POTENTIAL OF LEGUMES: GLOBAL NEEDS AND CHALLENGES

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DAVID BERGVINSON, Director General of the International Crops Research Institute for the Semi-Arid Tropics. David joined ICRISAT on January 5, 2015 to lead its strategy development to ensure solid science, demand-driven innovation and strategic partnerships that translate science into prosperity for rural families in the dryland tropics of Asia and sub-Saharan Africa. During David's eight years at the Bill & Melinda Gates Foundation and now at ICRISAT, he continues to lead teams to leverage the power of digital technology to accelerate the development and delivery of farmer-preferred products and services to increase agriculture productivity of smallholder farmers in a sustainable and equitable manner in the developing world.

ABSTRACT

Hunger and malnutrition are preventing millions of children from realizing their full potential that will have long-term implications for society and economic development. Undernutrition contributes to the death of over 3 million children each year and for those who survive, robs them of reaching their full potential in life. Of the 795 million who suffer from undernutrition, 780 million live in developing countries (FAO, 2015). Therefore, it is essential to adopt an inclusive and demand-driven approach to accelerate the design, development and delivery of science-based solutions to address undernutrition. Pulses (or grain legumes) offer a rich source of protein and nutrients to combat undernutrition and contribute to a balanced diet (Foyer et al 2016), while also improving soil health and increasing the agro-biodiversity of our cropping systems around the world (Siddique et al. 2012). Enhancing public awareness on the contribution of pulses to modern food systems was the intent of the 68th UN General Assembly declaring 2016 as the International Year of Pulses (IYP).

Pulses make tremendous contributions to sustainable food production systems through their ability to fix symbiotic nitrogen from the atmosphere. This has important nutritional implications for humans, livestock and the soil. However, adoption of improved production technologies for pulse crops is not keeping pace with the major cereal crops (maize, wheat, and rice). The area planted to pulses has gradually increased over the past 50 years, but it is still only a quarter of that planted to maize, wheat and rice. While changes in agronomic practices and new varieties of pulses have occurred over the past two decades, increase in pulse production is not keeping pace with demand that is leading to price volatility, especially in developing countries. Pulses play a critical role in conservation agriculture (CA) by rotating them with cereals, enabling minimum tillage and improved soil health over time. Adoption of CA is slowly picking up in smallholder farming systems in Asia and Africa, with increasing availability of herbicides and development of implements suitable for minimum tillage and business models to make mechanization economically viable. Decision support systems are now being developed to support smallholder farmers in choosing cultivars, sowing date, and best agronomic practices that are fundamental to enhance pulse production and profitability for farmers.

Despite being important crops from different perspectives, the average productivity of pulse crops is very low as they are exposed to a number of biotic and abiotic stresses in sub-Saharan Africa and Asia. Therefore, with the objective of increasing production, reducing poverty, hunger, and malnutrition of smallholder farmers, while improving the health of humankind and the sustainability of farming systems in the next 10 years, ICRISAT is leading the CGIAR Research Program - Grain Legumes (CRP-GL) that is targeting research for development in eight major food legumes including chickpea, common bean, cowpea, faba bean, groundnut, lentil, pigeonpea, and soybean that are primarily grown by smallholder farmers in South and South East Asia, sub-Saharan Africa, Central and Western Asia, North Africa, Latin America and the Caribbean. The main aim of the CRP-GL is to combat poverty, hunger, malnutrition and environmental degradation by increasing productivity, profitability and consumption of grain legumes. During last four years, CRP-GL partners have leveraged their knowledge and research capacities by coordinating strategies with diverse public and private organizations. CRP-GL partners have released over 250 grain legumes varieties, 4 pigeonpea hybrids, and facilitated production of over 445,847 tons seeds of improved varieties of legumes. To create awareness among farmers, processors and policy makers, over 23,000 demonstration trials were conducted to support best management practices. In brief, 30,000 people (including 17,000 women) were trained in short-duration training courses.

With an objective to enhance genetic gains, the CRP-GL partners have also made significant advances in developing genomics tools, technologies and platforms for accelerating genetic gains and innovative seed systems to support the delivery of improved pulses to farmers. For instance, the genome sequences that are now available for legume crops include chickpea, pigeonpea, common bean, groundnut, and soybean, and efforts are underway in lentil and faba bean. Several thousands to millions of molecular markers are now available in legume crops (Varshney 2016). High-density genotyping platforms such as Affymetrix SNP arrays, Illumina arrays, genotyping-by-sequencing have

been developed for cost-effective genotyping in several legume crops. By using these genotyping platforms and precision phenotyping, a wide range of marker-trait associations have been established for grain legumes to enhance precision and efficiency of breeding programs. Successful examples of molecular breeding include the development of superior lines with enhanced drought tolerance, Fusarium wilt and Ascochyta blight resistant lines in chickpea, leaf rust and late spot resistant lines in groundnut, improved oil quality lines in groundnut and utilization of markers for assessing purity of hybrids/parental lines in pigeonpea (Varshney 2016). Hybrid pigeonpea is now available and being adopted in India and Kenya by seed companies and farmers, and Bt-chickpea and Bt-pigeonpea are being test in trials at ICRISAT.

During the past year, pulses have enjoyed increased demand by producer and consumers in response to the awareness of the nutritional and environmental benefits pulses offer – thanks in part to the International Year of Pulses. This in turn is leading to economic benefits for smallholder farmers in the developing world who can respond to market signals and access domestic and international market opportunities. However, more is required to support farmers access appropriate knowledge, inputs and mechanization to reduce production costs and equitable markets to translate increased productivity into profitability.

In summary, grain legumes, provide an opportunity to ensure nutritional security in both the developed and developing world and through increased demand, enhance farmers' income and profitability. With recent advances in modern tools for breeding, agronomy and market integration, it is now possible to unlock the full potential of grain legumes to support the realization of the Sustainable Development Goals within 14 years. To realize this, public-private-producer partnerships will be required that draw on science-based, demand-driven innovations and enabling policies to ensure pulses play an increasingly important role in global nutritional security that will enable us to live within the planetary boundaries.

KEYWORDS

pulses, grain legumes, pest and disease resistance, drought tolerance, genetic gains, conservation agriculture, inclusive market oriented development, nutritional security

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Varshney RK, 2016: Exciting journey of 10 years from genomes to fields and markets: Some success stories of genomics-assisted breeding in chickpea, pigeonpea and groundnut. Plant Sci. 242: 98-107.

Potential of Legumes:
Global needs and challenges

David Bergvinson
Director General
ICRISAT

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Outline

- IYP key messages
- Why pulses?
- Pulse global production, trade and consumption
- Health benefits of pulses – Chickpea & Pigeonpea
- Conclusions

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Zero Hunger Challenge

3

17 Sustainable Development Goals with emphasis on sustainable and equitable food systems

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Why Pulses?

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2016 INTERNATIONAL YEAR OF PULSES

nutritious seeds for a sustainable future

Food and Agriculture Organization of the United Nations

fao.org/pulses-2016 | pulses-2016@fao.org | #IYP2016

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Objectives of the International Year of Pulses (IYP)

- Promote the value and utilization of pulses throughout the food system
- Raise awareness about the benefits of pulses, including sustainable agriculture and nutrition
- Encourage connections to further global production
- Foster enhanced research
- Advocate for better utilization of pulses in crop rotations
- Address the challenges in the trade of pulses

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Global investment in pulse R,D&E is too low compared with cereal crops: (US $ 175 million per annum in 13 pulse crops)

nature plants
PERSPECTIVE
PUBLISHED: 2 AUGUST 2016 | ARTICLE NUMBER: 16072 | DOI: 10.1038/NPLANTS.2016.72

Neglecting legumes has compromised human health and sustainable food production

Christine H. Foyer[1,2*], Hon-Ming Lam[3], Henry T. Nguyen[4], Kadambot H. M. Siddique[5], Rajeev Varshney[6], Timothy D. Colmer[2,5], Wallace Cowling[5], Helen Bramley[7], Trevor A. Mori[8], Jonathan M. Hodgson[9], James W. Cooper[1], Anthony J. Miller[9], Karl Kunert[10], Juan Vorster[10], Christopher Cullis[11], Jocelyn A. Ozga[12], Mark L. Wahlqvist[13,14], Yan Liang[15], Huixia Shou[16], Kai Shi[17], Jingquan Yu[17], Nandor Fodor[1], Brent N. Kaiser[18], Fuk-Ling Wong[3], Babu Valliyodan[3] and Michael J. Considine[2,5,19]

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Food and Agriculture Organization of the United Nations

2016 INTERNATIONAL YEAR OF PULSES

10-Year Pulse Research Strategy

IYP Global Dialogue
FAO, Rome
22-23 Nov 2016

Shoba Sivasankar
Director
CGIAR Research Program on Grain Legumes

CGIAR Research Program on Grain Legumes · ICRISAT · CIAT · ICARDA · IITA · and public and private institutes and organizations, governments, and farmers worldwide

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Sustainable Intensification Nutrition Continuum towards achieving the Sustainable Development Goals

Reliable water enables diverse food production	Diverse food production enables nutrition	Nutrition enables people to realize their full potential	Empowered people enable sustainable development
Watershed management minimizes soil erosion, provides predictable water and extends the growing season	Increased productivity enables diversification of diets and incomes for farmers	First 100 days of life and access to good nutrition enables women and children to..	..increase their incomes, opportunities and ultimately to socially, economically and environmentally realize sustainable development

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Semi-arid Tropics

Covers **6.5 million** sq. km.
Across **55** countries
with **2 billion** people
of which **644 million** are the poorest of the poor

High levels of **poverty, malnutrition and environmental degradation**

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About ICRISAT

We **believe** all people have a **right** to **nutritious food** and a **better livelihood.**

Our Vision
A prosperous, food secure and resilient dryland tropics

Our Mission

Overcoming Poverty · Overcoming Hunger · Reducing Malnutrition · Preventing Environmental Degradation

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Holistic Approach to Improve Livelihoods

Cross-cutting issues

- **Mainstreaming nutrition**
- **Empowering women** – women are consulted, involved and supported to lead
- **Attracting youth** to agriculture

Approach for Adoption

- **Participatory approach and partnering** – working side by side
- **Building capacity** – at a national and local level
- **Integrating communications** - to build awareness and share knowledge
- **Monitoring and evaluation** – for feedback and adjustment
- **Policy support** – work closely with government to encourage the needed policies

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Science of Discovery through to Science of Delivery

With an interconnected world, society is enjoying an unprecedented pace of scientific discovery; however, we often underestimate the Science of Delivery and Adoption of science-based solutions

- Demand-driven innovation with rapid feedback loops
- Anthropology of Adoption
- Non-linear scaling through a consortium
- Building and mentoring local capacity and advocates
- Soft skills of science for brokering innovative partnerships
- Pragmatic Policies for Prosperity through sustainable growth - socially, economically, and environmentally

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Why Pulses are a Smart Food ?

1. Good for you

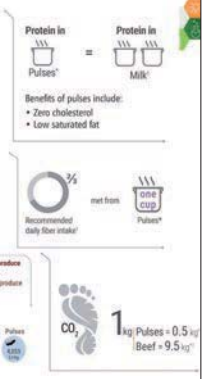
- Pulse crops like lentils, pigeonpea, chickpea are affordable sources of protein
- Help address non-communicable disease like obesity, diabetes etc

2. Good for the Planet

- Highly water use efficient: most pulses are drought tolerant eg. pigeonpea, chickpea, mothbean
- Helps improve soil fertility by fixing atmospheric nitrogen to improve soil health

3. Good for smallholder farmer

- Important for mixed cereals-livestock systems to diversify risk for smallholder farmers
- Diversify income sources (as cash crops)



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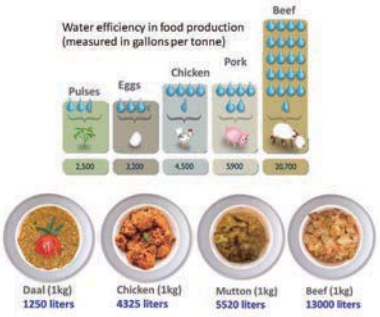
Pulses are climate smart crops with less water requirements



Source: ICARDA

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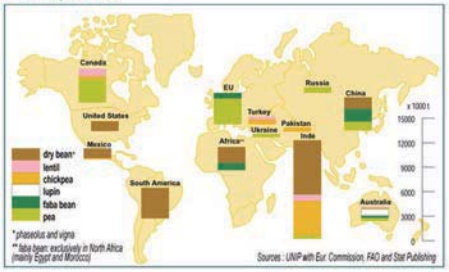
Pulses are grown in agroecologies ranging from tropical to temperate



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Legume fixed N for food production

Region	Source & estimated annual N input million ton N/year	
Asia & middle East	19	47
Europe	3	14
North America	8	14
Africa	3	5
South America	10	6
Australia	4	1
Total Global	47	87

value =>US$50 billion

Source: Herridge *et al* (2008) *Plant & Soil* 311:1-18
Peoples *et al* (2009) *Nitrogen Fixation in Crop Production: Agronomy Monograph 52*, pp.349-385

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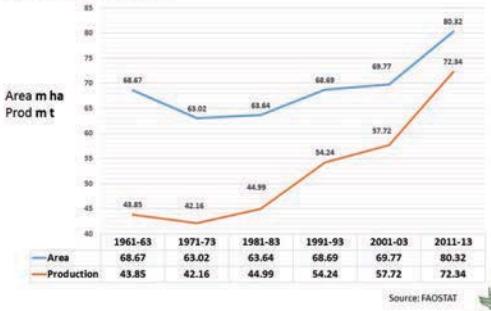
Global Pulse Production



	1961-63	1971-73	1981-83	1991-93	2001-03	2011-13
Area	68.67	63.02	63.64	68.69	69.77	80.32
Production	43.85	42.16	44.99	54.24	57.72	72.34

Source: FAOSTAT

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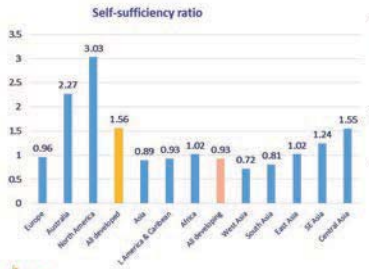
Region-wise self-sufficiency in pulses



- At aggregate level, developed countries have surplus while developing countries have a deficit in pulse production
  - Northern America and Australia have large surplus, while Asia has a high deficit
- Self-sufficiency is increasing in developed countries and further declining in developing countries
- West and South Asia are highly deficit in pulses
  - Self-sufficiency is declining fast over the years

Source: P.K.Joshi, IFPRI

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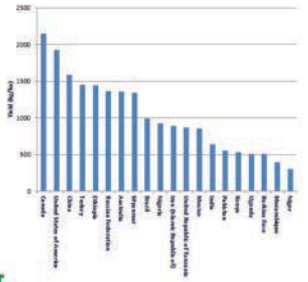
Yield of all pulses in different countries, 2011-13



- There is large inter-regional and inter-country yield variation
- Average yields of developed countries was > 1.2 t/ha
  - Canada> 2 t/ha; US near 2 t/ha
- Developing countries average yield was <1 t/ha
  - Myanmar and Ethiopia are exception
  - Most of the African and S Asian countries yields are < 500 kg/ha

Source: P.K.Joshi, IFPRI

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Growing importance of pulses in many countries - especially more vulnerable populations

Source: P.K.Joshi, IFPRI

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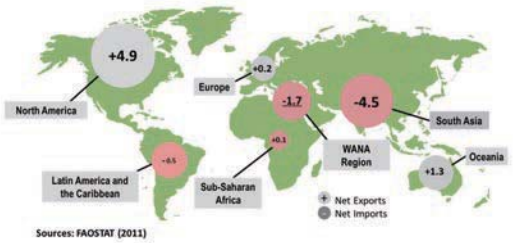
Global pulse trade: about 12 million tons (2011)



Sources: FAOSTAT (2011)

Source: ICARDA

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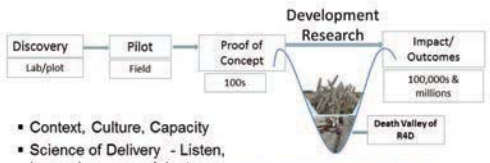
Why Country-Specific Strategies?



- Context, Culture, Capacity
- Science of Delivery - Listen, Learn, Leverage, Adapt, Ownership
- Pragmatic Policies for Prosperity

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Pulses Self-Sufficiency in India : Challenges Opportunities and Strategy

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Pulse production in India is volatile

- Pulses self sufficiency is essential for nutritional security of India
- Pulses import put a stress on India's forex reserves

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Key constraints of pulse production in India

- India is largest producer, consumer and importer of pulses. However, some key constraints of pulses production include:
  - Low investments by farmers, researchers and policymakers; inadequate policy and market support
  - Highly susceptible to both biotic (pests and diseases) and abiotic stresses (temperature extremes and aberrant rainfall driven by climate change); Pulses are prone to damage by storage pests
  - Largely grown in marginal lands under rainfed conditions
  - Labor costs are high; few labor-saving options are available (varieties suitable for machine harvesting, herbicide resistance) for pulses

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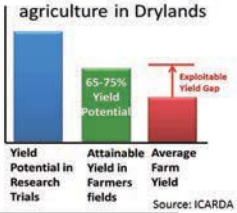
Strategies for Enhancing Pulse Production

- Crop genetic improvement and new genetic gains for improved varieties
- Bridge the yield gap (24 m ha)
- Vertical increase in productivity through sustainable intensification of production systems
- Area expansion – Rice fallows (12 m ha)
- Crop diversification (rice-wheat systems)
- Rainy season fallows
- Reduce post-harvest losses

Yield potential for rainfed agriculture in Drylands



Source: ICARDA

- 25-60% yield gaps in pulses
- Reasons are many...
- Closing the yield gaps can alone supply 60% of pulses deficit
- Farmers participatory research

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Improve pulse value chain and correct price policy in India

- Unorganized, fragmented and inefficient
- High transaction costs and high losses; leading to rise in prices

Source: P.K.Joshi, IFPRI

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Research thrusts

- Restructuring plant type for higher productivity
- Machine harvestable varieties – minimum tillage; mechanical sowing and harvesting
- Herbicide tolerance
- Climate smart varieties
- Hybrids – transfer pigeonpea hybrid technology to other pulses
- Reduced maturity

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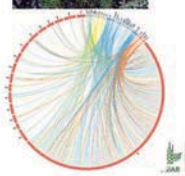
Research thrust areas....

- Enhanced phosphorus acquisition efficiency (PAE)
- Exploitation of wild species and transgenic for insect resistance
- Protein enhancement and bio-fortification
- Refinement of agronomic practices for crop establishment in rainfed-rice fallows
- Modernization of pulses breeding programs (forward breeding)



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Impacts of early maturing chickpea varieties

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Pigeonpea production ('000 t) trends

Source: Ganga Rao, ICRISAT

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Pigeon pea growth trends in Africa

Country	In '000 t		% increase		
	2001	2014	Production	Area	Yield
Tanzania	87.1	249.3	186	106	39
Mozambique	31.6	120.9	282	261	6
Malawi	105.8	301.0	184	69	68
Kenya	73.46	274.5	274	68	122
Uganda	80.0	93.6	17	28	-8
Africa	380.6	1047.3	175	96	40

Source: Ganga Rao, ICRISAT

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Pigeonpea drivers of success

- High yielding, wilt resistant MD varieties
- Sustainable intensification through ICM with women participation
- Regional and international export and participation of large traders
- Innovative seed systems in partnership with local farmers, NGOs and Government
- Value addition and export to regional and international markets
- Very strong participation of partners, donors (BMGF, USAID, Irish Aid etc.,) Governments initiatives -Kilimo Kwanza (Tanzania)

Mrs. E.Mollel of Kikatiti, Tanzania
In front of her old house of 1988
In front of her new improved house

Source: Ganga Rao

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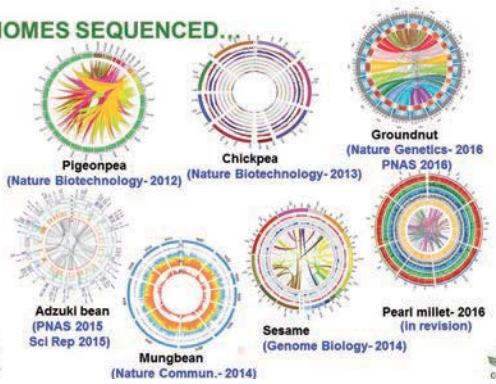
GENOMES SEQUENCED...



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The chickpea genome

- Illumina sequencing used to generate 153.01 Gb
- 73.8% of the genome is captured in scaffolds
- Genome analysis predicted 28,269 genes
- High levels of synteny observed between chickpea and *Medicago*
- > 81,845 SSRs and 4.4 million variants (SNPs and INDELs)

VOLUME 31 NUMBER 3 MARCH 2013 NATURE BIOTECHNOLOGY

with

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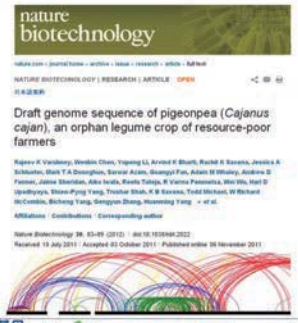
The pigeonpea genome

- Illumina sequencing tech used to generate 237.2 Gb
- 72.7% (605.78 Mb) of the total pigeonpea genome assembled into scaffolds
- Genome analysis predicted 48,680 genes
- High levels of synteny observed between the pigeonpea and soybean
- >50,000 SSR and SNP markers identified
- Higher abundance of drought tolerance genes



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Crop germplasm at ICRISAT genebank

Crop	Conserved		Distributed	
	# of accessions	# of Countries	# of accessions	# of Countries
Sorghum	39,923	93	509,661	110
Pearl millet	23,092	52	155,534	81
Chickpea	20,602	59	347,186	88
Pigeonpea	13,778	74	161,453	113
Groundnut	15,446	92	200,576	96
Finger millet	7,186	25	43,713	54
Small millets	4,278	39	33,464	55
Total	124,305	434	1,451,587	597

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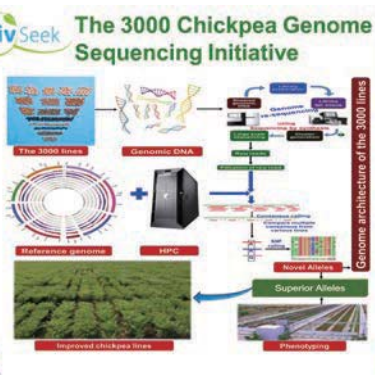
The 3000 Chickpea Genome Sequencing Initiative



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Over 50 traits mapped

Drought tolerance
Root traits- root length density, root length, root surface area
Yield, harvest index, 100-seed weight, number pods per plant, biomass, specific leaf area, delta carbon ratio, days to flowering, days to maturity

Heat tolerance
Pods per plant, heat tolerance index, yield, biomass, harvest index, days to flowering, days to maturity

Salinity tolerance
Pod number, seed number, seed yield, Shoot dry weight, harvest index
100 seed weight

Ascochyta blight
Seedling resistance and adult plant resistance

Helicoverpa
Leaf damage rating (flowering), Unit larval weight, Helicoverpa larvae/10 plants, Days to first flowering

Fusarium wilt, Botrytis grey mould, Protein content

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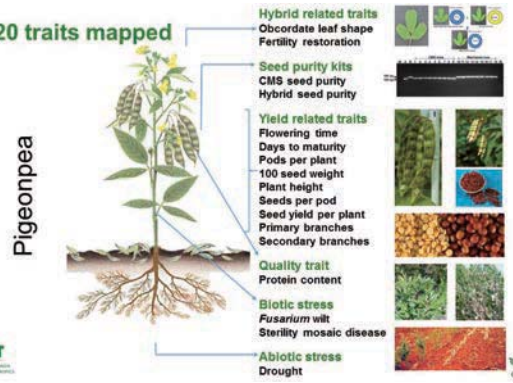
Over 20 traits mapped



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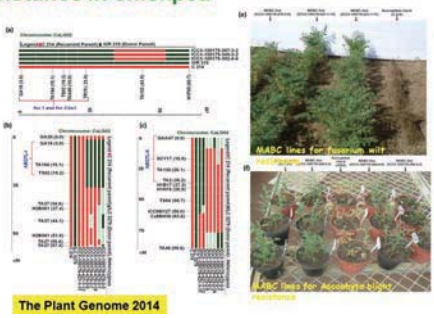
Molecular breeding for fusarium wilt and ascochyta blight resistance in chickpea



The Plant Genome 2014

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Research thrust areas - Transgenic

- Transgenic trait development for biotic and abiotic stresses; nutrition and food safety; herbicide tolerance
- High throughput genetic transformation systems
- Functional gene validations for key traits
- Double haploidy
- Genome editing tools
- Systematic mutant populations for accelerated genetic gains
- Translational research for transgenic product development & deployment

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ICRISAT – JIRCAS collaboration

Completed collaborative projects between ICRISAT and JIRCAS

- GOJ Project Phases I-III (1985-2000) – Addressed P nutrition, N nutrition and P &N nutritional issues in sorghum-pigeonpea production system
- Soil Fertility Project in West Africa (2005-2009) – Soil fertility preservation through organic matter management and introduction of legumes
- Sorghum Biological Nitrification Inhibition (BNI) Project at ICRISAT (2010-2014) – Development of sustainable soil fertility management for sorghum and sweet sorghum through effective use of BNI

- *Japanese collaboration with ICRISAT produced the most comprehensive research on nutrient dynamics (N, P) and root function of the cereal-legume systems (sole, intercrops) for the SAT.*
- *One of many key findings was the role of root exudates from pulses in releasing sparingly available P for crop uptake.*

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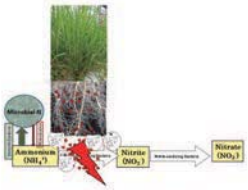
Ongoing ICRISAT – JIRCAS collaboration

Biological Nitrification Inhibition (BNI)



BNI can reduce the loss of nitrogen from agricultural systems (leaching, denitrification) by keeping soil N in ammonium form

Ongoing collaboration between ICRISAT and JIRCAS

Development of genetic markers for BNI-component traits in sorghum

Proposed new initiatives between ICRISAT and JIRCAS

Characterization of sorghum mini-core and West-African germplasm panels for sorgoleone production

Identification of high-sorgoleone producing genetic sources in sorghum

Use modelling approaches to quantify BNI benefits in reducing N_2O emissions and in improving NUE in sorghum-based production systems

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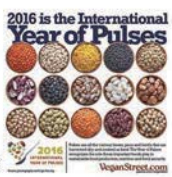
Conclusions and way forward

- **IYP2016 is timely** as we create awareness on the role of pulses to achieve nutritional security, environmental sustainability, and mitigation of climate change – all in service of achieving the SDGs within 14 years!
- Demand for pulses is growing but supply constraints result in price volatility
- **Research needs to focus on increasing profitability for farmers** (reducing inputs and ensuring market-traits in new varieties and realized markets)
- **Global funding** for pulse research must be increased along with an enabling policy environment that includes international grades and standards to support fair trade
- **National interventions** include closing yield gaps by investing in integrated research (GMP) to increase domestic production and reduce loses and increase value addition; improve pulse value chains to benefit producers and consumers; attract private sector investment; promote innovative institutions for scale
- **Local capacity to increase mechanization, knowledge exchange, value addition and market integration** will be key to closing the gender yield gap for pulses and incentivizing youth to see legumes as part of a modern farm



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Onward with urgency to support pulse research that empower farmers and consumers to realize the SDGs – Together!
CGIAR
Grain Legumes
ICRISAT
CIAT
ICARDA
IITA
and public and private institutes and organizations, governments, and farmers worldwide
CGIAR

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Chair Doi
Good morning, ladies and gentlemen. I am Kunihiro Doi, the Director of Research Strategy Office of JIRCAS. It is my pleasure to introduce our keynote speaker today. Before the introduction, I am explaining a little bit about the background of today's symposium.

This year is the International Year of Pulses. It comes to me as a surprise that pulses do not include soybean and groundnuts. In Japan, it is common notion that all beans including soybean and groundnuts belong to the same group. I think my colleagues here, they love Natto and peanuts with alcohol, so they will not accept excluding these two legumes from today's symposium. While we will celebrate this year of pulses, of course, also we should realize the need to promote the importance of the nonpulses legumes.

With this consideration, we decided to change the English title of this symposium from pulses to legumes.

Today, we are honored by the presence of the two prominent scientists who are well known for their expertise in their own field. We are confident that their presentation would provide profound insights into the role of legumes in our lives. Then, I am pleased to introduce our first speaker, Dr. David Bergvinson. Dr. Bergvinson is the Director General of the International Crops Research Institute of the Semi-Arid Tropics, ICRISAT, and International Research for Development Organization and member of the CGIAR Consortium. He joined ICRISAT in January 2015 to lead its strategy development to ensure solid science, demand-driven innovation and strategic partnership that translate science into prosperity for rural families, and he continues what he has done during the former assignment at Bill and Melinda Gates Foundation, to spearhead the advancement of the agricultural development by harnessing digital technology to generate goods and benefits for the poor farmers.

I think I cannot say enough about his scientific career. The title of his presentation is "Potential of legumes: Global needs and challenges." Director General Bergvinson, the floor is yours.

Dr. David Bergvinson
Thank you and good morning. Special acknowledgement of Dr. Masa Iwanaga, President, JIRCAS, thank you for hosting us. Director General Saigo for his insightful comments around partnerships with the private sector and the MAFF perspective, and of course, Dr. Takemoto who is kindly offering this facility to us to have this important dialog around legumes and their role in addressing global needs, especially the Sustainable Development Goals.

Professor Doi, I also am shocked that groundnut and soybean are not considered pulses. So, I won't dwell too much on that because Professor Maeda will give us a very luminary lecture on the definition of pulses and grain legumes more broadly. Mine is really to look at how the pulses or grain legumes will contribute to modern food systems and it will empower us to realize the Sustainable Development Goals in under 14 years, but also highlight the challenges we have ahead of us in realizing that as far as production, trade and consumption of these important commodities.

And then I will highlight in detail two of the grain legumes, chickpea and pigeonpea, which are the largest pulses traded internationally, and how we can unlock biological sciences to realize their full potential, and then some concluding remarks around the interventions at the global, national, and local level that need to be taken to realize this.

In 2012, the Secretary-General, Ban Ki-moon, announced the Zero Hunger Challenge in which we wanted to ensure that we ended hunger, eliminated all forms of malnutrition, and we enabled inclusive sustainable food systems for the entire world. And so framed in five challenges was really this embodiment that last year we moved forward as the Sustainable Development Goals which most of these five challenges are reflected in the 17 Sustainable Development Goals. I would add actually the third goal around good health, especially as we look at the role of legumes in reducing non-communicable diseases like type 2 diabetes. But you can see that the footprint of legumes touches not just Sustainable Development Goals 1 and 2 around poverty and ending hunger, but in many other aspects of our development agenda, including partnerships, the last goal, we often don't talk about goal 17, but I think this symposium is a reflection of that.

So, why pulses? Well, pulses or grain legumes for that matter, they are very important for food security, they are definitely important for improved nutrition and health, for our livelihoods as a diverse source of income, for smallholder farmers particularly in the developing world, and an aspect of grain legumes that's not

considered, but critically important, is their contribution to improving soil health by fixing nitrogen and improving the biological health of our soils.

So, as was pointed out, 2016 is the International Year of Pulses, and creating awareness amongst consumers, policymakers, researchers, and of course, farmers themselves of the importance of pulses and sustainable food systems. So, the objectives for the International Year of Pulses or grain legumes is to promote the value in utilization of pulses throughout our food systems, raise awareness of their benefits, especially in the context of sustainable agriculture and nutrition, and encourage the connection to further global production. Grain legumes are very important within a cropping system, and that's often underestimated or undervalued. Enhanced research – the research on grain legumes versus the three main food cereals is very meager compared to the demand. Advocate for better utilization in crops, especially in their rotation and also in trade through the private sector.

So, just to highlight within the global research agenda for pulses, compared to cereals, there is approximately only $175 million per annum for 13 pulses. When we compare this to maize, this is roughly one-fifth the maize global budget for research, public and private sector. So, clearly, for one crop maize, which is a very important crop around the world, these pulses are definitely, if you will, "neglected" in comparison.

So, this year for the International Year of Pulses, a 10-year research strategy is being formulated during this month actually, in November in Rome, to look at what are the different components of research that need to be addressed along the whole continuum of research from basic discovery through to delivery of improved varieties and agronomic practices to realize the full potential of grain legumes over the next decade.

I think another area that we often underappreciate is the role of sustainable water management in the context of sustainable food systems and the role that pulses play or grain legumes play within that. Water is a commodity that we don't value in our current food system, but we need to as there is increased demand for water, which currently consumes about 70% for agriculture, but as we seek increased urbanization, the demand for water is going to grow. And as a result, we need to be thinking about the drops of water per gram of protein produced, and here I think we can make a very strong statement for the importance of grain legumes in diversifying our food system to improved human nutrition, that improve nutrition, especially during the first thousand days of life will lead to increased cognitive ability of future populations, and that in turn will empower society to realize the Sustainable Development Goals.

So, the role of legumes and better use of our water resources for sustainable food systems also needs to be emphasized.

ICRISAT is focused on the semi-arid tropics of Asia and Africa, and this ecology covers roughly 6.5 million square kilometers, including 55 countries, in which 2 billion people of our current 7.3 billion are homed or housed, but it also is a concentration for poverty and malnutrition, and here, grain legumes can play a critical role, both in addressing poverty through structured markets and malnutrition by offering higher value and more nutritious food that restores degraded soils that are common in these ecologies. So, at ICRISAT, we believe that all people have the right to nutritious food and better livelihoods, and grain legumes is a key vehicle for us to realize and address poverty, hunger, malnutrition, and environmental degradation.

For us to really unlock the full potential of grain legumes, we need to take a holistic approach of defining what are the market opportunities for grain legumes, so that's the analysis of the problem, and then looking at how grain legumes contribute to soil and water management so that we have sustainable food systems that allow us to live within the ecological boundaries of our planet, looking at crop improvement, currently we use about 1% of the genetic diversity of our grain legumes. So, clearly, there is a huge opportunity for us to unlock genetic diversity in service of improving nutrition, productivity, and profitability for these crops. We need seed systems that actually deliver these improved varieties into the hands of farmers. This is another area for grain legumes that has been underinvested traditionally.

We need to appreciate how grain legumes fit within a farming system and to ensure farmers have the knowledge to integrate legumes into a mixed farming system that includes cereals, livestock, fish, and agroforestry.

Markets increasingly are going to become important for us to address the issue of poverty, and having structured markets that have grades and standards for our grain legumes, so farmers can actually access the full value of their produce will be very important.

As was mentioned by Director General Saigo, the role of the private sector in processing grain legumes so that more value is captured by farmers locally is very important, and of course, the whole mandate of the International Year of Pulses around creating market opportunities for these commodities is critical as consumers become aware of not just the nutritional benefits of grain legumes but also their important role in sustaining the environment and environmental services that they offer within Agrifood Systems.

So, for research organization like ICRISAT, it's part of the CGIAR, the Consultative Group for International Agricultural Research, we have mobilized a group of research centers that includes CIAT focused on common bean, IITA that's focused on cowpea and soybean, ICARDA that's focused on faba bean and lentils, and ICRISAT that's focused on chickpea, pigeonpea, and groundnuts, to look at not just the discovery of basic science, and you will see the genomics work that we have done through this consortium, but also the science of delivery. As Dr. Norman Borlaug said, "Our research doesn't count until it reaches a farmer's field." So, this is an area where we have an interconnected world that is accelerated our basic science at astonishing rates, and yet, we often underestimate the science of delivery and adoption to make sure that our science is translated to adoption in farmers' fields.

So, as I go through this talk, I want to highlight some of these areas such as demand-driven innovation or participatory approaches that provide rapid feedback for our research agenda to make sure our research is focused on the needs of farmers and of value chain actors to ensure adoption, the anthropology of adoption recognizing that not all farmers are equal or the same or have the same aspirations and that we have to take this into consideration as we design how we communicate our science to a wide range of stakeholders.

The whole area of scaling up technology is becoming very exciting, especially with the use of mobile technology and our ability to offer timely targeted interventions that are personalized to the needs of farmers that would incentivize them to adopt new technologies.

The role of capacity building, and this university is really focused on building capacity and educating the leaders of the future, but we need the same at the local level with farmers, lead farmers, and how do we empower them to serve their communities and empower their fellow farmers to realize their full economic potential and feed into modern food systems.

I think one area in science that we don't do very well in and that is the soft skills of science that allow scientists to engage with policymakers, with farmers, so that we can actually create a movement, an innovation movement and to this end, especially our young career scientists and empowering with the skills to communicate and convince is very important.

And finally what I would call pragmatic policies for prosperity. Quite often in policy dialogs, we overanalyze problems at the expense of acting on implementing urgent solutions, and so I was very encouraged by the comments of Director General Saigo, the urgency of this agenda that we are discussing today, in order to offer sustainable, equitable solutions that will lead to not only social sustainability, economic sustainability, but also environmental sustainability as we deliver on the SDGs.

So, why grain legumes and considering them as a smart food? At ICRISAT, we consider these commodities good for you as consumers because they offer affordable sources of protein, they have low fat and high fiber, which can lead to improved health of the consumer over time, especially addressing non-communicable diseases like obesity and type 2 diabetes. They are good for the planet because they fix atmospheric nitrogen and convert it into a usable form of nitrogen for all crops. They are also very high in the use of water for generating protein and micronutrients, and in so doing they improve soil health by, of course, fixing nitrogen. But they are also good for smallholder farmers because they offer diversified sources of income. In the case of Africa, intercropping of sorghum or maize with pigeonpea offers farmers two sources of income, the cereal crop which is first harvested but after the harvest of the cereal for grain and fodder, pigeonpea then flourishes as an intercrop that offers a second source of income, improves the soil health for smallholder farmers, and in years of drought is a fallback to ensure at least some income is realized on the farm even in drought.

Pulses are also a smart food in that they generally consume less water and are very climate hardy. They are climate smart commodities, especially crops like cowpea, chickpea, pigeonpea, extremely resilient to high temperatures and low water. And so if we look at the water footprint of pulses versus beef, there is a dramatic reduction in the use of liters of water to produce a kilo of commodity that are enriched in protein.

Pulses are grown around the world in different ecologies. As I mentioned, they are particularly important in drier ecologies where there are suited to take on the harsh production environments, and I will show later in the case of India how chickpea is actually shifted from an irrigated system into a rainfed dry production system. But you can see that the grain legumes are grown around the world in different commodities, with India actually being the largest producer but also the largest consumer of grain legumes or pulses in the world.

But the grain legumes represent over a $50 billion market. Now, while this is relatively small compared to the rice or maize or wheat markets, they play a critical role across all continents in providing nutritious food and fixing nitrogen. And so here is the estimated value of legumes that includes the nitrogen input into the soil through nitrogen fixation.

Pulse production as a result of these benefits is on the rise. Productivity has increased faster than area expansion, but still we cannot relax because we are looking at a nitrogen deficit, especially for core segment of society, and so grain legumes are going to actually have to increase both in their area, especially by being cultivated in new ecologies or in rotation with cereal crops, but also in their productivity, and the drive to increase productivity is going to have to be realized by increasing their profitability for smallholder farmers in particular. So, I am going to speak to some of that a little bit later on.

Where we see the increased production? We see most of that in response to market opportunities in the developed world; Australia and Canada, as major export crops to Asian countries that are deficit in the production of pulses, especially South Asia, India in particular.

When we look at the yield of pulses in different countries, we see this response to market opportunities with Canada, United States, and China being the leaders around productivity of pulses, whereas countries in sub-Saharan Africa that don't have a strong market signal and infrastructure to support its realization show much lower productivity of pulses, under 500 kilos per hectare in the case of Niger, Mozambique, Burkina Faso. So, clearly, there is a tremendous opportunity to increase the productivity of smallholder farmers in sub-Saharan Africa, and this is an area that ICRISAT and the CGIAR partners along with national programs are working in concert to address.

When we see the countries where growth is taking place, we see emerging economies like Myanmar responding to this opportunity as well as Nigeria and Kenya, and so there is clearly a signal and, if you will, optimism that we can respond to these market opportunities in developing countries to markets that are being generated as consumers become increasingly aware and interested in consuming pulses in order for sustainable food systems.

If we see where the global trade imbalance is taking place, you can see that North America, Canada as being a very large exporter, especially of chickpea and lentils. Australia is a major exporter of chickpea as well. But you see where the deficit is being realized in South Asia at 4.5%, especially in the case of India. So, the Prime Minister's office in India has taken notice and is being very pragmatic in looking at how can India become pulse self-sufficient over the next 5 years, and ICRISAT and the Indian Institute of Pulse Research along with many other partners are coming together to realize that vision.

So, to do this, we really need to take a country-specific approach to unlocking the full potential of grain legumes around the world, because we need to make sure that it's context-specific, that we understand the culture, as well as the capacity of the whole agri-food value chain for pulses to realize their full potential. And if we do this, we can actually jump over what we call the death valley of research for development of moving from small pilot stage projects into large scale, large impact programs that reach millions of farmers. In order to do this, we have to think about our science in a slightly different way, the science of delivery which we learn by listening to our key stakeholders, adapting our science, and creating ownership of the whole process of achieving pulse self-sufficiency around the planet. And to support this, we need pragmatic policies from governments, especially the willingness to invest in longer term research for development in pulses which have traditionally been underinvested.

So, in the case of India, I mentioned the Prime Minister's office has been taking up this challenge and looking at very targeted strategies to achieve pulse self-sufficiency. One of the things that has really undermined pulse production has been the volatility in prices. Farmers are interested in responding to markets but markets that are predictable. So, in the case of India, there has been predictable rise in wheat markets because of the government's procurement policy for these commodities. And now recently, the Government of India has put in place the Minimum Support Price for the pulses. They have offered a price signal to smallholder farmers to increase their production. And so this year there has been an increase of approximately 2 million hectares in pulse production to respond to that. But still we see price volatility because the infrastructure required to offtake and store that surplus production is not currently in place. And this is where we need to bring the public and the private sectors together to support.

So, the key constraints that we are addressing in pulse production in India, first is the low investment by farmers to increase their productivity because historically there hasn't been a price signal. Secondly, pulses because they are nutritious for us, they are also nutritious to disease and insects, and so protecting legumes biotic stresses is very important, but also they are exposed to harsh production environments, as I mentioned, often grown in rainfed environments that have high temperatures. And so, developing varieties that are climate smart is very important.

Also, they tend to be grown on marginal lands where soil has been degraded. Now, they contribute to the restoration of soils, but the soils in which they are cultivated are often less productive. And increasingly for all of agriculture but specially pulses, labor costs are major consideration, and so we have to think about mechanization as a way to reduce the cost of production for all of our crops but especially grain legumes.

So, in enhancing pulse production, we really need to see how we can close the yield gap, which is significant for many countries. You saw the wide range in productivity from over 2 tonnes in Canada to less than 500 kilos in the case of Niger. We have to close that yield gap through the intervention of not just improved varieties but also improved agronomic practices and the communication of knowledge to realize their full potential.

We also see an opportunity to expand the area of pulses as part of a rotation with cereal systems. And one of the big opportunities in the case of India is in the rice fallows where approximately 12 million hectares can be utilized that's currently only used for open grazing because of the lack of protection for cultivation in these areas after rice.

We also need to look at the diversification of existing crops systems, of rice, wheat, and other commodities, especially in Africa where we are seeing an emerging trend of maize intercropped with legumes, especially pigeonpea and cowpea.

We also have to look at the rainy fallows and how do we better use water harvesting techniques to expand the productivity of pulses, and something that we often don't consider the losses that occur after harvest, and so postharvest losses of legumes is very high.

So, this takes me to this slide around improving value chain efficiency. In our traditional system now, our agricultural value chains are very long and in every node in that value chain, farmers and consumers are losing value. What we can do now with technology, especially mobile phone technology, is actually compress that value chain and now we are using mobile phones to support farmers-producers organizations sell directly to retailers. And so we are taking out four or five nodes in the traditional value chains and compressing that value to the farmer and to the consumer and offering a higher unit price for farmers and a higher quality product at a lower price to consumers. So, this is really the new era of opportunity for unlocking grain legume value chains in both developed and developing countries.

For research for grain legumes, we are really seeing a need for increasing plant productivity by looking at the plant architecture that supports mechanization. We are looking at reduced use of labor requirement such as weeding through herbicide tolerance. I have already mentioned the need for developing varieties that have a tolerance to higher temperature and can produce a bountiful crop with less water.

Hybrid technology is very important. It's what's driven the maize seed sector and a large investment in maize. What does that look like for pulses or grain legumes? ICRISAT with its partners has developed hybrid pigeonpea and these products are now being commercialized in India and being converted and adapted into African markets as well. We are now gaining insights into the molecular level of hybrid technology through

cytoplasmic male sterility and looking at how we can convert and adapt this technology to the other grain legumes which will be very important for future seed systems.

And we also need to look at how do we compress the time to a viable harvest as we adapt to climate change and increase the intensification of our farming systems around the planet. So, reduced maturity is a very important research thrust.

Another area is our nonrenewable resources like phosphorous and how do we increase the phosphorus use efficiency of our legume crops. This is especially important for common bean, for example, that its production is very much dependent on phosphorus availability.

As I mentioned, we haven't utilized very much of our genetic diversity, the wealth of genetic diversity we have in our gene banks. We really need to exploit this more as well as to look at artificial diversity that we can create, especially with the new genome editing like CRISPR-Cas9 technology that's available.

Protein enhancement and biofortification are other areas where we have invested but need to invest more in our grain legumes. Refining the agronomic practices that go along with improved varieties is an area that we have underinvested. We tend to work in isolation as agronomists and as breeders and social scientists, and bringing these disciplines together to unlock the full potential, especially in areas that have been underexploited like rice fallows, is going to be critically important for the future.

We have to modernize our breeding programs. This past week at ICRISAT we have actually brought together most of the CGIAR centers and many of our lead national programs like the Indian Council of Agricultural Research to look at how do we use forward breeding tools to accelerate genetic gain in our crop improvement programs globally.

So, one of the successes that illustrate how we can respond to climate change and increase grain legume productivity is chickpea in India. And so from 1970 through to 2010, you can see the red line showing the increase in area of chickpea production in the central zone of India, where we moved from an irrigated system in the north to a largely rainfed system in the central zone that's exposed to high temperature, very harsh production environment. We have basically maintained the productivity as we moved into this harsher transition zone. So, while the productivity per unit hectare has not gone up dramatically for chickpea, chickpea has adapted itself now into a much harsher production environment, and I would submit, has now become a climate smart crop in response to this. And it's been science that's enabled this to make this transition.

Pigeonpea production is another important crop that's responding to market signals, and you can see the volatility on the blue line in the north, largely South Asia or India, but the red line below is showing tremendous encouragement as we see that production of pigeonpea in sub-Saharan Africa increasing steadily and dramatically in response to market opportunities. This is very important because pigeonpea is now being introduced as an intercrop with cereals in sub-Saharan Africa to increase not just profitability but also sustainable productivity through enhancing soil health. And we can see that in Africa, countries like Tanzania, Mozambique have dramatically increased the area of pigeonpea production in response to these market opportunities in Asia. Our challenge, though, is how do we ensure that these crops are consumed also in sub-Saharan Africa where malnutrition is also very acute. So, I think this is a challenge for us as a research community to look at partnerships with the private sector to capture more value addition and convenience of pulses for local consumption in sub-Saharan Africa.

So, some of the drivers of our success in sub-Saharan Africa have been around high yielding, disease-resistant varieties that are part of an integrated crop management system, especially for women who have been the ones benefiting most especially from the early stages by producing seed and sharing seed with other women farmers, especially for pigeonpea. Integrating with large regional traders has been very important, and the role of NGOs and government in providing innovative incentives for those seed systems to really flourish and for the expansion of pigeonpea to be realized. And also, strong participation of donors has been a key driver, especially the Bill and Melinda Gates Foundation and Irish Aid.

So, what does the future look like? I think it looks very bright for pulses, because pulses of now through this genomics revolution have enabled us to sequence all of the grain legumes and to now really unlock their full genetic potential through the use of these genetic maps. And so ICRISAT and its partners have now sequenced and now is in the process of resequencing these crops. In the case of the chickpea genome as well as the

pigeonpea genome, this has been enabled through international consortium across the globe, working in concert to unlock the genetic code for these crops. And by so doing we are going to be able to now tap into the wealth of genetic diversity that we have. One case and point is as you are probably aware, the rice community has re-sequenced 3000 rice varieties from around the world, and now ICRISAT and its partners has done the same for chickpea where we have re-sequenced 3000 chickpea accessions both from the gene bank as well as from elite lines from around the planet to now understand the key phenotypic traits that include the physiological basis for drought tolerance, for heat tolerance, for salinity tolerance, for disease resistance such as Ascochyta blight as well as for insect resistance, and to test these 3000 lines in six different production environments, and we have this data now for 2 years, and bringing all of this data together, we can make much more strategic recommendations on unique alleles that can address these major production constraints.

Likewise we have done the same for pigeonpea for 20 different traits, including the hybrid technology, looking at genetic diversity and how we unlock it to increase profitability for smallholder farmers. One early example of this has been Ascochyta blight for chickpea and using molecular markers now to integrate this important production constraint to agronomically elite varieties and accelerating their release into national systems.

Transgenics is another very important area. Apart from the challenges we have with socializing the use of transgenic, I think if we can turn this around and communicate to the general public the nutritional importance of these commodities and the need to use transgenic tools strategically to improve the nutritional value of these commodities is very important, including genome editing, I mentioned CRISPR-Cas9 technology, and we are looking at how we can unlock artificial genetic diversity to improve nutritional quality of grain legumes and increase their profitability for smallholder farmers.

In closing, I would just like to highlight our collaboration that ICRISAT has had with JIRCAS over the years. We have had a very rich collaboration, especially in the area of soil science as we unlock, as I pointed out, the importance of intercropping cereals with grain legumes to improve sustainable food systems, especially as we look at soil nutrition. And so our rich research history of 15 years looking at the interaction of legumes, especially pigeonpea, for increasing the availability of phosphorus and nitrogen in African cropping systems was very important.

Lot of this work was then translated into improving soil health in West Africa through our partnership with JIRCAS, and more recently looking at sorghum biological nitrogen inhibition. Nitrification is a very important process that actually converts ammonium into nitrite, and once it's in nitrite, it's subject to leaching and we lose about 70% of our fertilizer because of this process.

And so looking at native alleles in sorghum that impede this conversion of ammonium to nitrite offers us opportunities to genetically engineer and inhibit this process so that more of our nitrogen applied to crops is realized in increased productivity and reduced nitrification or eutrophication of our water waste.

So, in closing, I would like to leave you with a few highlights. The International Year of Pulses 2016 was extremely timely, and I agree with the sponsors it should be broadened to include grain legumes so that soybean and groundnut, two commercially very important commodities are also included. We have used this platform, though, to create awareness among consumers of the critical role pulses or grain legumes play in nutritional security and in making sure that we live within the ecological boundaries of our planet. We need to create increased demand for pulses by ensuring that we dampen price volatility and we put in place the market value chains that allow for their efficient conversion into economic opportunity for smallholder farmers and to affordable consumption for consumers. We need research to focus on profitability for farmers. If we fail to do that, we will fail to realize the full potential of these commodities long-term and to incentivize youth to come back into agriculture, especially pulse production.

At a global level, we need to increase the funding to grain legumes research to make sure that we provide an enabling environment as well as the research required to rise to the challenge of nutritional self-sufficiency around the planet. But to do this, we also need to put in place appropriate grades and standards that are lacking to support global trade. At a national level, we need to be looking at integrated approaches that include genetic improvement of new varieties but also management of those varieties within an integrated farming system and pragmatic policies that allow them to unlock their full potential. If we do this, we will increase domestic production, we will reduce postharvest losses, and we will increase the value of these crops to smallholder farmers and rural communities but also make them more accessible, especially to rural poor consumers who currently do not have good access to nutrition. We have to, in the process, attract the private sector to make

appropriate investments along these value chains to make this a reality. And finally, at the local level, we need to look at mechanization to increase the profitability for smallholder farmers, knowledge exchange that allows them to harness innovation and to increase their profitability, and to make sure that value chains are equitable and in service of smallholder farmers to realize their full economic potential, especially for women and youth so that we can deliver on the Sustainable Development Goals.

So, with this, onward with urgency, the agenda is critically important but we need to work in concert to realize this urgent agenda of achieving nutritional security through grain legumes. Thank you very much.

Chair Doi
Thank you Dr. Bergvinson, I am very happy to know that ICRISAT has not forgotten the non-pulses legumes, and I am very impressed that your India project is stressed about the cost of the labor is an important point and our researchers have never forgotten that point. Again, let's give Dr. Bergvinson a round of applause for his excellent presentation.