Chickpea genotypes

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This research aimed to evaluate the response of 25 fababean and 24 chickpea genotypes under natural conditions, treatment with improved rhizobia and with PPFMs. Two experiments were laid out in Sids Station, BaniSuef Governorate (Egypt) using a randomized complete block design (RCBD) with two replications. Total nitrogen (N%) was estimated by Kjeldahl method at ARC (Cairo, Egypt). Plant N content (mg/plant) was calculated by the following formula: Plant dry weight (gram) X N% X 10. The amount of N-fixed (mg/plant) was calculated by the following formula: (Plant N content X Ndfa)/100. Significant differences among genotypes, treatments and genotypes x treatments were obtained for all the evaluated traits in both crops. Significant to highly significant phenotypic correlation between the measured traits were detected in fababean while in chickpea only significant differences were detected between nitrogen content in the plant with dry plant weight and with nitrogen fixed by air. In fababean all tested genotypes had more than 9.5 nodules per plant and were much improved to 18 when inoculated with Rhizobia and to) and 32 when inoculated with Rhizobia and PPFMs.

Moreover, the nodules dry weight ranged from 42.24 in the native treatment to 84.88 and 146.54 mg/plant when inoculated with Rhizobia only and Rhizobia and PPFMs, respectively. Finally, the plant N content was increased from 238.64 to 284.23 and 360.56 mg/plant when inoculated with Rhizobia only and Rhizobia and PPFMs. In Chickpea the treatment with Rhizobia showed the highest values for N content 62 mg per plant as compared to rhizobia treatments with PPFMs although the dry weight of nodules/plant was significantly higher in rhizobia treatments with PPFMs. Two faba bean accessions 45/018/F8/7307/06A and Sakha 1 showed the best plant N contents (mg)/plant comparing to other genotypes.

Biological control: Harnessing biodiversity for restoring ecological balances in grain legume crops

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We are presenting challenges and opportunities for the development and deployment of a 'biological control pipeline' addressing insect pest problems in grain legumes, focusing on cowpea (Vigna unguiculata) in West Africa. Biodiversity and population genetic studies have been carried out to guide the identification of novel biological control candidates, which are subsequently assessed for their potential in sustainably reducing pest populations. Pre-release assessment studies are targeting critical questions such as potential impact on biodiversity and biosecurity in general, together with factors leading to successful establishments such as host-finding capacity and intra-guild competition. Also, experience from the field has indicated the importance of the right deployment system for establishing a population of the released natural enemy through inoculative releases. Using the case study of the legume pod borer Maruca vitrata, the poster briefly leads through the various steps of this development-to-deployment process and discusses its potential impacts.
Microorganisms produce a range of metabolites which play key roles in agriculture including pest control properties. With this concept, 15 strains of *Streptomyces* spp. with insecticidal activity against the lepidopteran pests such as *Helicoverpa armigera* (Hübner), *Spodoptera litura* (Fabricius), and *Chilo partellus* (Swinhoe) were identified. Based on the activity units, *S. griseoplanus* SAI-25 and *Streptomyces* sp., CAI-155 were further studied to identify the key insecticidal metabolites against *H. armigera*. An insecticidal compound called cyclo (Trp-Phe) belongs to the diketopiperazine class was purified from SAI-25 by bioactivity-guided fractionation. Cyclo (Trp-Phe) exhibited antifeedant (70%), larvicidal (67%), and pupicidal (59%) action against *H. armigera* in a dose-dependent manner. The lethal doses were observed to be 619 and 2750 ppm, for LD₅₀ and LD₉₀ respectively. In addition, the purified compound prolonged larval (10.3–11.1 days) and pupal (10.9–11.8 days) periods compared with the untreated control (larval duration 9.8 days, pupal duration 10.6 days). This is the first report on the presence and biological activity of cyclo (Trp-Phe) isolated from the genus *Streptomyces*. In the context of *Streptomyces* sp., CAI-155, a novel fatty acid amide derivative called N-(1-(2,2-dimethyl-5-undecyl-1,3-dioxolan-4-yl)-2-hydroxyethyl) stearamide with the insecticidal activity of 70–78% against 2nd instar *H. armigera* under laboratory and greenhouse conditions was identified. Under laboratory conditions, this metabolite displayed similar lethal dose values of Cyclo (Trp-Phe) with 627 and 2276 ppm for LD₅₀ and LD₉₀ respectively. Further characterization of these metabolites in the field conditions, will bring out the potentiality of microbial metabolites for pest management.

Host plant resistance against insect pests: one approach across multiple legume crops

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1ICARDA; 2ICRISAT; 3IITA

Host plant resistance is the most economical, practical and environmentally friendly means for controlling insect pests. Entomologists and geneticists have been mining the CGIAR genebanks and others to look for sources of resistance to legume pests. ICARDA, in collaboration with its partners, has led the development of the Focused Identification of Germplasm Strategy (FIGS). This approach enables large gene bank collections to be mined for specific traits such as insect pests’ resistance. FIGS is based on the paradigm of co-evolution of, and interaction between, host and pest. It analyzes the agro-climatic characteristics of sites from which plant germplasm was originally collected, to make predictions of best-bet accessions that are most likely to contain the trait of interest. Through field screening in hot spots in the field and/or under artificial infestation in the greenhouse, several sources of resistance have been identified in cultivated legume crops and in wild relatives to key legume pests such as chickpea Pod borer and Leafminer. Germplasm carrying resistance to these legume pests, along with molecular markers associated with the resistance have been developed. Mechanisms of resistance to some of the legume pests have also been determined.
In chickpea, flowering time and crop duration are the two major traits for adaptation of the crop to a given environment. For short season environments, earliness in both flowering and maturity are needed. Understanding allelic relationships of different early flowering genes can greatly facilitate the development of early maturing varieties. A study was conducted to establish allelic relationships of the early flowering genes \textit{efl-1} (ICCV 2), \textit{ppd} or \textit{efl-2} (ICC 5810), and \textit{efl-3} (BGD 132) with the early flowering genes present in ICC 16641, ICC 16644 and ICCV 96029. Late flowering was dominant to early-flowering. The \textit{efl-1} gene identified from ICCV 2 was also present in ICCV 96029. ICC 16641 and ICC 16644 had a common early flowering gene which was not allelic to other reported early flowering genes. The new early flowering gene was designated \textit{efl-4}. In another study involving four F\textsubscript{2} populations (ICCV 96029 × CDC Frontier, ICC 5810 × CDC Frontier, BGD 132 × CDC Frontier and ICC 16641 × CDC Frontier) the genomic regions controlling flowering time were identified. QTL analysis detected seven major (\textit{Qefl1}-2, \textit{Qefl2}-1, \textit{Qefl2}-2, \textit{Qefl2}-3, \textit{Qefl2}-4, \textit{Qefl3}-3, \textit{Qefl3}-4) and three minor QTLs (\textit{Qefl1}-1, \textit{Qefl3}-1, \textit{Qefl3}-2) for flowering on linkage groups CaLG01, 03, 04, 06 and 08. Analysis of QTL regions on CaLG04 and CaLG08 provided several important candidate genes that are reported to be involved in regulation of flowering time and homeotic functions. The new sources of alleles identified for early flowering provide several options for developing early and extra-early maturing chickpea varieties suited for rain-fed environmental conditions.

Genetics of flowering time in chickpea

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In chickpea, flowering time and crop duration are the two major traits for adaptation of the crop to a given environment. For short season environments, earliness in both flowering and maturity are needed. Understanding allelic relationships of different early flowering genes can greatly facilitate the development of early maturing varieties. A study was conducted to establish allelic relationships of the early flowering genes \textit{efl-1} (ICCV 2), \textit{ppd} or \textit{efl-2} (ICC 5810), and \textit{efl-3} (BGD 132) with the early flowering genes present in ICC 16641, ICC 16644 and ICCV 96029. Late flowering was dominant to early-flowering. The \textit{efl-1} gene identified from ICCV 2 was also present in ICCV 96029. ICC 16641 and ICC 16644 had a common early flowering gene which was not allelic to other reported early flowering genes. The new early flowering gene was designated \textit{efl-4}. In another study involving four F\textsubscript{2} populations (ICCV 96029 × CDC Frontier, ICC 5810 × CDC Frontier, BGD 132 × CDC Frontier and ICC 16641 × CDC Frontier) the genomic regions controlling flowering time were identified. QTL analysis detected seven major (\textit{Qefl1}-2, \textit{Qefl2}-1, \textit{Qefl2}-2, \textit{Qefl2}-3, \textit{Qefl2}-4, \textit{Qefl3}-3, \textit{Qefl3}-4) and three minor QTLs (\textit{Qefl1}-1, \textit{Qefl3}-1, \textit{Qefl3}-2) for flowering on linkage groups CaLG01, 03, 04, 06 and 08. Analysis of QTL regions on CaLG04 and CaLG08 provided several important candidate genes that are reported to be involved in regulation of flowering time and homeotic functions. The new sources of alleles identified for early flowering provide several options for developing early and extra-early maturing chickpea varieties suited for rain-fed environmental conditions.

Impact of early maturing chickpea varieties in Myanmar

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Chickpea is an important legume crop in Myanmar, not only for local consumption but also for export. About 96% of the chickpea area is in the Central Dry Zone (CDZ) in Sagaing (47%), Mandalay (25%) and Magway (24%) regions. The CDZ is characterized by erratic and low (<750 mm) rainfall. Chickpea is grown in the post-rainy season on residual soil moisture, mostly without irrigation, and often experiences drought and heat stresses during reproductive phase. The chickpea varieties with early maturity, resistance to Fusarium wilt and tolerance to terminal drought and heat stresses are required for CDZ. Department of Agricultural Research (DAR) of Myanmar has worked closely with ICRISAT for the development of chickpea varieties suited to CDZ. Since 2000, seven early maturing (85 to 95 days) chickpea varieties, four in kabuli type, Yezin 3 (ICCV 2), Yezin 5 (ICCV 3), Yezin 8 (ICCV 97314) and Yezin 11 (ICCV 01309), and three in desi type, Yezin 4 (ICCV 88202), Yezin 6 (ICCV 92944), and Yezin 12 (ICC 07118), have been released in Myanmar from the breeding lines supplied by ICRISAT. Farmers have rapidly adopted these varieties. During 2014-15, 96% of the chickpea area was under five of these varieties (43% Yezin 3, 20% Yezin 4, 16% Yezin 6, 16% Yezin 8 and 1% Yezin 11). Adoption of these varieties along with improved crop production practices has given an impressive compound annual growth rate of 5.6% for chickpea yield during the past 15 years (2000-01 to 2015-16). The chickpea production increased 5-fold (117,000 to 581,000 tons) due to 3.3-fold increase in area (164,000 to 373,000 ha) and 2.2-fold increase in yield (712 to 1560 kg ha). Myanmar has emerged as an important chickpea exporting country from 2001 with an average annual export of 47,500 tons (valued at US$ 24 million).
South Asia has one-fourth of the world's population but only one-twentieth of the world's land. To ensure food security in the world's most densely populated region, there is only one option – produce more food from every piece of arable land. ICARDA and its partners in South Asia under the CRP-GL are exploring an option of growing an extra crop during periods when farms are usually left fallow. Over 14 million hectares of rice fields in South Asia are left fallow in the winter season. ICARDA and NARS partners in Bangladesh, Nepal and India have developed new short duration varieties and crop management methods for cultivating the fallow land. The approach has already proven its potential in Bangladesh and Nepal and on scaling out stage in India. The major example of documented uptake of lentil varieties is Bangladesh, which grows about 165,000 ha of lentil and has traditionally imported more than half of its consumption. A key scientific enabler in establishing a thriving rice-lentil system Bangladesh is new higher-yielding varieties (BARI Masur4, BARI Masur5, BARI Masur6, BARI Masur7, BARI Masur8) of lentils tolerant to rust and stemphylium blight, and extensive training of farmers in managing lentil crops. This has led to increase in lentil production from 126,000 tonnes in 2001 to 210,000 tonnes at present, mainly because of the yield increase from 790 kg/ha in 2001 to 1270 kg per ha. Lentil cropping has spread to more than 85 percent in the Bangladesh alone, bringing in an additional annual income of US $26.6 million. For small-scale farmers numbering ~ 1 million, obtaining a harvest of lentils from the same piece of land has improved not only their livelihood but also nutrition for their families. Identification of a new source of extra earliness in from a wild accession, ILWL118 having 90 days maturity opens up the prospect of rice-lentil-Boro rice system in South Asia.

In order to reduce the cost of cultivation and make agriculture profitable, the farmers in India are gradually adopting mechanization of farm operations. In India, chickpea ranks first in area and production among various pulses grown. The farmers are demanding chickpea varieties those are amenable for combine harvesting as most of the present day varieties are bushy or semi-erect type having inadequate plant height hence not suitable to machine harvesting. Development of varieties having >70 cm plant height, and semi-erect to erect (>600 branch angle from base) growth habit will make chickpea crop amenable to combine harvesting. Such varieties will also be allowing better solar light penetration inside crop canopy helping in minimizing losses due to foliar diseases and ease in intercultural operations including application of plant protection chemicals.
Therefore, tailor-made varieties having erect growth habit will also help in re-establishing chickpea cultivation in traditional areas of northern India and as an intercrop with autumn planted sugarcane in other parts of the country bringing additional area under this crop. ICAR-IIPR, ICRISAT, IARI and State Agriculture Universities are working to develop machine harvestable chickpea varieties under Department of Agriculture, Cooperation and Farmers Welfare, Government of India supported the project and contributed towards Product Line 7 of the CGIAR Research Program on Grain Legumes. Recently, two high yielding chickpea varieties (NBeG 47 and GBM 2) identified having suitability to machine harvesting are becoming very popular among farmers. Concerted efforts led in development of large number of elite breeding lines including IPC 2012-49 and IPC 2011-85 having desired traits like tall and erect plants, profuse primary branches of equal height with more than 20 cm ground clearance, non-lodging behaviour, erect growth etc. ensuring better sunlight penetration in crop canopy reducing prominent foliar diseases like botrytis grey mould (BGM) and Ascochyta blight.

Herbicide tolerance in chickpea, lentil and faba bean

Weed management in cool-season legumes (chickpea, lentil and faba bean) is difficult in the absence of effective post-emergence herbicides, while manual weeding is expensive, and pre-emergence herbicides are effective only in the initial stage of plant growth. Over the last three years a large number of germplasm lines of these legumes were screened against different post-emergence herbicides using visual injury score on 1-5 scale. In chickpea, 1251 lines (against imazethapyr), 575 lines (against metribuzin), 376 lines (against carfentrazone-ethyl); in lentil, 315 lines (against imazethapyr and metribuzin); and in faba bean, 750 lines (against imazethapyr, metribuzin and oxyfluorfen) and 300 mutant lines (against glyphosate) were screened. Large genetic variability was observed in chickpea, lentil and faba bean for tolerance to different post-emergence herbicides. In general, chickpea and lentil genotypes were found more sensitive to metribuzin than imazethapyr, while faba bean was found more sensitive to imazethapyr and oxyfluorfen than metribuzin. Most of the genotypes in these legumes were found sensitive to different post-emergence herbicides but later showed a recovery after 15-20 days of spray. In chickpea, a number of genotypes tolerant to imazethapyr (ICC 637, ICC 1398, ICC 17109, GLW68, GLW12039, GLW12040, GL10061, GLK10093), metribuzin (ICC 11378, ICC 14595, GL22044, GL28127), and carfentrazone-ethyl (GL12011, GLK10101, BG3028, GL22044) were identified. In lentil, the genotypes EC28514, LL1376, LL1252, LL1203, LL1366, DLP15, ILL262, ILL6447, ILL4400, ILL7668, ILL7547, ILL5533 were found tolerant to imazethapyr, whereas genotypes EC78477, EC267687, LL1336, LL1383, ILL6434, ILL89517, ILL10810 and ILL10833 showed tolerance against metribuzin. Similarly, in faba bean, 25 and 24 genotypes showed tolerance respectively against metribuzin and imazethapyr. Among them, IG99328, Spanish845, Spanish972 and INRA2583 were found tolerant to both herbicides, while Mu418 was found tolerant to glyphosate. These genotype scan be used for developing herbicide tolerant cultivars and for carrying out genetic and physiological studies on herbicide tolerance.
Orobanche tolerance in fababean and lentil

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Broomrapes (Orobanche spp and Phelipanche spp), parasitic weeds, are a serious threat to legumes cultivation in North and East Africa. The estimated yield losses in faba bean and lentil due to Orobanche spp, are as high as a complete loss of a crop in Morocco, Egypt, Tunisia and Ethiopia. Among various species prevalent in the region, O. crenata is most widespread. Integrated management revolving around tolerant varieties is the only option to manage the weed menace. To identify resistance sources, 216 lentil and 194 faba bean elite lines and 280 recombinant inbred lines (RILs) of a faba bean cross (BPL710 x ILB4347) were screened against O. crenata in a sick plot at Douyet experimental station, Morocco during 2013/14 and 2014/15. Observations were recorded on the number of emerged heads and underground tubercles per host plant, orobanche dry weight, and per cent infestation. Based on these parameters, a severity score on a 1-9 scale was worked out. Two-year results indicated a wide range of responses from 1 (immune to no infection) to 9 (susceptible). Of total lines tested, 40 lentil and 49 faba bean lines showed high tolerance with no emergence of orobanche heads. The spatial model analysis revealed significant variation among RILs for number of emerged orobanche heads per host plant. Some of tolerant lines of lentil (ILL4164, ILL7701, ILL6783 and ILL10952) and faba bean (F402, ILB4338, ILB4357, ILB4358, SelF5/3382/2003-4, Giza843, Najah, Amcor, Hend) are being utilized in the breeding program to combine orobanche resistance in desired agronomic background. Recently, two faba bean varieties, Hashbenge in Ethiopia and Misr 3 in Egypt, have been released for cultivation in orobanche infested lands.

Advances in host plant resistance to Fusarium wilt, sterility mosaic disease and Phytophthora blight diseases of pigeonpea

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The production and productivity of pigeonpea is severely constrained by diseases-Fusarium wilt (FW; Fusarium udum), Sterility Mosaic Disease (SMD; Pigeonpea sterility mosaic virus) and Phytophthora blight (PB; Phytophthora cajani). The severity & yield losses of these diseases differ from place to place owing to the existence of G x E, virulence and variability of the pathogen. Breeding for host resistance is an efficient means to combat these diseases. Significant progress has been made in identifying resistance sources, genetics and breeding for resistance in pigeonpea. Epidemiologically sound, effective, repeatable, sustainable field and greenhouse screening techniques are available for these diseases. All the cultivars released so far in pigeonpea have gone through these screening followed by their confirmation for the stability of resistance in greenhouse and multi-environment/multi-year testing. Combined resistance to FW and SMD was found in five mini-core accessions (ICPs 6739, 8860, 11015, 13304, and 14819). Recently, through multi-environment field testing, four genotypes (ICPLs 20094, 20106, 20098 and 20115) have been identified as the most stable and resistant to SMD. Three genotypes (ICPLs 20096, 20107, 20110) showed moderately stable performance against SMD. All these lines have a medium duration of maturity and could be valuable sources of resistance for a pigeonpea breeding programs to FW and SMD. Four vegetable type genotypes (ICPs 7991, 12059, 13257 and 14291) originated from different countries were found highly resistant with no incidence of FW and SMD. Using new screening protocol for PB, over 800 pigeonpea genotypes including released cultivars, earlier reported PB resistant lines, breeding lines and water-logging tolerant lines have been screened. Repeated screening of promising genotypes has so far identified four genotypes with moderate resistance to PB (ICPLs 99004, 99008, 99009 and 99048).
Advances in genomics are leading to a new revolution in pigeonpea hybrid breeding, as these inventions facilitate the study of genotype and its relationship with the phenotype. The draft genome sequence of pigeonpea and Next Generation Sequencing (NGS) technologies has made it possible to sequence multiple genomes. This allows discovering genes, regulatory sequences and provides large collections of molecular markers. For instance, re-sequencing of 104 parental lines of pigeonpea hybrids has provided 511 GB sequence data with the coverage ranging from 5X to 10X. A total of 3.4 million SNPs could be identified across 104 lines while comparing individual genotypes with the reference genome and SNPs ranged from a minimum of 15,388 to a maximum of 84,851. In parallel, these parental lines have been used to develop test-crosses in factorial mating design. Fhybrids along with parental lines have been phenotyped for yield and yield related traits. The availability of genome-wide SNP variations combined with the phenotypic data should provide clues on candidate genomic regions associated with yield and yield-related traits as well as those associated with heterosis and heterotic pools in pigeonpea for accelerating hybrid improvement. Sequencing-based approaches have also provided markers for cytoplasmic male sterility, fertility restoration and hybrid purity assessment. The tagging of above-mentioned traits/genes will have a lot of implications in breeding and rapid development of high yielding hybrids.
Medium duration and Fusarium wilt tolerant pigeonpea cultivars for Eastern and Southern Africa: their development and adoption

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Pigeonpea is the crop of about 6 million smallholder subsistence farmers in Eastern and Southern Africa (ESA) with 1.14 million ha of area and 1.047 million tonnes of production (FAO Stat 2014). Pigeonpea has huge regional and international export potential and India imports about 570,000 t annually. ESA countries export 290,000 t of grain/year worth of $ 203 million.

ESA is the secondary centre of genetic diversity and region-specific genetic enhancement program is in operation using this diversity with an emphasis on high grain yield, inter-cropping compatibility, photo-period insensitivity, grain quality, resistance, and/or tolerance to Fusarium wilt and Helicoverpa pod borer and resilience to climate change. During the last five years seven varieties were released for cultivation in Tanzania(4), Kenya(1), Malawi(1), Zambia(1) and several varieties are in the pipeline. The successful dissemination of Fusarium wilt-resistant medium and long duration varieties in ESA countries resulted in area and productivity increases. Most of the cultivated varieties are susceptible to insects, but regional germplasm contributed to developing insect-cum-drought tolerant, high yielding and big seeded genotypes (28 g/100 seed mass).

Formal and informal seed systems are being strengthened to produce and disseminate about 4250 t of seed which to cover about 0.5 million ha. Sustainable intensification through P-micro dosing, intercropping with cereals/legumes had increased yields. Tremendous yield gains have been recorded with new varieties, integrated crop management, effective seed systems, export demand and policy support. This led to productivity gains in the region up to 917 kg/ha and in Malawi about 1309 kg/ha. In order to develop a strong breeding pipeline, genetic enhancement using trait-specific/multiple trait donors are being used. At present, a large number of medium duration varieties with high ratoonability and Fusarium wilt resistance are available. Value addition and utilization at household, community and village level are being tried to improve the food and nutritional security.

Sustainable Legume Business: a Public-Private Partnership experience from South Eastern Ethiopia

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Chickpea is a widely grown food grain legume in rotation with cereals and an important source of food and income. The chickpea value chain comprises diverse actors at different functional levels. Evidence indicates that it is characterized by weak chain coordination leading to poor production performances and market information asymmetry. An N2Africa project facilitated Public-Private Partnership brought together a private commercial farm, public agricultural research, a private chickpea exporting and an inoculant supplying company. Coordination and joint planning greatly improved chickpea technology dissemination and the business relationships between out-grower farmers, the nucleus farm and the input and output supply companies.
The nucleus farm, Balegreen Spice and Grain Development, pioneered mechanizing chickpea farming and breaking a long cereal mono-cropping practice. They are involved in seed multiplication, grain production both on its own and through small holder-out-growers, extension services, fertilizer and inoculant supply, grain bulking and delivery to the exporting company. The role of Oromia Agricultural Research Institute is technical support and Monitoring and Evaluation whereas basic seed supply and grain sourcing is attributed to Agricultural Commodity Supplies Ethiopia. Menagesha Biotech Industry is committed to producing and supply inoculants to the out-growers and other farm communities through the nucleus farm. Experience from this partnership model shows there is need for a built-in appropriate progress tracking and feedback mechanism and a coordinated effort of legume value chain actors is crucial to sustain technology dissemination and for a win-win business relationships at the different levels of the chickpea value chain.

**Varietal adoption and seed use of faba bean in Ethiopia: implication for national seed system**

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The paper presents the varietal adoption and seed use of fababean-based on primary data collected from 370 fababean producing farmers covering 19 districts in 13 major fabadbean growing zones of Amhara, Oromia, SNNPR and Tigray regions. The adoption rate at household level indicates that 25.9% of the farmers are full adopters, 1.6% partial adopters, and the remaining 72.4% were non-adopters based on plot level use of improved varieties. This has partly resulted in the productivity gaps between research estimated at 3.6 ton/ha, adopters of improved varieties and management practices (3.2 ton/ha) and national level (1.5 ton/ha). The current status calls for the need to strengthen the promotion of available improved varieties and for enhanced engagement of the formal seed system in fababean to ensure better adoption.

**Effects of storage temperature and relative humidity on development of the Hard-to-Cook (HTC) defect in common beans and the subsequent cooking properties and nutrition changes**

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Grain legumes, especially common bean, are a staple food for people in many parts of the world. Their high content of protein, carbohydrates, fibre, minerals and vitamins make beans an excellent nutrient source. The dry seeds of *P. vulgaris* are appreciated throughout the developing world also because they have a long storage life and can be easily stored and prepared for eating. Bean post harvest storage temperature and relative humidity strongly influence dry bean quality and the final product. Storage of beans at high temperatures (45°C) and high relative humidity (83%) may result in cumulative increases in cooking time, loss of cooking quality and reduced water uptake during cooking. This is characteristic of the hard to cook (HTC) problem in beans. The HTC defect is of great importance nutritionally and subsequently has commercial consequences as beans with this defect are characterized by extended cooking times for cotyledon softening, are less acceptable to the consumer due to loss of flavour and color, and are of lower nutritive value. The objectives of this study were to: (i) determine effects of storage temperature and relative humidity on the development of the HTC defect in popular common beans grown in Kenya and the subsequent physical and cooking property changes; and (ii) assess the effect of soaking pre-treatments on bean cooking properties.
Nutrition analysis was conducted on Rosecoco and Red kidney beans samples stored at different temperature and relative humidity for the following nutrients: ash, moisture, protein content, phytates, tannins, protein digestibility, iron, magnesium, calcium, and zinc. Postharvest storage conditions of high temperature and humidity cause the development of the HTC defect in both common bean varieties. HTC defect causes an increase in cooking time thus high energy, water, and fuel consumption. HTC defect also impacts negatively on bean texture and nutritional quality. Sodium carbonate soaking pre-treatment is an effective and safe way of shortening cooking time in beans.

Expansion of rice-fallow in South Asia using remote sensing data

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Cereals and grain legumes are the most important part of human diet and nutrition. The rural population of low income groups in dry land areas of South Asia depends on these staples. Expansion of grain legumes with improved productivity to cater the growing population's nutritional security is of prime importance and need of the hour. Rice-fallows are best niche areas with residual moisture to grow short duration legumes there by achieving intensification. Identifying suitable areas for grain legumes and cereal grains is important in this region. In this context, the goal of this study was to map fallow lands followed by rainy season (kharif) rice cultivation or post rainy (rabi) fallows in rice growing environments for 2000-01 and 2010-11 using temporal moderate-resolution imaging Spectro radiometer (MODIS) data applying Spectral matching techniques. This study was conducted in South Asia where different rice ecosystems exist. MODIS16days normalized difference vegetation index (NDVI) at 250m spatial resolution and season wise intensive ground survey data were used to map rice systems and the fallows thereafter (rabi-fallows) in South Asia. The rice maps were validated with independent ground survey data and compared with available sub-national level statistics. Overall accuracy and kappa coefficient estimated for rice classes were 81.5% and 0.79 respectively with ground survey data. The derived physical rice area and irrigated areas were highly correlated with the sub-national statistics with $R^2$ values of 84% at the district level for the year 2000-01 and 2010-11. Results clearly show that rice-fallows areas increased from 2000 when compared 2010. The results show spatial distribution of rice-fallows in South Asia which are identified as target domains for sustainable intensification of short duration grain legumes, fixing the soil nitrogen and increasing incomes of small holder farmers.

Grain legume consumption patterns and demand: A case study of common bean in Uganda, Chickpea in Ethiopia and Cowpea in Nigeria

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The study estimates household food demand using a two-stage censored demand system with a focus on common bean in Uganda, chickpea in Ethiopia and cowpea in Nigeria. The analysis is based on nationally representative household survey data collected under the LSMS-ISA project led by the Development Research Group at the World Bank in collaboration with the country respective National Bureau of Statistics. Results show relatively diverse consumption and expenditure patterns on legume crops among households of different sub-groups across the selected countries. Chickpea is least consumed legume constituting about one percent of the households’ food expenditure in Ethiopia.
Common beans in Uganda and cowpea in Nigeria are widely consumed crops and constitute 9.7% and 5.2% of the food expenditure in Uganda and Nigeria, respectively. For all legumes, per capita consumption is higher among better-off households compared with poor ones. Per capita expenditure on chickpea and cowpea in Ethiopia and Nigeria is also higher among urban population than their rural counterparts.

The results from econometric analysis are consistent with the descriptive statistics and support the finding that the poorer households consume smaller quantities of legumes than they desire. The food expenditure elasticities show that common bean in rural Uganda (1.026) and cowpea in Nigeria (1.06-1.05) are luxury goods. This means that the growth rate of demand for these legumes is expected to be high as economies in these countries improve requiring investment in productivity enhancing research given already high population pressure on land. Demand for common bean and chickpea is highly sensitive to price fluctuations, which suggests that policies that aim at reducing malnutrition in the respective countries should consider investments in yield stabilizing technologies to be critical for success. In Nigeria, the quantity demanded for cowpea is less responsive to price fluctuations compared to common bean in Uganda and chickpea in Ethiopia.

As compared to major cereal crops, CRP mandated legume crops in general didn’t enjoy the availability of genomic resources until recently. As a result, only limited reports have been available on trait mapping and molecular breeding in the legume crops. Under the framework of CRP-Grain Legumes, significant advances have been made in developing genomics tools, technologies and platforms for accelerating genomics research as well deploying molecular breeding. For instance, some of the genome sequences that have become available for legume crops including chickpea, pigeonpea, common bean, groundnut, soybean, and efforts are underway in lentil and fababean. Several hundred thousands to millions of molecular markers are available in majority of these legume crops. High-density genotyping platforms such as Affymetrix SNP arrays, Illumina arrays, genotyping-by-sequencing have been developed for cost-effective genotyping. By using these genotyping platforms and phenotyping a range of mapping populations and germplasm collections for traits of interest, marker-trait associations have been established for several traits in many legume crops. In some cases, molecular markers have been used to enhance breeding and efficiency of breeding programs by deploying marker-assisted backcrossing, marker assisted selection, marker-assisted recurrent selection and genomic selection. Breeding Management System of Integrated Breeding Platforms has also been used in some legume crops and capacity of several CRP partnering institutions in the use of BMS has also been strengthened. Furthermore, high-density genomic database is also being developed in chickpea as a part of Global & Open Breeding Informatics Initiative. Very recently, low-cost and high-throughput genotyping hub has been established in collaboration with Intertek Group Plc (Sweden) for initiating early generation screening (forward breeding). This hub is expected to provide genotyping for 10 SNP markers (including DNA extraction costs) @ US$ 1.50 per sample. In summary, grain legumes, are now ready to use both low- as well as high-density genotyping as well as other informatics platforms for understanding basic biological questions and also to deploy molecular breeding approaches for developing better lines to cater the demand of farmers as well as markets.
The genomics revolution has given hope that breeding would become easier and more efficient. Relevant phenotyping is now a main bottleneck and new technologies provide opportunities for easier, faster, more sensitive and more informative phenotyping. However, the development of automated phenotyping has to be driven by scientific questions rather than by a technological push, especially for complex constraints, starting from the proper framing of a target phenotype. Previous studies on drought adaptation of dryland crops showed that water availability during the grain filling period was critical for increasing yield and this depended on traits affecting the plant water budget at earlier stages. To that end, an imaging platform (Leasy Scan) was developed to assess canopy traits affecting water use (leaf area, leaf area index, transpiration). Leasy Scan is based on a novel 3D scanning technique to capture leaf area development continuously, a scanner-to-plant concept to increase imaging throughput, and analytical scales to combine gravimetric transpiration measurements. Close agreement was found in different crops between scanned and observed leaf area data of individual plants ($R^2$ between 0.86 and 0.94) or of plants cultivated at densities reflecting the field conditions ($R^2$ between 0.80 and 0.96). On-going applications are presented: (i) the leaf area development pattern of fine mapping recombinants of pearl millet; (ii) the leaf area development pattern of pearl millet hybrids targeted to different agro-ecological zones; (iii) the transpiration response to high VPD in sorghum and pearl millet. This new platform has the potential to phenotype at a high rate and precision for traits controlling plant water use, of critical importance for drought adaptation, opening the opportunity to harness their genetics towards the breeding of improved varieties.
STRATEGIC GENDER RESEARCH POSTER ABSTRACTS
The importance of women's and men's contribution to the agricultural sector in developing countries is now globally acknowledged. That differences, in the level of attainment in agricultural productivity by women and men farmers, exist has been acknowledged in literature. Assessing 'gender gaps' and the factors that contribute to their existence among farming communities in smallholder agriculture would contribute to greater understanding of how programs can be designed to ensure they, gender gaps, are closed and equity is attained in the farming systems. Panel data on 'key' indicators on gender gaps in cereals and legume systems would be useful in program design and monitoring interventions that lead to high levels of equity and inclusion among beneficiaries.

We propose to design a Q-Squared methodology that will facilitate the assessment of gender gaps through use of quantitative methods to measure the statistical significance of the gender gaps, while, qualitative methods validate the significance through sex-disaggregated panel data. We unpack the legume/cereals value chain and identify a minimum set of indicators at each node. This methodology will be tested among Barley farmers in Ethiopia and Groundnut farmers in Malawi.

We demonstrate that this methodology is appropriate because it will ensure data collection of quantitative and qualitative sex-disaggregated data that enhances the understanding of complex and dynamic role that gender gaps play in Barley and Groundnuts production. The methodology will also facilitate geo-referencing of sex-disaggregated to be considered in GIS and spatial models.

Aspirations of the youth: Implications for legumes and cereals value chains in the drylands

The challenge of engaging the youth in the legumes and cereals value chains in the drylands remains under represented because very little quantitative and qualitative research has been carried out on aspirations of the youth these systems. By utilizing the GENNOVATE methodology, with a specific aim of exploring with the youth about the community's: social norms and aspirations surrounding education, access to economic opportunities and household bargaining, qualitative data from 34 focus group discussions was collected between the year 2014 and 2016 in 6 countries (India-6, Mali -10, Bukina Faso -2, Niger- 6, Ethiopia-4 and Tanzania -6) by social scientists affiliated to the CRPs’ GL and DC. 17 focus groups were with young men with aged 16-24 years while 17 focus groups were with young women of a similar age grouping. Preliminary findings show that youths tend to have power & freedom to make some of their major life decisions on their own but with influence from their parents. Majority of the youth aspire to exploit non-agricultural livelihood opportunities as a pathway out of poverty while still accommodating the social norms and values of their communities. Education that should lead to formal employment and entrepreneurship was viewed as a pathway towards better livelihoods. These choices are strongly validated by the parents of the young people. Administering social norms’ controls seems more directed to the young women compared to the leverage accorded to the young men. Only few youths expressed a wish to engage in agribusiness by utilizing modern farming methods but in the horticultural production and livestock farming sectors. However, access to land and control over agricultural produce and income remains an impediment for them as it's guided by the social norms. Traditional cereals and legumes were not commodities of choice mentioned by the youth in these interviews. Attracting the youth into cereals and legumes value chains as an option for them to establish livelihood pathways requires innovative development of nodes of the value chains beyond production.
Exploration of cultural norms and practices influencing the Ethiopian women's participation and benefits in capacity building along chickpea value chains: The case study of Ada and Ensaro districts

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Women in Africa continue to adopt high yielding varieties at low rates and therefore research on women’s adoption of agricultural technology remains critical. However, reaching women farmers and enhancing their capacities to improve agricultural production is one of the key challenges of rural development. The challenge of accessing women farmers during ‘participatory varietal selection training on chickpea breeding activities in Ethiopia is of concern [Ojiewo, pers.comm. 2015]. Understanding the contextual factors that prevent women farmers from attending training meetings even when the project policy is ‘for all men to attend with their wives’ was the subject of this study.

Using vignettes, qualitative data was collected in November 2015. Sex-disaggregated focus group discussions, with representative group of fifty-eight chickpea farmers, were carried out in two districts, Ada and Ensaro, located in the Shewa region of Ethiopia. Discussions were facilitated to elicit the communities views on gender norms defining a good wife, the impact of the sex of the facilitator of the PVS trainings (representing the extension agents), the timing and organization of the PVS sessions; as well as family and community perceptions towards women’s attendance to trainings. The data was organized using Nvivo and analyzed based on the emerging themes.

Women’s radius of movement short and strictly enforced by their husbands, whereby women account for their ‘time out of home’. The culture has engrained the enforcement of this rule into the definition of a ‘good wife/good woman’. Women are expected to operate in ‘private space’ and hardly in the ‘public space’ unless accompanied by male relatives. Sexual identity of the trainer, male officers in particular, remains a key deterrent of women’s participation. The community proposes that having female extension workers would make it possible for the women farmers to spend time in training sessions.

How do agricultural innovations influence socio-economic hierarchies in rural agricultural communities? Findings from rural Rajasthan

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The main argument is that most cultural gender norms have a negative influence in the uptake of agricultural innovations. The findings are derived from research work conducted in Tanzania using the GENNOVATE methodology. The findings show that there are still traditional norms, particularly those based on superstition, that impede adoption of innovations; traditional norms around household decision-making in agricultural practices perpetuate gender discrepancies; more still, there is great disapproval if a person wanted to break away from the community’s gender expectations. A conclusion is made that a combination of superstition, gender biased decision-making, and the disapproval to break away from a community's expectations lead to endogenic processes of perpetuation of traditional customary behaviors that act as stumbling blocks to agricultural innovations. It is for this matter that if agricultural innovations have to be meaningful to the people, deliberate exogenic efforts that can have endogenic impact on gender norms are needed to alter patriarchy-based thinking in the formation of expectations.
Impacts of social norms on women's innovation pathways in cereals and legumes systems in Africa

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Although there are many women that are documented not to take advantage of innovations in the drylands of Africa and Asia, there are a number of individual women who have 'succeeded' in being innovative with cereals and legumes crops in the same regions. They would be considered 'outliers' in society. We wanted to find out, what makes them succeed, in environments where not many others do. Using the GENNOVATE methodology, 17 individual interviews were conducted with successful female innovators in 6 countries [India, Tanzania, Ethiopia, Burkina Faso, Mali, Niger]. We aimed to have in-depth analysis of the trajectories of their individual experiences, the role social norms had played propelling or inhibiting their individual capacities for innovations.

Strong women's individual agency in decision making [marked by high scores on ladder of power and freedom] for economic participation was a theme that kept recurring as being an important foundation for women to innovate. Social norms that inhibited this individual agency worked directly in inhibiting the women's ability to innovate. Relaxing of the social norms, through choices by communities, or because a woman had grown older and became more experienced in negotiating the social norms or because the dominant male members had ceased to be the centers of decision making, coupled by opportunities to access innovations, resources and markets almost always led to a better situation for the women to innovate. Social norms are the 'bed' on which all else seems to be organized, and for women to succeed as innovators at scale, we conclude that there is a need to focus attention on how social norms flux would best support the system.

Is Gender voice 'unheard' in breeding processes? A review

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In theory, participatory research is a process of inquiry between scientists and communities that aims to resolve problems through an interactive process of discovery, empowerment, knowledge sharing, and action. Inherent in the theoretical PR approach is the inclusion of marginalized voices to ensure that everyone’s inputs and needs are met. In the 1970s and 1980s, PR was adapted to agricultural research and development (R&D) and until now, participatory processes are often considered a panacea for acquiring context-specific and gender-sensitive stakeholder input; information that is essential to improve technology development and uptake. However, critiques of PR in R&D note that these processes are often applied in a topical manner that fails to give voice to marginalized stakeholders and neglects the PR objectives of empowerment and knowledge sharing. Likewise, gender researchers lament the failure of programs to thoughtfully engage in gender-sensitive design and analysis of R&D projects. Participatory plant breeding (PPB) is a type of PR used to create collaborative relationships between stakeholders and plant breeders in order to develop varieties that meet the expectations, environmental, and social needs of the end-users. Thus, PPB approaches should actively consider gender voice. PPB approaches have been adopted extensively in the CGIAR system and beyond, yet the extent to which PPB includes gender voice and gender analysis in the process is less documented. Building on a publication written in 1997, “Participatory Plant Breeding and Gender Analysis,” we assessed how inclusion of gender voice has progressed in practice, over the past two decades. We used grounded theory to evaluate the literature and determine if and how the functional, strategic, and conceptual barriers to gender analysis in PPB have changed. Results indicate that progress has been made, but new and emergent barriers still limit the inclusion of gender voice in PPB.
Little things matter. The negative role of cultural gender norms in up-taking agricultural innovations in Tanzania

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The main argument is that most cultural gender norms have a negative influence in the uptake of agricultural innovations. The findings are derived from research work conducted in Tanzania using the GENNOVATE methodology. The findings show that there are still traditional norms, particularly those based on superstition, that impede adoption of innovations; traditional norms around household decision-making in agricultural practices perpetuate gender discrepancies; more still, there is great disapproval if a person wanted to break away from the community's gender expectations. A conclusion is made that a combination of superstition, gender biased decision-making, and the disapproval to break away from a community's expectations lead to endogenic processes of perpetuation of traditional customary behaviors that act as stumbling blocks to agricultural innovations. It is for this matter that if agricultural innovations have to be meaningful to the people, deliberate exogenic efforts that can have endogenic impact on gender norms are needed to alter patriarchy-based thinking in the formation of expectations.
This paper explores if there is a link between gender attributes of the farmers, different activities along the cowpea value chain and food security and poverty using recent cross-sectional data set of 120 farm households in Eastern Zambia. We used probit and endogenous switching probit regression models to account for both observed and unobserved heterogeneity. Results suggest that female-headed households are less food secure: they have fewer productive resources and assets. They also have limited access to extension, education, credit village markets and improved agricultural technologies. This has a negative impact on women participation in activities of the value chain and their welfare. The results imply that there is a need for inclusive gender approach that would deal with gender-based constraints along the cowpea value chain.
Farming systems in WCA are mainly based on crop and livestock. Poor animal health due to seasonal volatility of feed and water supplies, and loss of traditional pastureland has been challenges for livestock production. Sorghum is principally grown for its grain that is used for human consumption. Among the cereals, sorghum fodder is the most used to feed animals especially during the dry season. During that period, farm animals remain underweight and underproductive due to lack of feed. Sorghum varieties currently used to feed animals are mainly landraces, characterized by poor stover quality due to leaf senescence before grain maturity and high lignin content. The former reduces nutrient value of the stover while the latter decreases digestibility. While crop residues (straw and stover) have become a main feed for farm animals, addressing the most basic livestock feeding challenges will require a strategic use of crop residue resources. ICRISAT and its partners have now developed sorghum varieties combining grain yield and quality with quality fodder in order to contribute to increase farm income, nutrition and resilience. These varieties were selected for high grain yield and high stover quality (stay green, low lignin, juicy stem) while having tolerance to foliar diseases. The average grain yield is 2t/ha with a biomass of 15t/ha and total sugar content of 10-16% Brix. A set of 14 dual-purpose varieties and 2 checks were tested on-farm in 2015, by 24 farmers in 12 villages in Mali, for agronomic performance and acceptability in terms of adaptation, food quality and fodder quality. The varieties performed well in farmer’s conditions and had similar grain quality as that of the local checks and better stover quality.

Dual-purpose sorghum: an option to increase total crop value for smallholder farmers in West and Central Africa

Baloua Nebie; Aboubacar Toure; Abdoulaye Gaoussou Diallo; Ibrahima Sissoko; Samba Traore and Ramadjita Tabo

During the last decade, several high yielding and adapted varieties and hybrids of sorghum, pearl millet, and legumes were developed and released in WCA. Despite their good performance, resource-poor farmers in WCA have limited access to these new, locally adapted improved crop varieties that could improve their livelihoods. Therefore, many farmers still grow old varieties and consequently fail to benefit from the most modern products of crop improvement. An enterprise approach was initiated locally for large-scale adoption of new varieties and hybrids through smallholder farmers. Thus, farmers’ cooperatives were trained in quality seed production techniques and distribution in their respective zones. Communication methods and tools were developed to reach acritical number of farmers thereby increasing the rate of adoption of new varieties.

Strategy for seed systems management in smallholder farming in West Africa

Baloua Nebie; Aboubacar Toure; Abdoulaye Gaoussou Diallo; Krista B. Isaac; Abocar Toure; Mamourou Sidibe; Bocar Diallo and Ramadjita Tabo

A total of 38 seed cooperatives were trained from 2014 to 2016 in seed production techniques. Over 200 tons of quality seed of hybrids and varieties of sorghum, pearl millet and cowpea were produced and sold locally in Mali. Mini-packages with key information on the crop variety, picture of the seed producer and the crop in the field were important tools for seed marketing in the target zones. Rural radios were used along with demonstration plot visits to create awareness and excitement about the benefits of newly developed varieties and hybrids. Rural radios staff was trained to better communicate on new variety and hybrid characteristics to increase seed dissemination. This communication impacted over 40,000 smallholder farmers who are using the new crop technologies presently.
A baseline survey was conducted in Burkina Faso, Mali, Niger and Nigeria, during Phase I of the bilateral project, Harnessing Opportunities for Productivity Enhancement (HOPE), to determine adoption status of improved varieties of sorghum and pearl millet prior to project interventions. Results show that during the period of 2009 to 2014, the rates of adoption of improved varieties varied between 23% to 32% for sorghum and 13% to 35% for pearl millet. Household producers in Nigeria have the highest rates of adoption. Among other things, the main reasons of the non-adoption of improved varieties were still seed unavailability, lack of resistance to insects, and late maturity of varieties. Other constraints include low yield of varieties, demand for fertilizers, lack of adaptation to food patterns, low resistance to drought, and high cost of seeds. The survey covered 50 villages (32 project participating villages and 18 non participant villages) in Burkina Faso with a total of 500 households producing sorghum and pearl millet. In Niger, the survey covered 68 villages (50 project villages and 18 non participant villages) with a total of 439 households producing pearl millet. In Mali, the survey covered 78 villages (60 project villages and 18 control villages) and a total of 728 households producing sorghum and pearl millet. In Nigeria, the survey covered 123 villages (78 project villages and 45 non-participants).

The objective of this work is to improve production systems based on sorghum and pearl millet in the Mopti and Sikasso regions of Mali by strengthened research-and-development partnerships for large-scale utilization of proven technologies with potential to improve nutrition, to benefit women and children, and to enhance the sustainability of smallholder agriculture. At the farm level, the focus has been to improve production by increasing access to selected new technologies and enhancing awareness and ‘know-how’ for the use of existing technologies to enhance sorghum and millet production. In the Mopti and Sikasso regions of Mali, the major technologies targeted for dissemination include: a) the use of seed treatment such as Apron Star 42WS; b) seed of improved varieties of pearl millet, sorghum (both hybrid and open pollinated varieties), groundnut and cowpea adapted to the Sahelian environmental conditions; c) integrated Striga and soil-fertility management practices; and d) biological control of the millet head-miner. Seed treatment of pearl millet with Apron Star significantly reduced the incidence and severity of diseases. Grain yield was 20% higher when seed was treated. Toroniou is the most preferred pearl millet variety due to its earliness, yield and large grains, compared to G16 which is a late variety. In sorghum, all producers from Koutiala appreciated the Pablo and Fadda varieties for their high yields, tolerance to drought and ease of cooking, relative to the hard-milling Sewa variety. In cowpea, the Korobalen variety is the most popular because of its high yield and adaptation to the Mopti region, compared to Wilibaly that had low yield. Among the fertilizer application rates proposed, a dosage of 2g (of what?) after first weeding is the most preferred by farmers, as it does not require additional manpower for application. Further, the practice increases yield by 39% relative to farmers’ current practice.
Sorghum and pearl millet are the top two cereal crops produced by farmers in the dryland areas of West and Central Africa (WCA), particularly in Burkina Faso, Mali, Niger and northern Nigeria. The analysis of the supply marketing of the two cereal crops show that only 25% to 30% of quantity produced by farmers in the dryland areas of WCA are sold into spot markets, indicating that millet and sorghum are sold to buyers once farmers have determined the quantity necessary to cover their own consumption. The marketing system is vertically integrated and consists of five categories of actors: farmers, collectors, wholesalers, retailers and consumers. In these four countries, result shows that marketable surpluses of pearl millet and sorghum are the lowest compared to other crops like rice, maize and groundnut. This implies that in the dryland areas of WCA, millet and sorghum are grown by farmers for their own household food consumption. In Mali, the analysis of the economic performance shows that sorghum sellers obtain a relatively higher profit and that they generate interesting value addition in the sorghum supply management. Wholesalers add more value to sorghum grain than collectors. The results of sorghum and millet marketing implies that in order to increase the productivity value of these crops, potential new market is important to increase the value addition and the gain to producer.

Supply management of dryland cereals in West and Central Africa (WCA)

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Pearl millet for West Africa

DC 06
Flagships: Seed systems & input services

Delivery of farmer-preferred, participatory-selected varieties of pearl millet in Niger

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Participatory plant breeding employs the active participation of farmers in breeding programs, and will usually involve farmers selecting genotypes from genetically variable, segregating material. An attempt was made to select improved open pollinated varieties of pearl millet in Niger with the help of farmers, seed producers, processors and NARS partners. We have selected, three open pollinated varieties viz., PPBV Falwel, PPBV Serkin Hausa and PPBV Tera. These PPBV varieties, along with other ICRISAT-bred millet varieties, are well known for high yield, quality and resistance to downy mildew. But the potential of these OPVs is not realized by the farming community. It may be due to lack of advertising, lack of seed companies, difficulty in pronunciation of names of varieties by farmers and inadequate representation of ICRISAT varieties in the national catalogues. The objective of this effort was to conduct a demonstration trial and to showcase improved pearl millet OPVs in farmers' fields. We have conducted 500 large-scale demonstrations across Niger with different stakeholders. The results show that farmers are utilizing ICRISAT millet varieties after seeing actual demonstrations in their villages. A major problem that remains is the accessibility of seeds of improved OPVs. There are very few points for seed sales in the villages and markets. To overcome this constraint, we support farm unions in seed production of these farmer preferred varieties and in establishing seed distribution points in each village. These five varieties were popularized among 5000 farmers by distributing brochures and 2000 leaflets during the rainy season of 2016.
On-farm augmentative releases of parasitoid wasps for biological control of the millet head miner in WCA

Ba N.M.; Baoual; Amadou L.; Karimoune L.; Muniappan R.; Norton G

The head miner (MHM) *Heliocneilus albipunctella* (de Joannis) (Lepidoptera: Noctuidae) is a chronic insect pest of pearl millet in Niger. Damage is due to larvae that feed on the panicle and caused up to 85% yield loss. Augmentative biological control with releases of the parasitoid braconid wasp *Habrobracon hebetor* Say is the most promising strategy for controlling MHM. To make the biological control program sustainable, parasitoids need to be available for use every year. For this, an available option the establishment of a cottage industry to scale up parasitoids production. Parasitoid production needs to be optimized to make the cottage industry viable and to meet farmers' needs. Since 2013, different experiments have been carried out to fine-tune and standardize the rearing and release techniques for *H. hebetor* for industrial use. Our findings indicated that parasitoid numbers can be increased by 50% when adding a small proportion of cowpea flour to the millet-based diet of *C. cephalonica* larvae. Releases of the parasitoids significantly increased the parasitism of MHM as compared to control villages, and significantly higher parasitism was recorded in villages where 1600 parasitoid were released. Discussions with farmers have established the "public good" nature of distributing the parasitoids. It appears that the solution is to establish community-based businesses that sell to farmers' groups for the whole community in multiple villages.

Preliminary yield testing of single and top cross hybrids of pearl millet in Niger and Senegal

Gangashetty Prakash; Stefania Grando; CT Hash; Ahmed Issaka; Sy Ousmane and Ramadjita Tabo

Today, approximately 40% of the world's pearl millet is grown in Africa; about 85% of this is in West Africa. Africa's major pearl-millet producing countries include Niger (7Mha), Nigeria (5 Mha), Chad (3.0 Mha), Burkina Faso (1.5 Mha), Mali (1.5 Mha), & Senegal (1.0 Mha). The average yield of pearl millet in this region ranges from 0.7 to 1.5 t/ha and predominant cultivation is by open pollinated varieties. The overall goal of this research activity is to enhance pearl millet productivity in West and Central Africa (WCA) through breeding of high yielding, downy mildew resistant, nutritious hybrids there by contributing to food security, income generation and improved nutrition. The activity started with production of 350 test crosses and were evaluated for fertility and sterility maintenance in rainy season 2014. We found 14 fertile and pheno typically distinct hybrids and reconfirmed their fertility in off season of 2015. The fertile experimental hybrids were produced by hand crossing and pollination in off season of 2014-15. An experiment was set up with total of 26 hybrids (14-ICRISAT-Niger (SCH), 2-InRAN-Niger (population cross hybrids) and 10-ISRA- Senegal (TCH) along with two checks in a RBD with 3 replications in 4 locations (2 locations each in Niger and Senegal).The results showed that, days to 50 percent flowering in hybrids range from 50 to 59 days compared to local improved varietal checks (58 to 64 days).Average yield across four locations range from 0.5 t/ha (Local land race check) to 2.7 t/ha (ICMH IS 14012). The phenotypically distinct hybrids yield was about 1.77 t/ha for ICMH IS 14003, 1.6 t/ha for ICMH IS 14006 and 1.47 t/ha for ICMH IS 14009. Further, these hybrids were in second year of testing in 6 locations in Niger and Senegal for agronomic, yield and associated traits in Niger and Senegal.
Evaluation of sorghum hybrids in ESA

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Sorghum hybrids research at ICRISAT-ESA is still in its infancy, but it is picking up steadily. Already two hybrids were released in Tanzania in 2013 through a partnership with NACO Seed Company. In Kenya, hybrid IESH 211001 (SDSA1 x ICSR 43) was released in July 2016 through a partnership with Egerton University and three hybrids are under DUS testing in collaboration with Kenya Seed Company. All these hybrids have 30-40% yield advantage over farmer/improved OPVs. In 2015/16, 25 hybrids were evaluated at Kiboko, Kenya, Mpambaa and Miwaleni, Tanzania and Matopos, Zimbabwe. Sixteen hybrids were evaluated at Chitedze and Ngabu in Malawi. The trials were sown in four-row plots of 4m length in three replications using square lattice design. Significant differences (P=0.05) were observed among the hybrids within and across test sites. The highest mean grain yields were recorded at Matopos (4.514 tha⁻¹) and lowest at Miwaleni (2.287 tha⁻¹). Mean days to flowering was lowest at Kiboko (70) and highest at Matopos (78) where also the highest mean plant height (191.4cm) was recorded. In Malawi, the highest mean grain yield (7.196 tha⁻¹) was recorded at Chitedze with highest yielding hybrid (IESH 22002) attaining a remarkable 9.182 tha⁻¹. The most stable hybrids across Kenya, Tanzania and Zimbabwe locations were ESH 28001, IESH 22012 and ICSA 276 x ICSR 162. Hybrids with specific adaptation were IESH 29010, ICSA 15 x ICSR 93001 (Kampi ya Mawe), ICSA 11003 X IESV 92136 DL, ICSA 88001 X ICSR 160 (Matopos) and IESV 25008 (Mpambaa). In Malawi IESH 22010, IESH 90003, IESH 22002, IESH 22005, IESH 22011 and IESH 22012 were selected for on-farm testing. These hybrids have the potential to increase sorghum productivity to meet the increasing grain demand especially as new uses of sorghum emerge.

Improving Sorghum productivity, utilization and marketing in Kenya and Tanzania - a value chain approach

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The Sorghum for Multiple Uses project aims to support the development, dissemination and uptake of new sorghum cultivars and improve markets linkages in the semi-arid agro-ecologies of Eastern Kenya and Northern and Central Tanzania for household food security and poverty reduction. On-station evaluation of elite sorghum cultivars (16 short and 25 medium duration varieties and 25 hybrids) was done at Kiboko, Kenya and Mpambaa and Miwaleni in Tanzania in 2015/16. On-farm trials of 8 varieties and 8 hybrids were done at 10 and 5 sites in each target district in Kenya and Tanzania respectively. In on-station trials significant differences (P=0.05) were observed between the cultivars within and across locations. OPVs IESV 214002 DL, IESV 214007 DL, IESV 214013DL and IESV 92043DL (grain yield 2.400 to 2.550 tha⁻¹) and hybrids IESH 25008, IESH 25006 and IESH 29010 (grain yield 2.993 to 4.711 t ha⁻¹) were selected for on-farm testing. From the on-farm trials, OPV IESV 23010DL and hybrids IESH 22023 and IESH 25008 were selected for NPT. In Kenya Sorghum hybrid SDSA 1 x ICSR 43 and varieties IESV 91018LT and IESV 93042SH which were under DUS in 2015 were released in July 2016. Over 300t of seed was produced through selected farmer seed growers who were linked to local seed retailers. Post-harvest handling to reduce drudgery and improve grain quality was promoted by enabling farmers to access threshers. Farmers were linked to markets through the aggregator model. To promote sorghum consumption at household level, commercialization and product diversification, value addition trainings were conducted in both countries. Use of sorghum grain as fish feed was initiated in Kenya. The partnership along the value chain has resulted in over 8000 farmers marketing grain to malting industry per year, grain price improvement of about 40% and increased utilization of sorghum at household level.
Prevalence of sorghum diseases in Tanzania and Uganda

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A survey was conducted in 2014 to determine the prevalence of sorghum diseases across different agro-ecologies of major sorghum production areas in Tanzania and Uganda. In Tanzania, 40 sorghum fields were sampled in Dodoma and Singida Provinces representing the central drier areas, and in Simiyu, Shinyanga, Mwanza, and Mara Provinces representing the humid Lake-zone region. In Uganda, 143 fields were sampled across 4 agro-ecologies of Teso, Western, Northern, and West Nile. Farmers were purpose fully selected, at least 30 plants per field along two diagonal transects were visually assessed for disease, and samples were taken to the laboratory to confirm the diseases observed. In Tanzania, 16 diseases were identified and the most prevalent (% of fields) were leaf blight caused by Exserohilium turcicum, at 76%, anthracnose caused by Colletotrichum sublineolum, at 56%, and rust caused by Puccinia purpurea, at 43%. In Uganda, 15 diseases were identified and the most prevalent were leaf blight at 55%, anthracnose at 43% and ladder leaf spot caused by Cercospora fuscumaculans, at 20%. Disease prevalence differed significantly between Tanzania and Uganda. More prevalent in Tanzania were leaf blight (P = 0.0007), covered smut caused by Sporisorium spp. (P = 0.0002), rust (P < 0.0001), bacterial leaf blight caused by various bacteria (P = 0.0007), head mold caused by different fungi (P < 0.0001) and long smut caused by Sporisorium ehrenbergii (P < 0.0001). In contrast, diseases more prevalent in Uganda than in Tanzania were anthracnose (P = 0.032), ladder leaf spot caused by Cercospora fuscumaculans (P = 0.0018), loose smut caused by Sporisorium cruentum (P = 0.015), gray leaf spot caused by Cercospora sorgi (P = 0.0098), oval leaf spot caused by Ramulipora sorghicola (P = 0.001), and downy mildew caused by Peronosclerospora sorgi (P = 0.001). Generally, significant differences were observed in the incidence of major diseases between local or improved varieties. This is the first comprehensive sorghum disease survey report in over 15 years in both countries.

Yield stability, heterosis and performance of sorghum hybrids in the semi-arid areas of Kenya

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Sorghum is the 2nd most important cereal crop after maize in all agro-ecologies of Africa. It is an important food, feed, and industrial crop. Production area in Kenya has risen from 122,368 to 210, 000 ha between 2005 and 2013, whereas yields have declined from 1.223 to 0.66 t/ha over the same period. This decline has been attributed to the use of low yielding and drought susceptible varieties. This study aimed to estimate the heterosis, yield performance, and stability of sorghum hybrids and their parents in the ASALs of Kenya. Thirty-fourCGMSfemale lines and twelve restorer lines were used to generate 34 hybrids in 2014. The hybrids, their parents and a commercial variety, Seredo as check were evaluated at Kiboko and Kampi ya Mawe in 2014LR and 2014-15SR for yield stability and heterosis using a lattice design. Hybrids yielded more than their parents with 2.691 t/ha and 2.264 t/ha respectively. Seventeen hybrids yielded better than Seredo. The hybrids with the highest better-parent heterosis (BPH %) for yield were ATx623 x Macia (57%), ICSA29005 x ICSR24010 and ICSR89058 (49%). Hybrids, ATx623 x Macia (48%), ICSA11004 x ICSR24008(47%), ICSA11033 x ICSR160 and ICSA29005 x ICSR24010(41%) had the highest standard heterosis (SH%). Over dominance and dominance effects were responsible for heterosis in the parental lines used.
From GGE biplots, hybrids ATx623 x Macia (3.835tha⁻¹), ICSA29005 x ICSR24010 (3.826tha⁻¹), ICSA29011 x ICSR89058 (3.673tha⁻¹) and ICSA11040 x IESV91104 DL(3.656tha⁻¹) were high yielding and stable. The best parents (high yielding and stable) were ICSR24008 (3.175tha⁻¹), ICSA29004(3.091tha⁻¹) and ICSR24010(3.045tha⁻¹). The best female parental lines for improving grain yields were ATx623, ICSA29005, ICSR24008, ICSR24010 and Macia for the restorers. These results will be useful in hybrids development to improve sorghum productivity in the semi-arid areas of Kenya.

Ready-to-use therapeutic foods (RTUF) from full-fat milk powders, high quality vegetable oil, peanut paste, sugar and micro-nutrients have been used to treat severe acute malnutrition. The objective of this study was to produce ready-to-use food incorporating finger/pearl millet and sorghum blended with pigeon peas and soy with locally available, ground nuts, palm oil and sugar, and including minerals and vitamins. Germination, sun-drying, roasting, de-hulling, mixing and pasting were methods used to prepare the samples. Samples were subjected to standard methods of nutrient analysis, and nutrients were compared to existing standards, (Vijay et al, 2014). Results showed that moisture was comparable to standard, protein was higher at 13.8% - 20.1% relative to the standard 10% - 20%. Energy Kcal% 445 - 466.2 was within most set limits (250 – 500) of existing RTUFs. The study products indicate potential of using finger millet RTUFs by communities to treat server acute malnutrition. It is recommended that further studies be carried out to determine the efficacy of the products.

Finger millet production in Eastern Africa remains low due to a variety of factors including low soil P. Improvements in managing soil nutrient quantity and availability of less renewable nutrients like P is important. The yields in Kenya are typical of low input systems ranging below 1.0 t ha⁻¹ against a potential of 5.0 t ha⁻¹ in a season. In an attempt to overcome this constraint, on-station experiments were conducted at the Alupe, Kiboko and Kakamega research stations during the long and short rains of 2015 to investigate the influence of phosphate rates on growth, N uptake, Yield and quality of finger millet varieties. Increased N uptake was observed with increasing P rates where partitioning of N was highest in the grains. Phosphorus enhanced the growth of the crop and significantly reduced the days to 50% flowering and maturity. Yields responded positively to P application with a 28% increase observed on the 25 kg ha⁻¹ P₂O₅ rate over the control Varietal differences were observed on N uptake, partitioning, growth, yield and grain nutrients where P224 yielded the highest in Kakamega and Busia while U15 was the best in Kiboko. The interaction between U15 and 25 kg ha⁻¹ P₂O₅ exhibited highest protein content with 15.31 mg/100 g. Plant biomass, plant height, effective tillers, leaf blade length, seedling vigor, grains per spikelet, days to 50% flowering, days to maturity and threshability had high direct positive effects on the grain yield. The findings from this study indicate that application of 25 kg ha⁻¹ P₂O₅ significantly led to higher yields in finger millet improved varieties. Further studies should evaluate long-term phosphate influence on soil P availability and pH stability.
Evaluation of nutrient-dense finger millet accessions for nutrient stability across agro-ecologies in East Africa

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Finger millet is the most important small millet in the tropics with superior nutritional qualities, excellent storability, and provides food security during extreme droughts. As a promising source of micronutrients and protein besides energy, finger millet can make a contribution to alleviating micronutrient and protein malnutrition, also called hidden hunger, affecting more than half of the world’s population, especially women and preschool children in most countries of Africa and south-east Asia. The most cost effective approach for mitigating micronutrient and protein malnutrition is to introduce millet varieties selected and/or bred for increased Fe, Zn and protein content through plant breeding. However, grain nutrient content has been shown to be affected by environmental conditions. Twenty-nine accessions selected for high Ca, Fe, Zn and N and a check (U15) were evaluated for nutrient stability across three locations in Kenya and Tanzania. High and variable nutrient content were determined. The location was highly significant for all the nutrients with higher values being determined across locations. Alupe had averages of (Ca=445.9, Fe=4.5 and Zn 2.4 mg/100gm) compared to Miwaleni (Ca=364, Fe=4.8 and Zn=2.3 mg/100mg) and the least Kiboko (Ca=388.4, 3.1 and Zn 1.4 mg/100gm). Accessions with the highest concentration for Ca were IE 2014 (470.3), KNE 628 (454.6), IE 5485 (439.1); for Iron IE 6025 (7.1), P224 (4.8), IE 6025 (5.6) and for Zinc IE 2034 (2.5), IE 3704 (2.4), IE6029 (2.4) and Nitrogen IE2034 (1883.8), IE6029 (1859.3) and KNE 741 (1816.2). Positive correlations were recorded among the different micronutrients suggest that it is possible to improve Ca, Fe and Zn concentrations in finger millet grain simultaneously. Although there were differences among locations, accessions performed relatively the same across. Accessions KNE 628, KNE 741, P224, KNE 1149 and U15 are already being promoted for high Ca, Fe, Zn and yield.

Harnessing benefits of finger millet in combating micronutrient malnutrition through genetics and genomic approaches

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Micronutrient malnutrition, characterised by vitamins and mineral deficiency, affects almost 2 billion people across all age-groups and genders and is endemic to both developing and developed countries. Besides causing specific deficiencies, it also aggravates other infectious and chronic diseases, resulting in almost 80% deaths in developing regions. Identifying health benefitting characteristics and micro-nutritional richness in traditional crops, and breeding them into staple crops consumed on a daily basis, offers a low cost sustainable food-based solution to the problem. A traditional crop grown in most marginal areas of Africa and Asia, finger millet, is a rich source of health benefitting micronutrients, phytochemicals, vitamins and several essential amino acids. To better understand the genetic control of these health benefitting traits and to breed them effectively into other staple crops, we are making use of genetics and genomics approaches. We have assembled a set of 190 genotypes incorporating a minicore collection of finger millet together with a number of elite breeding lines to capture and characterise entire genetic variation associated with such traits in finger millet gene bank. These genotypes have been extensively characterised for micronutrients (such as iron, zinc, calcium, magnesium, sodium, and potassium), protein and anti-nutrients (phytate and oxalate). Further, large-scale genotype-by-sequencing performed on these genotypes has generated 156,157 SNPs across these germplasms and breeding lines. Genome-wide association analysis of these data has identified a number of genomic regions associated with both the health benefitting traits as well as with other factors that affect their bio availability. These findings are also paving ways of assessing how such genetic variations are distributed in other staple crops. Progress made in the project so far and of our future directions will be discussed.
Barley improvement under CGIAR Research Program on Dryland Cereals to addressing the global challenges

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The International Center for Agricultural Research in Dry Areas (ICARDA) has a global mandate for barley improvement, specifically for the dry areas across the globe and has reorganized the spring and winter barley research to address the requirements of North and East Africa, Central, West and South Asia regions. The program targets germplasm improvement for optimal and stressed environments to address the feed, forage, food and malting uses in spring barley from Rabat, Morocco and winter barley program from Ankara, Turkey. The partnership with the focal country in each region is the new strategy, which utilizes the complementing capabilities with national programs. Each year, >15000 advanced lines are evaluated for various agronomic, biotic and abiotic stress tolerances, and quality parameters at ICARDA. The focal countries help in the evaluation of the elite germplasm for target region(s). Under the improved germplasm sharing program, annually more than 390 sets of international trials & nurseries are distributed to more than 55 collaborators in 38 countries. The process has helped the partner countries to release more than 255 barley varieties across the globe during 1977-2016, as direct introduction out of that 23 varieties has been released in last five years only. Improvement for malting barley and nutritional qualities (Zn, Fe, and β-Glucan) are new initiatives. Since the demand for industrial uses of barley is on a sharp rise in East Africa and south Asia, contract farming and seed production through private-public partnership is big potential to raise the benefits to the smallholder farmers. Another aspect of such partnership includes the application of advanced molecular research and technologies including the doubled haploid are also supported under CRP Dryland Cereals. Post-harvest and value addition aspects still need the collaboration with advanced research institutes and industry to make it the real research for development.
ICARDA has a global mandate for barley to preserve its genetic diversity, develop and distribute improved and better-adapted germplasm for sustainable production in dry areas. Amongst various biotic yield limiting factors, the economic losses inflicted by the barley rusts and foliar blights are substantial. Yield losses caused by net blotch (*Pyrenophora teres*) accounts for 29% in Morocco and similar is the situation in several other countries. The major activities of barley crop protection include pest and disease surveillance, understanding the pathogen diversity, evaluation of germplasm for host resistance, and identification of diverse sources of resistance. Based on the disease surveys net blotch, spot blotch, scald, powdery mildew, leaf rust, yellow rust, barley yellow dwarf virus (BYDV), Russian wheat aphid and barley stem gall midge were identified as biotic stresses of economic importance in target countries in Asia and Africa. Regarding host plant resistance, more than 15,000 advance breeding lines of barley were screened annually under the dryland cereals program. More than 200 barley genotypes were selected with stable resistance to various biotic stress factors for their utilization in barley improvement. Likewise, the study of pathogen population dynamics was monitored through trap nurseries in order to decipher the importance of resistance genes to mitigate the new virulent races of the pathogens. In addition, specific barley subsets generated with FIGS (Focused Identification of Germplasm Strategy) approach have been evaluated, and new sources of resistance to yellow rust, powdery mildew, net blotch, spot blotch and BYDV have been identified. Furthermore, work on molecular markers application for determining the pathogen variability as well as host resistance have been initiated, and a few potential markers have been identified for spot and net blotch. This exercise will result in the identification of novel sources of resistance which will be deployed in barley cultivars to prevent the farmer’s yield losses associated with biotic stresses and stabilize their production.

In order to enhance genetic gains in the barley breeding program, MAS and doubled haploid technologies were integrated with an aim to improve biotic stress tolerance. To identify markers for resistance to net blotch and yellow rust, two association panels AM-16 and Hi-AM respectively were screened and genotyped with Illumina iSelect 9k Chip. GWAS had identified 24 QTL for net blotch in AM-16 for field screening, while a new candidate gene is observed for seedling screening in this panel at NDSU, Fargo by ICARDA staff. In Hi-AM panel, 33 QTL associated with resistance to yellow rust at seedling stage and 11 QTL associated with adult plant stage were identified. To increase level of tolerance against BYDV in barley, the two resistant loci Ryd2 and Ryd3 were combined by molecular markers assisted selection for the presence of the resistance encoding allele at respective loci (Ryd2, Ryd3, QTL on chromosome 2H) in F2 population derived by resistant (Ryd2) x resistant (Ryd3) crosses. These selected lines will be carried forward to subsequent generations to develop pure lines. Additional markers for other biotic stresses will also be deployed in the barley breeding program in due course of time. Over 1920 haploids were produced from microspores of four F hybrids. Over 1400 doubled haploids (DH) are expected produce by September, 2016, which are segregating for net blotch resistance, Zn and Fe uptakes. The DHs will be further used for QTL mapping and selection.
Resource management in barley to enhance yield and farmers income under dryland conditions

R. Verma; A. Jilal; A. S. Kharub and A. Khippal

Renowned as a short season, drought tolerant and low input crop, barley has been often neglected when it comes to its resource management causing huge yield gap between its potential and its actual undervalued performance in developing world. Enhancing yield and farmers' income under dryland conditions is a real challenge faced by the CGIAR Research Program on Dryland Cereals. The specific resource management aspects in crop system, production conditions and product specific cultivation, experiments were conducted in South Asia and Morocco for barley. In addition to the limited irrigation and fertilizer, experiments with organic fertilizers, direct drill (DD) under conservation agriculture and nitrogen use efficiency (NUE) (input management) applications have been conducted at farmer's fields and research stations in collaboration with NARS institutions. The production technology for malt barley cultivation to ensure the acceptable grain and malt quality with good yield in India have also been standardized. Similarly, experiments with dual purpose barley have been refined to ensure optimum forage and grain yield in dry areas. Relay cropping with cotton has indicated big potential in raising the crop yields and income by advancing the sowing and averting the delayed sowings. These experiments tend to increase the performance of barley varieties and improve the welfare of farmers. Weed control strategy for rain fed cultivation in entire CWANA region is one aspect we need to work more and bring it as a common practice for the resource poor farmers. Through barley farmers' field, on the farm and experimental stations experiments/ demonstrations, the resource management technologies for different components have been successfully applied to reduce the yield gap with reduced input cost for the poor farmers.
Determinition of variability in rancidity profile of select commercial Pearl millet varieties / hybrids

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Pearl millet (*Pennisetum glaucum*), one of the world's hardiest cereal crop can grow under harsh climatic conditions. It is grown in the drylands, mostly by smallholder farmers and forms part of the staple diet for millions of resource-poor people in the drylands. However, flour prepared from this climate-change-ready crop has a low shelf-life, attributed to the nature of the fat. Thus, pearl millet has to be ground fresh before use adding to the drudgery of the consumers, especially women. Commercialization of pearl millet flour, which is also in demand in the urban market due to its health benefitting properties, has been constrained due to this rancidity problem. Thus, a study was initiated to evaluate the suitability of popular Indian commercial varieties / hybrids for obtaining shelf-stable flour.

Two parameters indicating rancidity namely acid value (indicates enzymatic rancidity) and peroxide value (indicates oxidative rancidity) were monitored during the study. Flour from each variety was stored under three storage conditions – Refrigerated (4°C), room temperature (25°C) and accelerated (35°C, 70%RH) and their acid and peroxide values measured at regular intervals. The study clearly established the existence of diversity in the rancidity profile among the select varieties / hybrids of pearl millet studied. Pearl millet varieties / hybrids that are least susceptible to rancidity can be promoted for use in production of self-stable pearl millet flour in conjunction with appropriate processing and packaging technologies.
Accelerating pace of cultivar development using genomics and molecular breeding in pearl millet

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In the current phase of CRP, ICRISAT and NARS developed a synergistic response towards addressing challenges of food and nutritional security, climate change, environmental degradation, and poverty alleviation for the millions of marginal farmers through genomics and molecular breeding. In pearl millet, the partnership has resulted in significant benefits to the small holder farmers, and capacity building of the partners. HHB 67-Improved continues to benefit the farmers of North and North-Western India from the scourge of downy mildew (DM) pathogen, through support of breeder seed of the parental lines, and seed production. Anticipating the typical life span of HHB 67-Improved, ICRISAT in partnership with the All India Coordinated Pearl Millet Improvement Project (AICPMIP) has worked on the second cycle improvement of the hybrid. Some of the downy mildew (DM) resistance QTL introgression lines and test cross hybrids have shown promising results in terms of agronomic superiority over the best checks. Another very popular hybrid GHB 538 has been improved for downy mildew resistance through transfer of DM resistance QTLs to its pollen parent with promising results. On genomics, in association with NARS, a high-density consensus linkage map was developed by saturating linkage maps of four pearl millet RIL mapping populations using newly developed pearl millet EST-SSR and DArT markers. Four large effect QTLs for new virulent DM isolates from Gujarat, Rajasthan and Haryana were mapped. We also developed chromosome segment substitution line (CSSLs) for all the seven linkage groups in agronomically elite ICMB 841B-P3 genetic background. About 1,000 pearl millet genomes were sequenced including world reference genotype Tift23D,B-P1-P5, association mapping panel (PMiGAP), wild species from West and Central Africa (WCA) and hybrid parental lines from SAUs and private companies. ICRISAT in association with partners will use the sequence information to accelerate the pace of cultivar development.
About 3.2 m ha in Rajasthan and 0.45 m ha each in Haryana and Gujarat falls in this zone. Here, the farmers are either unaware of hybrid technology or suitable hybrids are not available. This zone was selected in HOPE project and pearl millet hybrid technology and a balanced use of fertilizers was demonstrated to the farmers to increase pearl millet productivity in this region. Cluster villages were selected in two districts each in Rajasthan, Gujarat and Haryana. About 25,000 trials with the seed of improved hybrids and balanced fertilizer were conducted at farmers' fields during 2010-2015 to demonstrate the potential of hybrid pearl millet production technology. This led to the identification of some promising hybrids such as RHB 173, RHB 177, MPMH 17, GHB-538, JKBH 676, HHB 223, HHB 197 and 86M66. Crop management trials on weed control (Atrazine @1.0 kg/ha), white grubs (Chloropyriphos), and micronutrient (ZnSO₄ 20 Kg/ha) demonstrated 14-24%, 7-14% and 11-19% yield increase, respectively over control. Field days and exposure visits were also conducted for the dissemination of improved technologies (use of improved seed, seed treatment, balanced fertilizer and weed control through herbicide) to pearl millet farmers. The results of the trials conducted at farmers' fields showed about 30-100% yield increase over local practices of pearl millet cultivation. The seed of the identified hybrids was made available to farmers by sensitizing seed production agencies both public and private sector.

Management of the blast disease, an emerging threat to pearl millet production in the semi-arid tropics of India

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Pearl millet blast, caused by Magnaporthe grisea has emerged as a serious disease of pearl millet hybrids in India in the past 7-8 years. Host plant resistance is the economical and viable disease management strategy to control pearl millet blast; however, resistance in the commercial hybrids being grown in India is not available. Therefore, efforts are being made to identify different patho types of M. grisea and resistance sources effective against them. One hundred sixty two designated B-lines of pearl millet and 305 accessions of Pennisetum violaceum, a wild relative of pearl millet, were screened for blast resistance against five pathotypes of M. grisea. Nine B-lines (81B, ICMB 88004, ICMB 92444, ICMB 97222-P1, ICMB 02111, ICMB 06444, ICMB 07111, ICMB 09333 and ICMB 09999) were found resistant to all the five patho types tested. High level of resistance was also observed in P. violaceum accessions IP 21525, IP 21536, IP 21594, IP 21610, IP 21706, IP 21711, IP 21716, IP 21719, IP 21720, IP 21721, IP 21724, IP 21987, IP 21988 and IP 22160 against all the test isolates. Of the 112 lines from IARI evaluated against three patho types Pg 118 (Haryana), Pg 232 (Uttar Pradesh) and Pg 238 (New Delhi), eight lines were resistant to any one patho type, line 9931 was resistant to Pg 232 and Pg 238, and 10182 was resistant to all three patho types. For the management of the disease through fungicides, the efficacy of nine fungicides- Chlorothalonil, Tricyclazole, Hexaconazole, Kasugamycin, Benomyl, Carbendazim, Nativo (Tebuconazole 50% + Trifloxystrobin 25% WG), Tilt (Propiconazole 25% EC) and Ridomil was tested under field conditions. Three sprays of Nativo @ 0.4 g/l or Tilt @ 1 ml/l were found effective in controlling blast.
Pearl millet breeding for non-conventional traits and ecologies in South Asia (SA) and Eastern and Southern Africa (ESA)

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ICRISAT organizes Consortium Consultation Meeting (CCM) biennially with partners from both public and private sectors to identify emerging issues requiring possible research interventions by ICRISAT. Research on blast disease, forage, and heat tolerance were some of the key priority areas identified for SA program in these meetings held in 2009, 2011 and 2013. ICRISAT initiated generating basic information and desired materials on these traits. Breeding materials comprising of hybrid parents and germplasm accessions were identified having multi-pathotype resistance to blast and were utilized in the development of Seed Parent and Restorer Parent Blast Resistant Composites. A new wave of blast resistant hybrid parents have been developed utilizing these newly developed materials which are now available for distribution. For heat tolerance, multi-year and multi-location screening of breeding materials were done in target ecology (air temperatures of >42°C) during the summer season of 2009-2015 and stable sources of heat tolerance were identified. New Heat Tolerant Composites were developed for seed and restorer parents using these newly identified materials and selections were made in early segregating generations in heat stress ecology. These selections were further alternated with generation advance during the rainy season at ICRISAT, Patancheru which led to the production of S−S progenies that have shown very high seed set (ranging from 67 to 90%). On forage research, new high biomass materials were identified and utilized to generate hybrids and anew wave of OPVs providing green forage yields of 45-55 tons ha−1. With the objective of expanding pearl millet hybrid technology to Eastern and Southern African (ESA) region, some of the experimental hybrids developed at ICRISAT, Patancheru evaluated in ESA region in 2012-2015 led to the identification of some promising hybrids which out yielded local checks by 20-40% in grain yield. Efforts are ongoing to establish these identified hybrids in the region.

Vision 2030 for Pearl millet in India: Setting research priorities via consultation process

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ICRISAT-Pearl Millet Hybrid Parents Research Consortium (PMHPRC) went through a feedback survey in 2015 involving the major pearl millet breeding programs in both public and private sector to assess the focus traits/areas for research prioritization to be addressed on the short to long term basis. About 25 respondents from private seed companies and public sector institutions engaged in pearl millet hybrid research and development participated in this exercise. Each one of these respondents were senior plant breeders linked to pearl millet improvement research from last 5-20 years and indirectly bring feedback on the concerns and expectations of pearl millet breeders. The survey revealed following order of prioritization of current pearl millet hybrid segments: 57, 24, 16, 15, and 8 percent of market investment is occurring on rainy season hybrids, summer season hybrids, hybrids for drought-prone environments, exclusive forage hybrids and high grain-Fe hybrids, respectively. Further, the traits of importance for each of these segments were captured. For rainy season hybrids, following traits were identified in order of prioritization: downy mildew resistance (1), lodging tolerance (2), blast resistance (3), and cytoplasmic diversification (4), and so on. Drought tolerance, stay-greenness and early maturity were the priority traits identified for drought-prone environments, while heat tolerance ranked highest for summer hybrid market. Multi-cut trait and disease resistance were identified as priority traits for forage hybrids. Overall, the survey indicated disease resistance (DM, blast and rust) to be the highest prioritized traits followed by lodging and heat tolerance. The inputs of this feedback will help to create a clear road map on the critical research areas that needs attention in different pearl millet segments and also set an expectation from pearl millet breeders to focus and development of germplasm and breeding material catering to the identified needs.
Genetic inheritance of shoot fly resistance, morphological and agronomic traits of sorghum

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Sorghum shoot fly, Atherigona soccata is an important seedling pest that influences the grain productivity in sorghum across the production environment. Shoot fly resistance in sorghum is a complex trait with quantitative inheritance. To understand the trait better, generation mean analysis was performed using two different crosses IS 18551 × Swarna and M 35-1 × ICSV 700 during 2013-14. The F1, F2, BC1 and BC2 progenies along with the P1 and P2 parental lines were studied for different traits, acting against shoot fly, A. soccata. The cross IS 18551 × Swarna exhibited significant difference between the parents for shoot fly deadhearts (%) in the post rainy season, the other progenies exhibited lower shoot fly damage indicating at least one of the parent should bear resistance genes for developing the shoot fly resistant hybrids. Leaf glossiness, leaf sheath pigmentation and plant vigorscore exhibited non allelic gene interactions with dominant gene action, whereas 100 seed weight showed both additive and dominant gene interactions. The trait presence of awns showed the recessive nature of the awned gene. Generation mean analysis suggested that both additive and dominance effects were important for most of the traits evaluated in this study, but dominance had a more pronounced effect. This finding is different from earlier findings where in mostly additive effects reported. The knowledge on allelic and non-allelic interactions of the traits acting against shoot fly will be helpful in adopting the suitable breeding strategies for developing the shoot fly resistant sorghums. Based on these at least one of the parents should have shoot fly resistance to develop Sorghum hybrids with shoot fly resistance.

Identification of QTLs and genes for grain Fe and Zn concentration in sorghum

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Sorghum is a major food crop in the semi-arid tropics of Africa and Asia. There is no report of QTLs controlling grain Fe/Zn in sorghum so far. To identify genomic regions associated with grain Fe/Zn, a sorghum RIL population (342 individuals derived from 296B × PVK 801) was phenotyped for two years at three locations and genotyped with SSRs and DArTs. Highly significant genotype x environment interactions were observed for both micronutrients; grain Fe showed greater variation than Zn. Sorghum genetic map was constructed with 2088 markers (1148 DArTs, 927 DArTSeqs and 13 SSRs) covering 1355.52 cM with an average marker interval of 0.6cM. A total of 18 QTLs controlling grain Fe and Zn were found stable across environments. Three QTLs were identified for grain Fe with 3.94 to 5.09% of phenotypic variation explained (PVE), and 15 QTLs for grain Zn with PVE ranging from 3.17 to 9.42%. Of the 18 stable QTLs, 11 were located on chromosome SBI-07. Favorable alleles for 11 QTLs (co-located) for Fe and Zn on SBI-07 were contributed by the parent PVK 801. QTLs were analyzed in silico to identify underlying candidate genes and 62 candidate genes involved in Fe/Zn metabolism were identified within QTL interval; 23 were found in QTL with highest phenotypic effect (PVE 9.42%). Identified sorghum genes within QTL interval, shown gene synteny with Oryza sativa (44-97%) and Zea mays (49-99%). Fe/Zn QTL positions in sorghum were cross compared with sorghum gene homologue derived from other cereals, the position of 20 QTLs identified in this study (on chromosome SBI-02, SBI-04, SBI-06, SBI-08, SBI-09 and SBI-10) were same as the Fe/Zn gene homologues positions identified on sorghum genome in our earlier Insilco homology study. Genetic resources identified can help in developing biofortified sorghum lines in cost-effective and efficient manner in future.
Improving charcoal rot tolerance in sorghum

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Charcoal rot caused by Macrophomina phaseolina is a major disease of sorghum in the post-rainy season that affects grain production and fodder quality. Thus, attempts were made to identify charcoal rot resistance in sorghum and biocontrol agents effective against the pathogen for the management of this disease. A total of 581 sorghum lines including 78 hybrids, 36 elite B lines, 34 R lines, 125 hybrid parental lines, 11 varieties, 245 sorghum minicore accessions and 52 stay green introgression lines were screened against charcoal rot in the post-rainy season of 2013-14. None of the hybrid was found tolerant to charcoal rot whereas varieties SPV 1411 and M 35-1 were found to have moderate levels of tolerance. Among breeding lines, one B line (IS 19587 x ICSB 333)-3-1-2-1-1-2-1-1 and three R lines (Gidd|Maldandi x (M 35-1 Bulk 3xSPV 1359)-4-1-3-1)-1-1-1-1, (Gidd|Maldandi x (M 35-1 Bulk 3xSPV 1359)-4-1-3-1)-2-2-1-1 and CSV 18R were found moderately tolerant to charcoal rot. Among stay green introgression lines, S35SG 06008, N13, ICSR93024 and ParbhaniMoti = SPV1411, S35SG 06028, S35SG 07001, S35SG 06014, SP 39105-P7 and ICSV700-P10 exhibited tolerance to the disease. Five mini core accessions IS 2397, IS 21512, IS 23216, IS 24503 and IS 31186 were also found tolerant to charcoal rot. IS 123216 and IS 24503 also exhibited tolerance to the disease in 2015-16. Seven strains of Streptomyces sp. (BCA-546, BCA-659, BCA-667, BCA-689, BCA-698, CAI-8 and CAI-133) were evaluated for their antagonistic potential against M. phaseolina. All the seven strains inhibited M. phaseolina in both dual culture as well as secondary metabolite production assays. BCA-546 and CAI-8, significantly reduced charcoal rot in sorghum (296B) when evaluated under greenhouse conditions. Thus, Streptomyces strains BCA-546 and CAI-8 can be effectively used along with moderately tolerant cultivars to manage charcoal rot of sorghum.

Innovative seed consortium for thriving the post-rainy sorghum seed chain

A AshokKumar; Ch Ravinder Reddy; Belum VS Reddy; Sharad R. Gadakh; UttamChavan and HV Kalpande

ICRISAT-Patancheru, India; ‘Mahatma Phule Krishi Vidyapeeth (MPKV), Maharashtra, India; ‘Vasantrao Naik Marathwada Krishi Vidyapeeth, Maharashtra, India. Corresponding author email: a.ashokkumar@cgiar.org

Post rainy sorghum is critical for the sustenance of dryland farmers in the Maharashtra state of India wherein OPVs are the cultivar choice. However, the seed replacement ratio was very low (20%) leading to low on-farm productivity (0.6 t ha⁻¹). To change this situation a partnership effort led by ICRISAT worked with an aim to increase crop productivity and farmers’ incomes by reducing the gap between on-station sorghum yields (2.5–3.0 t ha⁻¹) and farmers yields (0.6 t ha⁻¹) and by adding value to grain and stover and by providing market linkages under a large international project funded by the BMGF which led to significant increase in productivity and profitability of farmers. During this effort, the partners realized the need to improve the post rainy sorghum seed systems to increase the adoption rates and there by the productivity. Accordingly, a ‘Seed Consortium’ was formed during 2013 involving Indian NARS (IIMR, MPKV and VNMKV), public sector seed agencies (Mahabeej and MSSCA), Dept of Agriculture and the farmers. Under this Consortium, all the partners come together, fix the targets to be achieved for seed chain sustainability and work together to achieve the targets on a yearly basis. The State seed development corporation (Mahabeej) gives the buy-back guarantee and procure the seeds from the seed farmers. It processes the seeds and supply to the farmers through its network. With the concerted efforts of all the partners, the Seed Consortium during the year 2013 produced a total of 300 tons of improved varieties seeds in farmers’ fields and supplied to 30,000 farmers. In 2014 it produced 1000 tons of seeds and supplied to 100,000 farmers and in 2015 it produced 1500 tons of seed and distributed to 150,000 farmers. With this, there is a steady increase in post rainy sorghum productivity which is now more than 800 kg/ha and growing.
Marker-assisted backcrossing (MABC) for the development of improved shoot fly (Atherigona soccata) resistant sorghum varieties

Sunita Gorthy; Lakshmi Narasu; Santosh Deshpande; Hari Chand Sharma; G Anil Kumar and A Ashok Kumar

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Shoot fly (Atherigona soccata L. Moench) is a major biotic constraint in sorghum production leading to the reduction of sorghum yield in many areas of the world. Improvement in shoot fly resistance for target component traits is one of the important objectives of sorghum breeding programs. In this study, we used MABC (marker-assisted backcrossing) for transferring shoot fly resistance QTLs into elite sorghum varieties. Three quantitative trait loci (QTLs) associated with shoot fly resistance were selected for introgression into elite post rainy season adapted cultivar Parbhani Moti (=SPV1411) and an elite sorghum hybrid parent ICSB29004. The three QTLs for shoot fly resistance were present in the BTx623 background (transferred from shoot fly resistance donor IS 18551). The foreground selection was carried out in F1 and BC1F1 generations with 33 polymorphic markers. Background selection in the progenies was employed with evenly distributed 43 SSR markers in the sorghum genome to select plants with higher recurrent parent genome recovery. The results showed that the best plants of BC1F1 generation carry segments of the donor, which had 80-90% of the recipient genome. Phenotyping of these lines has identified resistant lines for each QTL region present on chromosome SBI 01, SBI 07 and SBI 10 in ICSB 29004 and SPV1411. Some of the introgression lines showed better shoot fly resistance than the recurrent parents and their agronomic performances were the same or better than the recurrent parents. All these lines had medium plant height, desirable maturity with high yield potential. To summate, MABC successfully improves the shoot fly resistance in sorghum without a yield penalty. This is the first report on the use of MABC for improving shoot fly resistance in sorghum.

Transforming the post-rainy sorghum production systems for enhanced productivity

A Ashok Kumar; Belum VS Reddy; Sharad R. Gadakh; Uttam Chavan and HV Kalpande; Ambika More; RL Aundhekar and ST Borikar

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Post-rainy sorghum is a major food and fodder crop in the Deccan Plateau of India, particularly in the drylands. The crop is grown purely on residual moisture on black soils wherein the average rainfall during the crop growth period ranges from 50-70 mm. Farmers prefer the superior grain and stover quality of post rainy sorghum. However, the productivity of the crop was very low (~600 kg/ha). Terminal drought, non-adoption of improved cultivars and management practices, poor market access, were the main reasons behind low-productivity. Therefore we developed interventions to address these issues and implemented them successfully in six clusters of major post rainy sorghum growing regions in Maharashtra state of India. Large-scale dissemination on insitu moisture conservation and adoption of improved crop cultivars and cultivation practices was carried out to increase the awareness among farmers. Seed of improved varieties adapted to target regions Parbhani Moti, Parbhani Jyoti, Phule Vasudha, Phule Chitra and Akola Kranti was distributed for cultivation in 10,000 farmers' fields in the target areas in the first year (2009) and this activity continued for five years by distributing to different farmers every year and encouraging them to save seed and share with others. In seven years, this partnership effort reached 300,000 farmers in Maharashtra state.
These efforts led to significant increase in grain productivity by 39% and stover productivity by 30% for post-rainy sorghum. The early adoption studies results indicated that our interventions enhanced technology adoption rates, reduced the yield gaps (by 30-65%), increased the productivity and gave higher returns to farmers (35-44%) for post rainy sorghum farmers. Women participation was given high priority in all project interventions particularly in seed production, crop management and value addition to grain and stover and marketing. With this, the adoption rates in project areas are >70% and productivity in Maharashtra increased to >800 kg/ha.

Mapping major cropland of Ethiopia using MODIS multi-temporal data

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Overarching goal is to map the cropland areas of Ethiopia using moderate-resolution imaging spectroradiometer (MODIS) time-series data for the year 2014. The population of the region is growing faster than its ability to produce cereals. Thus, accurate and timely assessment of where and how cereals are cultivated is important to craft food security and poverty alleviation strategies. We used a time series of sixteen-day, 250-m spatial resolution composite images from the MODIS sensor to produce crop type maps and crop characteristics (e.g., intensity of cropping, cropping calendar) taking data for the year 2014 and by adopting a suite of methods that include spectral matching techniques, decision trees, and ideal temporal profile data banks to rapidly identify and classify crop areas over large spatial extents. These methods are used in conjunction with ancillary spatial data sets (e.g., elevation, precipitation), national statistics, and maps, and a large volume of ground survey data. The resulting crop dominance maps and statistics are compared against a subset of independent ground survey points and the best available sub national statistics on crop areas for the main crop growing season. A fuzzy classification accuracy assessment for year 2014 crop land product, based on ground survey data, demonstrated accuracies from 77% to 100% for cropland classes, with an overall accuracy of 82% for all classes. Most of the mixing was within wheat and barley classes. These results suggest that the methods, approaches, algorithms, and data sets we used are ideal for rapid, accurate, and large-scale mapping of major crops as well as for generating their statistics over large areas.

Geographic priorities for research and development on dryland cereals and legumes

Glenn Hyman1; Elizabeth Barona2; Chandrashekhar Biradar3; Edward Guevara4; John Dixon4; Steve Beebe5; Silvia Elena Castano6; Tunrayo Alabi7; Murali Krishna Gumma1; Shoba Sivasankar5; Ovidio Rivera; Herlin Espinosa1; Jorge Cardona1

1CIAT-Cali, Colombia; 2Independent Researcher, Miami, USA; 3ICARDA-Beirut, Lebanon; 4Australian Centre for International Agricultural Research, Canberra, Australia; 5IITA-Ibadan, Nigeria; 6ICRISAT-Patancheru, India. Lead author email: g.hyman@cgiar.org

Dryland cereal and legume crops have often received less attention than maize, wheat and rice in terms of research and development priorities. But these crops are important globally because they serve populations living in poverty and environments where they are uniquely adapted to socioeconomic and biophysical conditions.
Unfortunately, less is known about the global distribution of dryland cereal and legume crops and the conditions where they are grown compared to other major crops. This research reports on an international effort to compile geographic information on cereal and legume crops and the conditions under which they are cultivated. Our approach was to compile geographic information, to use metadata and standards to document the information, to use spatial overlay for analyzing relationships in the data and to develop an online Atlas for sharing the information with the research and development community. The study focused on chickpea, common bean, cowpea, faba bean, groundnut, pigeon pea, soybean, barley, pearl millet, small millet and sorghum. The study suggested that dryland cereal and legume crops should be given priority in 18 farming systems worldwide, representing 160 million ha. The priority regions include the drier areas of South Asia, West and East Africa, Middle East and North Africa, Central America and other parts of Asia. These regions are prone to drought and heat stress, among other biotic and abiotic constraints. They represent 60% of the global poor and malnourished and make up half of the global population. Dryland cereal and legume crops merit greater research and development attention in a world of growing population and climate change. All the results and data are available in an interactive online Atlas, including links to download the original data. Interested users of this information can find more from our website at http://www.eatlasdcl.cgiar.org
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