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PERSPECTIVES

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Front cover art:
Logo of IFLRC-VII

EDITORIAL

Greetings! We hope you enjoy this snapshot of the International Food Legume Research Conference held in Marrakech, Morocco in May 2018. The conference was scientifically and culturally rich. It provided a venue for creative interactions among participants. Many thanks to the local organizing committee, the scientific committee, all participants, and the people of Morocco for helping to make the conference memorable. Best wishes, Tom Warkentin

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IFLRC-VII emphasized on partnership to deliver innovative solutions in food legumes

The 7th International Food Legumes Research Conference (IFLRC-VII), held in Marrakesh, Morocco on 6-8 May 2018, has brought together 320 food legume experts, students and policy makers from more than 42 countries to explore innovative solutions that extend the benefits of climate-smart food legume crops to various actors along the value chain. The Conference hosted by ICARDA and INRA and sponsored by FAO, GLDC, GRDC, UCOSEM, SPG, ICRISAT and ICARDA provided a platform for legumes researchers to promote international collaboration on basic, applied and strategic research to meet the current and future challenges associated with these crops. Mr. Aly Abousabaa, director general of ICARDA emphasized on to maximize the economic, environmental, and nutritional benefits of food legumes for smallholder farmers. Recent advances in plant science offer advanced technologies which can successfully be applied to develop resilient legume varieties. Some of the impressive stories of innovative tools being applied to develop climate resilient varieties include machine harvestable multi-stress resistant chickpeas, heat-tolerant bean varieties, short-duration lentils for rice fallows, orobanche tolerant faba beans for North Africa, hybrid pigeonpea, and extra-short duration mungbean for intensification and diversification of cereal based production systems in South Asia. As Peter Carberry, Director of the CGIAR Research Program on Grain Legumes and Dryland Cereals (GLDC) argued, research needs to go beyond a simple focus on yield to also consider how it can eradicate poverty and improve rural livelihood. He emphasized on the good partnerships as key to success to deliver the innovative solutions in food legumes. One potential approach, suggested Pramod Joshi of the International Food Policy Research Institute (IFPRI), was enhancing the efficiency of value chains so that farmers gain a better share of income. Another was strengthening seed systems – ensuring that improved climate-resilient and higher-yielding legume varieties were disseminated more effectively and efficiently to farmers. Emphasis was given on the demand-driven breeding strategies that adopt a highly localized approach – introducing new varieties that are adapted to local conditions and reflect customer needs. A focus on yield alone may also overlook the importance of increasing access to healthy and nutritious food. Biofortification of legumes could ensure that legume varieties are packed with Iron and Zinc to address this form of malnutrition. Rajeev Varshney of ICRISAT emphasized on mainstreaming genomics tools in breeding program to accelerate the genetic gain in food legume crops. Prof. Siddique emphasized on breeding and selection of phosphorus efficient genotypes utilizing variation existing in the diverse phosphorus-acquisition traits in legumes.

How do we build on successes in legume research and transform production systems so that new varieties can have impact – raising farmer incomes and enhancing global food and nutritional security? The question, posed at the Conference, gives an indication of the critical challenge now facing the research community dedicated to the improvement of these climate-smart crops. The Conference demonstrated the huge strides advanced technologies had made in recent years – developing varieties that were high-yielding, disease-resistant and heat- and drought-tolerant. However, these successes can only provide part of the effort to transform legume production. Summarizing the discussions over the three-day event, Jacques Wery, Deputy Director General for Research at ICARDA, called for a more integrated and holistic approach that goes beyond a single focus on yield and performance. Future efforts, he suggested, should take into consideration adoption constraints and many factors that inform farmer decisions. Strengthening seed systems is critical and participatory models which involve farmers in seed selection – like those pioneered by ICARDA and ICRISAT in Ethiopia – offer potentially useful frameworks. Additional considerations include: the ecosystem services that legumes provide and the role these plants can play in climate change adaptation; breeding resistance to new pests and disease that emerge with shifting weather patterns; and adopting south-south and south-north collaborations that generate new innovations and approaches.

Shiv Kumar Agrawal, ICARDA, Morocco

Group photo of the IFLRC VII Conference participants at the Palais des Congrès, Marrakesh, Morocco

An Overview of the IFLRC VII

Jacques Wery (ICARDA) and Peter Carberry (ICRISAT)

Over the many presentations and posters, the 7th edition of the International Food Legume Research Conference has shown significant achievements across the wide range of disciplines and regions of the globe. We saw significant changes in several parts of the world both in the consumption and in the production with expanding areas both in developed and developing economies. We heard many success stories on plant breeding for land productivity, grain quality (including biofortification) and resilience to pests and diseases in all our pulses. We also learnt how important it is to design these varieties and develop them in the context of farming systems, with an efficient seed system, proper policies and market organisation.

Beyond this pluri-disciplinary approach of Research For Development which is the DNA of IFLRC, we also had clear demonstration of the potential of innovative scientific approach to drive future breakthrough in pulse development: advanced suites of genotyping and phenotyping tools served by biostatistics and data management, fast trait measurements for heat and drought stress in field conditions, scenario analysis based on simulation models (economic, LCA, sustainability and resilience frameworks)…

Presentations and discussions also raised several issues which are emerging in research programs: (i) nutritional quality of pulses, how it is influenced by genetic and by growing conditions, how it contributes to nutritional security and health, how it is recognized or not by the market and the policy makers; (ii) the need to go beyond land productivity and integrate the provision of ecosystems services by pulses as well their potential role in climate change adaptation and mitigation; (iii) the need to go beyond breeding for pest and diseases (including the emerging ones) into Integrated Pest Management at cropping systems and landscape levels.

Opening session at IFLRC VII Conference

We also found some missing parts on issues raised during the introductory talks but not taken into account into research studies: (i) in the regions where pulses are under development we have a lack of clear demonstration of their role on poverty alleviation, nutritional security and sustainable development; (ii) the search for nutritional security is a chance for pulses but are we breeding and designing nutritious crops and for which type of diet and consumers? We need more food and nutrition sciences studies on pulses from which both consumers and farmers benefit from added-value products; (iii) we need socio-economic assessment of innovation driven by pulses, lock-in analysis and value-chains studies, studies on transition pathways of agri-food systems supported by pulses and studies on policies to support these transitions; (iv) many farmers of the world, especially in the dry regions, operate under a risky environment with limited safety nets such a credit. Any improved package based on pulses (variety x management x rotation) should also come with an analysis of the risk to close the yield gap and measures to mitigate this risk.

In order to see more of this at the next IFLR conference in Nairobi (Kenya) during 2022 we need to change the way we do research on pulses:

(i) <u>Think legumes and cereals together:</u> cereals are and will remain the pillar of the food and feed diets across the world. We should therefore design pulses crops not for themselves but for what they bring to soils, farms and diets. On the other hand, without legumes, there will be no breakthrough toward climate-smart cereal production, in terms of nitrogen, water-use efficiency, soil quality, pest, diseases and weed management.

Poster session at IFLRC VII Conference

(ii) <u>Change our metrics</u>: yield, as a measurement of land use efficiency, is worth to measure, but is less and less relevant to address labour use efficiency, food production, farmers income or ecosystems services. Closing the yield gap OF pulse is worth to consider but may not be the best route to close the country production gaps compared to increased production area dedicated to pulses in crop rotations. This may in return help to close the yield gap of cereals WITH pulses in many parts of the world where cereal monocropping is expanding supported by input use and mechanisation.

(iii) <u>Upscale our metrics</u>: the implication of the two items above is that pulses performances and impacts should be assessed at crop rotation level and beyond (household, landscape, country) instead than at crop and yearly levels in most research presented at this conference.

This leads to a message for ourselves but also to donors and stakeholders: we need to change the way we manage research for development on pulses:

(i) there will be no escape from the diversity of pulses if we want to cover the wide diversity of biophysical and socio-economic conditions of farming systems and food systems that pulses can sustain.

(ii) research will have limited impact if we do not create early convergence of knowledge and technologies with policies and institutions on pulse innovations.

(iii) research on pulses is suffering from a lack of investment across the world, but there is a high potential for South-South and South-North research collaboration as well as Public-Private for knowledge sharing and innovation in the agrifood systems driven by pulses.

Between this IFLRC conference and the next one there is a window of opportunity to organize ourselves as a unique community of practice to implement these ideas. The CGIAR and its centers working on pulses (ICRISAT, ICARDA, IITA and CIAT) are willing to support this momentum around the globe.

Session 1: Global Food Legumes Scenario

Production, consumption and trade

Chaired by Aly Abousabaa[1]

This session consisted of four presentations covering topics related to global pulse production, consumption and trade.

Peter Carberry (ICRISAT) described a global research initiative on pulse crops being undertaken within the CGIAR network. The initiative is aimed at benefitting small holder farmers in a warming climate. Approaches being used involve plant breeding, genetic resources and big data. One project is focused on breeding program management to accelerate genetic gain. Priority crops for the CGIAR were listed as: sorghum, ground nut, soybean, cowpea, pearl millet, pigeon pea, chickpea, finger millet and lentil. CGIAR is collaborating with multinational seed companies as well as NGOs.

Promod Joshi (IFPRI) indicated that global demand for pulse crops has increased from 42 million tonnes in 1980 to 81 million tonnes in 2016. However, per capita consumption has decreased from 10 kg per year in 1961 to 7 kg per year in 2013. In India, 69% of pulse production is used directly as food, 20% in value added products including snacks, and 7% as seed. Consumption of pulses is expected to rise if incomes rise. The rate of increase in global pulse crop yields has lagged badly behind cereals, i.e., 630 kg/ha in 1960 to 1000 kg/ha currently for pulses, compared to 1500 kg/ha in 1960 for cereals to 4000 kg/ha currently. Canada has >2000 kg/ha pulse yields, much greater than that of developing countries. India has a large gap in pulse crop yields between research trials and that achieved by farmers. The suspected reasons are a weak seed sector, poor seed quality, and non-optimised management practices. Pulse crops make up a substantial proportion of the annually cropped land in Myanmar (36%), Nigeria (31%), Kenya (26%), and India (18%). The self-sufficiency ratio for pulses differs widely among regions, i.e., North America (3.0), Europe (1.0), and Asia (0.9). Pulse trade has increased over the past two decades with a current volume of approximately 14 million tonnes per annum, with Canada, Myanmar, USA, Australia, and China making up 75% of the total. Key importers India, China, Bangladesh, Pakistan, and Egypt make up 62% of the total. Indian success stories with pulses include new varieties, minimum support prices and seed hubs for distribution.

Calles Teodardo (FAO) highlighted the successes of International Year of Pulses (2016). He encouraged increased investments in pulse crop breeding and management in order to improve yields and to advance under-utilized species.

Kumara Deevi (ICRISAT) provided a South Asian and African outlook on pulse crops. Goals of pulse improvement include reduction in poverty, increase in food security, increase in nutrition, and increase in soil health. Chickpea yields have increased in Ethiopia and India over the past two decades. Cowpea and pigeon pea yields remains low. Lentil yields have increased in Ethiopia, Nepal, Turkey and India.

Peter Carberry (ICRISAT)

[1] ICARDA, Rabat, Morocco

Session 2: Marketing, Promotion and Policies

Chaired by Pramod Joshi[1] and Brent Kaiser[2]

Plenary Session 2 provided a general insight into the challenges (past, present and future) in the marketing and promotion of legume seed commodities and their importance to both human and animal diets. A significant component of the session was focused on restrictions to technology adoption particularly by smallholder farmers.

[1] IFPRI, New Delhi, India
[2] The University of Sydney, Sydney, Australia

The first presentation was by keynote speaker **Frederic Muel** (Terres Inova, France) and expert in pulse linked supply chains related to European distribution and demand. His lecture titled 'A new era for an old challenge: legume supported food and feed chains in Europe' highlighted the continuing issue of under representation of pulses in European cropping systems and their ability to access a larger share of land availability from other activities including cereal production. The EU is still predominantly a pulse importer, where market opportunities and capability within Europe appear to be considering changes to this scenario based on quality requirements and self-sufficiency.

The next speaker was **Zeudie Bishaw** (ICARDA) with his lecture titled 'Chickpea seed system and farmers' commercial behaviour in seed: actors, challenges and implications.' The talk highlighted the challenges within Ethiopia small-lot farmers in delivering outcomes of advanced breeding initiatives where certified and improved seed supplies are not readily adopted. Traditional activities tend to see growers relying on their own seed supplies for planting rather than buying new seed or even buying certified advanced seed. Older varieties predominate in the field and there is a need to develop policies or incentivize change to see the introduction of modern pulse lines into production.

Chris Ojiewo (ICRISAT). Credits of the photo: Esther Njuguna (ICRISAT)

The third speaker was **Aziz Fadlaoui** (INRA), the title of his talk 'What strategy for the revitalization of the Moroccan legumes sector? The presentation highlighted a general call on the need for revitalization of the Moroccan legume seed sector. Current evidence suggested the Moroccan legume sector is stagnant and not expanding. Reviews were completed to explore what are the current drivers for supply and demand and where inefficiencies lie. In general, the reviews have suggested production practices remain traditional with limited mechanization and strategy. The rise of pulse imports into Morocco suggested policy failures. A Green Morocco plan has been developed to focus attention on production, quality, education and profitability targets for the industry.

Chris Ojiewo (ICRISAT) delivered a lecture titled 'Legume seed systems for better livelihoods of smallholder farmers: lessons from TL projects.' This continued the discussion of Zeudie Bishaw on the inability to readily deliver outcomes from germplasm improvement programs to smallholder producers. Seed supply and delivery mechanisms are limited by investments mainly due to the scale and nature of seed distribution business that will deliver seed to smallholder producers. Chris reported on efforts of ICRISAT and others to develop certified seeds and facilitate their access through extensive extension programs. Success has come from the bundling of seed with other supply channels that reach the grower directly. Continuing in this theme, **Srinivas Tavva** (ICARDA) presented a paper titled 'Role of extrinsic and intrinsic factors in the uptake of best agricultural practices among food legume farmers of Afghanistan.' The paper explored the various roadblocks encountered in the adoption of agricultural innovation. Data was presented based on surveys of Afghanistan farmers response to agricultural innovation related to mung bean chickpea and lentil. Adoption rates were linked to location and different extrinsic and intrinsic variable influenced the rate of technology adaption.

The last speaker was **Dawit Alemu** (BENEFIT) who presented a paper on the 'Trends and determinants of the adoption of improved chickpea varieties in Ethiopia.' The outcomes of the survey indicated roughly a 48% non-adoption rate with the remainder adopting to new lines as they are released. The study identified concentration of varieties used across both Desi and Kabuli lines. Key outcomes indicate the rate of adoption is linked to dependency ratio, the number of plots managed, livestock ownership, market access and social capital linked to cooperative memberships.

Session 3: Nutritional quality, post-harvest management and value addition

Chaired by Fernand Lambein[1] and Ramakrishna M Nair[2]

This session consisted of six presentations covering topics related to pulse crop nutritional quality as related to human health

Dil Thavarajah (USA) emphasized food security for all people. She outlined the challenges of malnutrition affecting nearly 800 million people, and micronutrient deficiencies. In contrast, obesity is a key problem in western countries. WHO targets by 2025 include reducing stunting (often related to a zinc deficiency) by 40%, reducing anaemia (often related to an iron deficiency) by 50%, reducing the prevalence of low birth weight, and a levelling off of the proportion of people who are overweight. Some carbohydrate types in pulses have pre-biotic effects and their consumption can be a tool to combat obesity.

Ashutosh Sarker (ICARDA) indicated that 2 billion people suffer from 'hidden hunger' caused by a lack of one or more micro-nutrients in their diet. Approaches that have been suggested internationally include diversifying diets, fortification, and supplements, however, all of these tend to be expensive. Biofortification is an approach that involves breeding cultivars with greater nutrient density which could be quite sustainable. In a survey of 2200 lentil accessions, Ashutosh observed a range in seed iron concentration from 34-172 ppm and a range in seed zinc concentration from 22-103 ppm. This diversity can be utilized in biofortification breeding. His program has released biofortified lentil cultivars with 75 ppm iron and 50 ppm zinc. Future research will elucidate QTLs, markers, and candidate genes related to improved mineral concentration, and reducing phytate concentration. Another branch of research will explore agronomic practices including adding micronutrient fertilizers.

[1] Ghent University, Ghent, Belgium
[2] World Vegetable Center, Patancheru, India

Monica Baga (Canada) described a recombinant inbred line (RIL) population developed by ICRISAT arising from a cross between a low protein concentration (19%) parent and a high protein concentration (26%) parent. The RILs were phenotyped over four station-years and genotyped using genotyping-by-sequencing. QTLs were identified related to seed weight, seed shape, flower colour, and seed concentration of crude protein and starch. QTLs were clustered on LG1 and LG3.

Tom Warkentin (Canada) described research aimed at enhancing mineral concentration and bioavailability in pea. In pea recombinant inbred line population PR-02, 5 QTLs were detected for Fe concentration explaining from 10-27% of the phenotypic variation, and 4 QTLs for Zn explaining from 7-26%, while in PR-07, 7 QTLs were detected for Fe concentration explaining 11-34% of the variation, and 11 QTLs for Zn explaining 9-50% of the variation. Evaluation of a pea genome wide association study (GWAS) panel of 175 varieties revealed substantial diversity in Fe and Zn concentration. The GWAS panel was genotyped using genotyping by sequencing and 14,391 SNPs were utilized. Three markers were detected for Fe concentration and 3 markers for Zn concentration; these will be validated on PR-02 and PR-07. A synchrotron-based X-ray fluorescence beamline method was found to be effective in predicting Zn, Se, Mn and Cu concentration in pea flour. This technique could be developed into a high throughput approach for assessing the concentration of many elements simultaneously.

Thomas Nemecek (Switzerland) described a case study to evaluate the potential benefits of including pulses in the Swiss diet on the environmental impact of food production. Total environmental impact can be reduced by 50% by reducing feed imports, food imports, and animal herds. The benefit could be even greater if calorie intake and food waste were reduced. Recommendations included a) reductions in the consumption of meat, alcohol, and vegetable oils, b) holding dairy consumption constant, c) increasing consumption of cereals, pulses, potatoes, fruits, vegetables, peanuts, and tofu; pulses could increase to 20% of protein in the diet, d) much less production of pork, beef, and chicken, with a moderate increase in production of laying hens. If implemented, these recommendations would greatly increase Swiss self-sufficiency in food.

Rajib Podder (Canada) investigated iron bioavailability of iron in Bangladeshi meals prepared with iron-fortified lentil. In southeast Asia and Africa, up to 60% of children are iron deficient. Meals were prepared including lentil, rice, vegetables, and fish. Lentil fortified with iron was compared to non-fortified lentil in these meals. The relative iron bioavailability of the two lentil sources was assessed using the CaCo-2 cell model and the fortified lentil provided 3X greater available iron than the non-fortified. Current research is aimed at fortifying lentil with both iron and zinc. x

Session 4: Breeding improved germplasm

Chaired by Ahmed Amri[1] and Kirstin Bett[2]

This session consisted of six presentations covering topics related to improving pulse breeding techniques, and pulse breeding success stories.

Jean-Marcel Ribaut (Mexico) described an Integrated Breeding Platform (IBP) that uses big data approaches with the goals of increasing breeding effectiveness, increasing data quality, establishing institutional data memory, and facilitating data sharing. Data management would include information on the selection environment, plant morphology, plant physiology, and genetic aspects. The software being utilized is open source. The IBP would be complementary to existing databases and statistical software packages.

Bodo Raatz (CIAT) described his work on common bean breeding for yield stability and improved nutritional value. His focus is on the large seed size Andean market classes of common bean. Breeding goals include heat tolerance, drought tolerance, and virus resistance. Bodo described a platform for marker assisted selection where DNA extraction and assays for 10 SNPs could be achieved for $1.5 in a two week period. They have identified climbing bean varieties with 2-3X yield, which are labour intensive, but fit well for small land holders. His research includes a biofortification component focused on iron and zinc. Genomic selection approaches yielded correlations of 0.4 to 0.5 for iron and zinc concentration which was considered sufficient for use in breeding.

Rebecca McGee (USA) described her work in developing winter pea cultivars. Goals of this program are suitability for autumn sowing in the northern USA, large seed size, and non-pigmented seed coat. Winter pea could serve as a rotation crop between winter wheat crops. Winter pea has greater yield potential (1.5-3X) than spring pea, but the workload is shifted from spring to autumn. Current challenges include improving seed type to gain market acceptance as food, optimizing planting date, and biotic stress resistances. Important genes are Hr (delayed flowering) and le (shorter internodes). Rebecca's group has made many winter X spring pea crosses to combine favourable alleles. Promising lines are being evaluated in several locations in northwestern, mid-west, eastern USA, and the Canadian prairies. Seedlings should reach the 5 node stage by November with good nodulation and multiple basal branches. They should be covered with snow through the winter, resume active growth in early spring, with harvest in mid-July. Best lines now have winter tolerance to -21C with acceptable seed appearance.

Colin Douglas (Australia) reported on his research with green gram (mung bean) and black gram which are high value pulses. Mung bean has abundant genetic diversity thus a nested association mapping (NAM) panel with 2000 lines was developed as a tool for breeding. Preference is for large seed size. Australian pulse industry is targeting production of 170,000 tonnes of mung bean per year, primarily for export, with some for domestic sprouting markets.

Shiv Kumar (ICARDA) is developing short duration lentil cultivars for use in rice based cropping systems. In India, Bangladesh and Nepal approximately 15 million hectares of land lie fallow after rice production. A short duration pulse crop could replace fallow, fix nitrogen, and increase livelihood to farmers. Shiv's goal is lentil cultivars with 90-100 days to maturity, photoperiod insensitive, high seed iron and zinc concentration, and with resistance to relevant diseases. Early season vigour and high biomass production are desirable. *Lens orientalis* is being explored as a source of early maturity.

Koaudio Nasser Yao (ILRI) reported on a 'demand-led' pulse crop breeding approach to address the slow rate of adoption of new cultivars in Africa. Reasons for the slow rate include lack of awareness, availability, and profitability. The demand-led approach is broader than participatory plant breeding involving strategies to set breeding goals, obtain market intelligence, raise funds, and determine return on investment.

Bodo Raatz (CIMMYT); Credits of the photo: ICARDA Flickr

[1] ICARDA, Rabat, Morocco
[2] University of Saskatchewan, Saskatoon, Canada

Session 5: Biotic stresses and their management

Chaired by Tom Warkentin[1] and Martin Barbetti[2]

This session consisted of seven presentations covering topics related to fungal pathogens and parasitic weeds affecting several different pulse crops.

Tom Warkentin (University of Saskatchewan)

Marie-Laure Pilet-Nayal (France) provided a broad overview of research arising from her group and that of her international collaborators addressing *Aphanomyces* root rot, which along with various *Fusarium* species, appear to be the key root rot organisms of pea and lentil. Winter pea can partially escape Aphanomyces due to its fall planting date. Substantial progress has been made in QTL mapping, and fine mapping of partial resistance, with two key QTLs identified, along with several minor QTLs. These QTLs are being validated phenotypically in near isogenic lines. Delayed symptom development appears to be a benefit of one of the QTLs. Pilet-Nayal's team are recommending integrated approaches to root rot management including using lines with beneficial QTLs, once they become available commercially, along with appropriate sowing dates and crop rotations, particularly with non-host crops like lupin, chickpea and fenugreek.

Diego Rubiales (Spain) and colleagues have addressed many biotic stresses of pulse crops in the Mediterranean region over the past two decades, including rusts, ascochytas, bacterial blights, Fusariums, powdery mildew, bruchids and aphids, and have identified effective host resistances, most recently to rusts. His presentation at IFLRC-VII focused on their research related to the parasitic weed *Orobanche*, which produces thousands of tiny seeds per plant. This pest remains a major constraint to pulse crop production in the region, and its area of influence appears to be spreading northward. Fortunately, the Rubiales team has identified sources of resistance in most pulse crops, and developed resistant lines using conventional breeding approaches, especially for faba bean and lentil, and the industry is now waiting for their deployment. In addition, experiments are in progress on using crop management approaches to aid in controlling *Orobanche*, including inter-cropping approaches.

Rebecca Ford (Australia) provided insights into the most influential fungal pathogen of chickpea, i.e., *Ascochyta rabiei*. Her group is studying the pathogen and host-pathogen interactions. International research has shown that chickpea resistance to ascochyta is quantitative in nature, as many QTLs having minor effects have been published. Ford's group have shown that only one mating type is present in Australia and the pathogen genetic diversity is rather narrow. A key challenge for chickpea breeders has been the rapid rise in aggressiveness of *A. rabiei* isolates over the past decade and with the predominating pathotype 4 able to overcome most host resistances used in Australia. A combination of improved cultivars, fungicides, disease-free seed, and crop rotations are being used.

Seid Kemal (Morocco) reported that the area planted to faba bean in Morocco is being threatened by Orobanche, Botrytis,

[1] University of Saskatchewan, Saskatoon, Canada
[2] The University of Western Australia, Perth, Australia

and rust. ICARDA has identified sources of resistance to Botrytis and rust, but rust resistance level is low and deployment has been slow. At present, fungicidal applications are required for control of these pathogens, particularly rust where strategic fungicide at flowering are essential to protect yield. Botrytis tends to affect faba bean in the vegetative stage when conditions are cool, while rust arrives as temperatures increase. Kemal's group investigated three fungicides on several faba bean varieties over several years and found that at least two of the fungicides were beneficial in disease control and improving crop yield by >20%.

Lone Buchwaldt (Canada) summarized her work on lentil anthracnose over the past 15 years. Anthracnose is an important fungal disease of lentil in Canada, USA, Ethiopia, Middle East and Eastern Europe. Fungicides have been used rather effectively in several countries. Buchwaldt's group developed decision-support guidelines for growers. The resting micro-sclerotia of anthracnose degrade in 2 years if left on the soil surface under zero-tillage conditions, but have a longer life of 3-4 years if buried. In addition to lentil, faba bean and vetches are hosts, while other pulse crops are non-hosts. More than 2000 lentil accessions were evaluated and three were identified with resistance to both major races. Resistance to one of the races has been deployed commercially in western Canada and progress is being made to deploy resistance to the second.

Rama Daadu (Australia) described approaches used to identify new sources of resistance to ascochyta in lentil. As global seed banks contain more than 10,000 accessions it is a massive challenge to screen them for disease resistance, so their group used an approach they called Focused Identification of Germplasm Strategy (FIGS). They used aspects of geo-referencing and knowledge of where the disease was most prevalent to filter the collection and identify 87 accessions with potential for resistance, then exposed these to an aggressive isolate of *Ascochyta lentis*, and identified one from Ethiopia with strong resistance. This accession is now being studied intensively.

Rachid Mentag (Morocco) continued the discussion of Orobanche with focus on the importance of the pest in Morocco. Orobanche has long seriously affected faba bean and field pea, but is now becoming increasingly important on chickpea and lentil in Morocco. Control methods being investigated include cultural (crop rotation, inter-cropping, allelopathy), herbicides (glyphosate and imidazilinones), biological (insects and fungi), and host resistance. Host resistance is the preferred approach.
Over-arching themes of this workshop include the identification of sources of resistance to biotic stresses, their introgression into adapted germplasm, but the slow progress in commercial deployment. It seems the international pulse crop industry needs a boost in getting improved germplasm to market, so the benefits of research can be realized!

Session 6: Agronomy, physiology and abiotic stresses

Chaired by Jacques Wery[1] and Rachid Dahan[2]

Thomas Nemecek (Agroscope)

This session consisted of seven presentations covering topics related to agronomy, physiology, and abiotic stresses of pulse crops.

Suhas Wani (ICRISAT) described strategies to overcome soil macro- and micro-nutrient deficiencies in pulse cropping systems. **Harsh Nayyar** (PU, India) described research to address heat stress in pulse crops, including investigations on pollen and ovule viability. Genetic variability in chickpea, lentil, and mungbean for heat stress allows for potential breeding gains. In parallel research, **Rosalind Bueckert** (University of Saskatchewan, Canada) is evaluating heat stress physiology in pea in temperate regions. Vegetative (leaf type, wax, lodging resistance) and reproductive (pollen, ovules) traits are affected by heat stress. Spectral reflectance data are being associated with heat stress response. **Yashpal Singh Saharawat** (ICARDA) described conservation and precision agriculture approaches to conserve water and organic matter in cereal-pulse crop rotations. **Helene Marrou** (CIRAD, France) described nitrogen fixation benefits and ecosystem services to boost pulse cropping in Mediterranean regions. **Thomas Nemecek** (Switzerland) used life cycle analysis to demonstrate the massive environmental benefits of including pulse crops in cropping systems, primarily due to the substantially reduced requirement for nitrogen fertilizer in these rotations. **Jana Kholova** (ICRISAT) described results on improved water use efficiency in pulse crops using high throughput phenotyping and genotyping leading to informative QTLs.

[1] ICARDA, Rabat, Morocco
[2] INRA, Rabat, Morocco

Session 7: Ecosystem Services

Biological nitrogen fixation and carbon, water and nutrient footprints

Chaired by Kadambot Siddique[1] and Suhas Wani[2]

Kadambot Siddique in his opening remarks highlighted that grain legumes are not only important food and feed sources, but they play a major role in the sustainability and productivity of cropping systems. Grain legumes contribute to cropping system diversity when grown with crops of other plant families (e.g. cereals), disrupting the pest and disease cycles that develop during monocropping. They also contribute to soil fertility, primarily through biological nitrogen fixation but also by adding organic matter and releasing sparingly-available soil phosphorus. Farming systems need to be profitable and sustainable to meet the growing needs of the global population and to respond to the changing climate. Farmers need to optimize the use of inputs such as water and fertilizers. Grain legumes play a significant role in cropping systems because of their sustainable and environmental benefits such as reducing the carbon footprint and the need for nitrogen fertilizers.

The first paper on "Tapping wild species of plants and microbes to improve nitrogen fixation in the chickpea crop" was presented by **Doug Cook**, University of California-Davis, USA, highlighting the findings of two decades of molecular and genomic studies in model systems have revealed the presence of exquisite genetic pathways that initiate symbiosis, but despite these advances we have essentially no understanding of genes that regulate symbiotic performance in the natural or agricultural environment. Sequencing the genomes of >1,000 chickpea symbionts from a systematic global survey of wild and cultivated systems revealed a domestication-driven network of horizontal gene transfer that has expanded the species capable of fixing nitrogen with chickpea from three to greater than fifteen. Current data indicates that cultivated species have a broader range of effective symbiotic partner species, but with lower average benefit from symbiosis, consistent with a selection trade-off during domestication to leverage such information to improve the effectiveness of nitrogen fixation in legume agricultural

[1] The University of Western Australia, Australia
[2] International Crops Research Institute for the Semiarid Tropics, India

Glasshouse study involving the screening of 266 chickpea reference set with diverse genetic background from 29 countries for phosphorus use efficiency.

systems were discussed.

The Paper on "Genotypic variation in phosphorus-use efficiency among a large set of chickpea germplasm and physiological mechanisms" was presented by **Kadambot Siddique**, The University of Western Australia. He presented the results based on 266 genotypes (including chickpea reference collection) originating from 29 countries with diverse genetic background and highlighting genotypic variation in P acquisition and P utilization. The results demonstrated that carboxylates mobilizes P and Mn from the soil with a strong correlation between Mn concentration in mature leaves and rhizosheath carboxylates ($r = 0.61$, $P < 0.001$). For the first time in crop plants, this finding demonstrates that leaf [Mn] can provide vital information on belowground functioning as a time-integrated proxy for P acquisition via carboxylate release, providing a valuable screening tool in breeding for high P-acquisition efficiency.

Paper on "Food legumes and conservation agriculture for sustainable cereal systems" presented by **Ravi G Singh**, CIMMYT. The role of conservation agriculture in enhancing resources use efficiency to further increased productivity of cereal systems as well as importance and conserving soil health was highlighted. The importance of diversifying cereals with legumes is a win-win proposition as legume needs less irrigation and chemical fertilizers while enriching soils through biological nitrogen fixation and reducing soil degradation.

Paper on "Genetic variability for nodulation among lentil advanced lines: implications for nitrogen fixation ability" presented by **Omar Idrissi**, INRA, Morocco. He reported high genetic variability for the number of nodules, their position in root system and their color was observed while studying 28 lentil advanced lines from the national breeding program.

Stefanie Christmann from ICARDA presented on "Shift focus on a neglected ecosystem service - Farming with Alternative Pollinators (FAP) highly increases yields of faba bean". This paper highlighted uniquely the environmental governance approach for farming with alternative pollinators (FAP) through pilot studies farming with alternative pollinators with different mandate crops was piloted and proved its replicability. Farming with alternative pollinators model, in Morocco used 75% area for growing main crop and faba bean 25% for habitat enhancement by other marketable plants indicated doubling the income per unit based in faba bean fields compared to control faba bean fields. The increased productivity and income was largely due to increased pollinators which was evident with increased number of pods and seeds in FAP than in control. This approach with faba bean which is economically remunerative and environment-friendly can contribute to pollinator protection.

Suhas P Wani summarized the importance of the eco system services provided by the legumes and conservation agriculture in terms of biological nitrogen fixation and carbon sequestration as well as reduced the water and nutrient footprints which can help in sustainable development of agriculture systems.

Stefanie Christmann (ICARDA)

Session 8: Genomics, genetics, and genetic resources

Chaired by Doug Cook[1] and Roberto Papa[2]

Rajeev Varshney (ICRISAT) summarized some recent advances in pulse crop genomics. In 2014 1000 pulse crop accessions had been sequenced and by 2018 it was >6000. The genome sequences of pigeon pea and chickpea have been improved in recent years. Pan genomes of chickpea and wild chickpea are under development, as are gene expression atlases of pigeon pea and chickpea. Root trait phenotyping has been a major activity at ICRISAT over the past two decades, resulting in markers related to drought tolerance. Additionally markers have been associated with ascochyta blight resistance, seed weight, beta-carotene, B vitamins, iron and zinc. Thus far, approximately 50 traits in chickpea have been mapped and are beginning to be used in breeding using diagnostic markers. Rajeev emphasized the need for a better seed system so improved varieties can be taken up more rapidly by farmers. Potential future activities include more sequencing, systems biology of complex traits, more molecular breeding, gene editing, and genomic selection.

Clare Coyne (USA) described pulse crop plant genetic resources and their utilization. Goals include open access to phenotypic and genotypic data and peer review. USDA shipped approx. 10,000 accessions per year of pulse crop seed samples over the past three years. Several pulse crop databases can be searched including GRIN (USA), KnowPulse (Canada), and ICRISAT core collections. The USDA pea core collection was recently genotyped giving rise to 66,000 SNPs.

Petr Smykal (Czech Republic) reported on research related to seed dormancy in pulse crops. Physical dormancy is related to impermeable seed coats. He is studying the association of dormancy and the geographic origin of accessions. Accessions arising near the tropics tend to be non-dormant, while those arising further north or south tend to have physical dormancy. Petr evaluated gradients of temperature and precipitation in relation to germination.

Noel Ellis (New Zealand) described the genetics of several traits in pea including powdery mildew resistance, translational initiation factor, and photoperiod. Genotype, environment, and their interaction affect phenotype. Noel argued in favour of a gene-based analysis over a trait based analysis. Many loci contribute to genetic variation even of a simple attribute. Null alleles (approximately 30,000 in a species) could be obtained to delimit the range of variation.

Donal O'Sullivan (UK) described his research on gene identification to improve faba bean. Faba bean has strong genetic synteny with *Medicago truncatula* and a consensus map was released in 2016 with an improved version coming soon. In collaboration with colleagues, recombinant inbred line populations are being characterized for traits including zero tannin, dwarfing, vicine/convicine, glycosides, hilum colour, and *Orobanche* resistance.

Ahmed Amri (ICARDA) described the pulse crop genetic resources of ICARDA. The ICARDA gene bank is still alive in Aleppo with secondary sites in Morocco, Lebanon, and Svalbard. Many gaps identified in wild species collections. Focused Identification of Germplasm Strategy (FIGS) being used to collect a subset of the germplasm for a trait using a geography-based algorithm. Typically 150-300 accessions are collected per targeted search.

Donal O'Sullivan (United Kingdom)

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[1] University of California Davis, Davis, USA
[2] Universita Politecnica delle Marche, Ancona, Italy

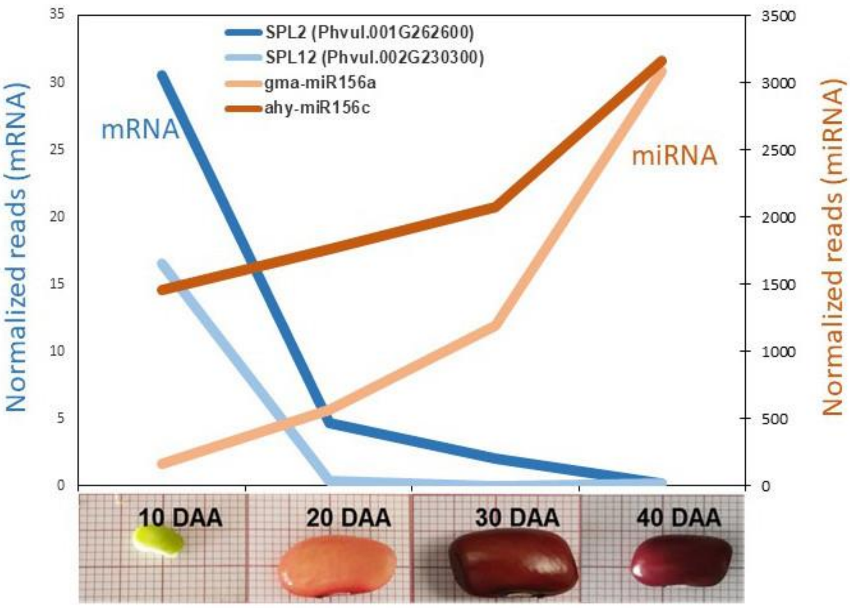
Session 8a: Genomics and Genetics

Chaired by M Carlota Vaz Patto[1] and Noel Ellis[2]

This session focussed on developments using genomic tools for genetic diversity assessments and the investigation of specific processes.

Phaseolus vulgaris (common bean) featured in two presentations. The first from **Roberto Papa** (Università Politecnica delle Marche, Ancona, Italy) described the results from re-sequencing more than 200 common bean lines from a range of sources that were accompanied by extensive phenotypic data. The picture of diversification into the Central American, Andean and Mesoamerican groups holds up strongly in this data set, but the study uncovered regions potentially associated with selection for specific agroecological niches. The extent, and fine scale, of introgression suggests that a great deal of recombination has contributed to phenotypic adaptation lines outside the original centres of domestication. The second talk on common bean in this session, from **Susana Araújo** (Instituto de Tecnologia Química e Biológica António Xavier, Universidade Nova de Lisboa, Oeiras, Portugal) focused on the role of microRNAs in relation to seed development. Different mi-RNAs, nearly half of them newly identified, were showing different patterns in relation to the phases of seed development. This was illustrated by the role of the miR156 family potentially targeting Squamosa Promoter-Binding Protein-like transcription factors with a putative role in regulating seed dormancy. Another candidate was identified that potentially targeted a dehydrin involved in the regulation of seed desiccation, suggesting an active post-transcriptional regulation of this process.

[1] ITQB NOVA, Oeiras, Portugal
[2] University of Auckland, Auckland, New Zealand

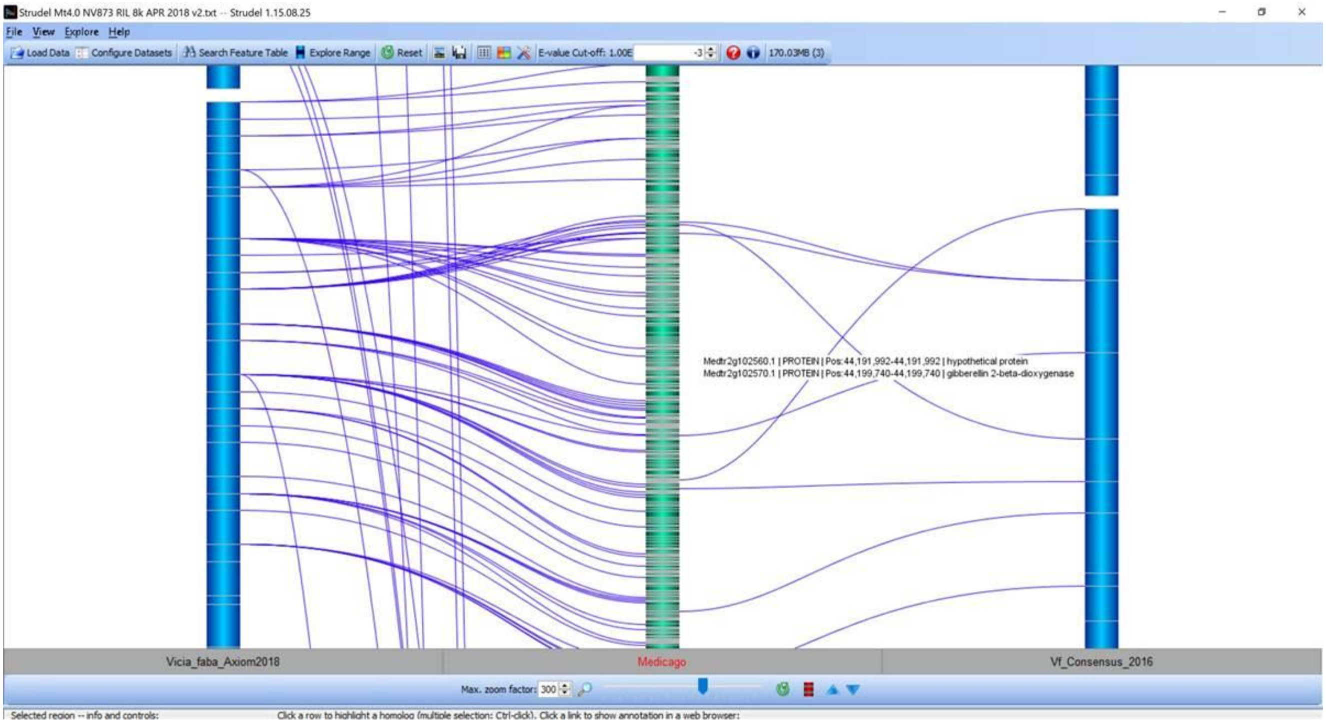


Expression profiles of some members of the miR156 family and respective targets belonging to the squamosa promoter-binding protein-like family of transcription factors established during seed development in common bean. Legend: DAA, days after anthesis (provided by Susana Araújo)

Progress in sequencing the lentil genome has been rapid and used to characterize the genetic diversity of a global collection of cultivated lentil that is being phenotyped by a collaboration among groups at ICARDA (Morocco/India/Bangladesh), in Spain, Italy and the USDA in Pullman. The implications for understanding lentil diversity were presented by **Kirstin Bett** (University of Saskatchewan, Saskatoon, Canada) highlighting relationships among wild species and defining regions of genomic diversity that underlie quantitative traits segregating in interspecific crosses. The lentil resources are publicly available through the AGILE project webportal at knowpulse.usask.ca.

Deepti Angra (University of Reading, Reading, UK) reported the development of the first faba bean 50K Axiom SNP genotyping array using publicly available transcriptome data, a stepping stone towards the development of a high resolution consensus genetic map. This new map was validated by greatly narrowing the genetic interval harbouring an important seed quality trait – namely, a recessive allele of the *VC* gene conferring a substantial reduction in the antinutritional factor vicine-convicine. This study together with those reported in lentil and *Phaseolus* show how sequence information can assist in the harnessing of broad genetic diversity for crop improvement.

Later in this session the use of genomics and genetics to better understand plant-pathogen interactions was discussed; two presentations focused on ascochyta blight caused by *Ascochyta rabiei* Pass Lab. a major production constraint of chickpea globally. The study of **Bunyamin Tar'an**

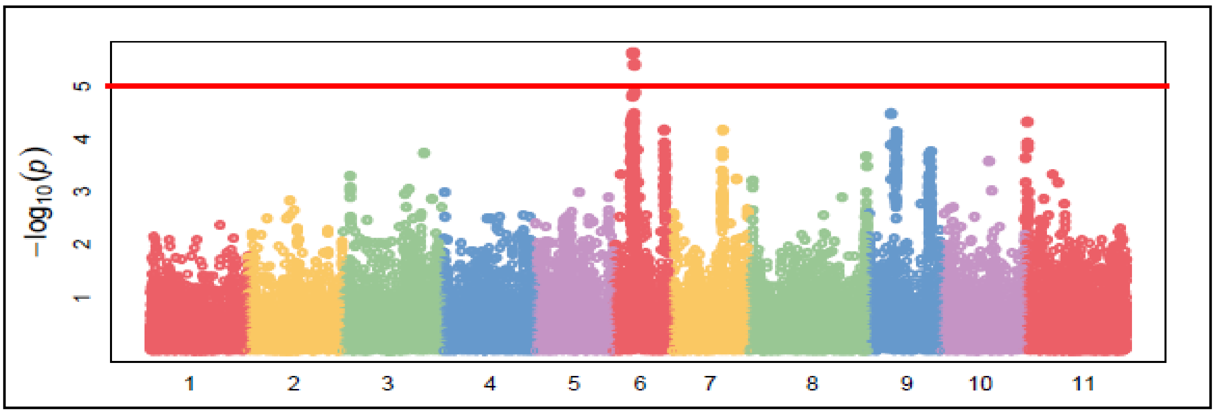


Comparative plot of re-arrangement between *Vicia faba* old (Vf_Consensus_2016, on the right) and new high resolution consensus genetic map (Vicia_faba_Axiom2018, on the left) and *Medicago truncatula* (in the middle), showing the increase in marker density represented by the new array. (provided by Deepti Agra)

(University of Saskatchewan, Saskatoon, Canada) successfully demonstrated, the higher speed and cost efficiency of whole genome sequencing of bulked segregants (NGS-BSA) when compared to conventional bi-parental mapping (by reducing the scale of the analysis with comparable power) on the identification of QTLs and candidate genes associated with ascochyta blight resistance in chickpea.

Next, the presentation of **Ido Bar** (Griffith University, Nathan, Australia) also making used of whole-genome sequencing but In this case of the pathogen DNA, detailed the establishment of a genome wide catalogue of function associated pathogenicity markers in *Ascochyta rabiei* with the subsequent identification of the pathotype genomic variants present on Australian isolates. Notable SNPs were found within genes involved in plant-pathogen interaction, including Zinc-finger proteins, hydrolase/drug resistance proteins, RNA helicase binding and growth protein.

On the other hand, the presentation of **Jennifer Wilker** (University of Guelph, Guelph, Canada) focused on the use of genomics and genetics to better understand symbiotic plant-microbe interactions. It is known that when nitrogen-fixing legumes are grown, the need for added nitrogen fertilizer is reduced. However, common beans (*Phaseolus vulgaris*) are considered poor nitrogen fixers. In this study it was however still possible to detect genotypes with superior nitrogen fixing capacity within Mesoamerican germplasm, highlighting the potential to reduce the need for added nitrogen fertilizer even among common bean cultivation. Additionally these authors were able through a genome wide association study (GWAS) to identify genomic regions associated with this ability that might be used in the future to enable marker assisted selection (MAS).



Manhattan plot of percent nitrogen derived from the atmosphere (%Ndfa) from a genome wide association study (GWAS) using 280 *Phaseolus vulgaris* genotypes from the Middle American genepool phenotyped at Belwood (Ontario, Canada; 2015). %Ndfa values were calculated using the Natural Abundance method, comparing N levels in fixing genotypes versus a non-nodulating navy bean mutant. The SNP data was generated by GBS and provided by North Dakota State University. The SNP data was imputed then pruned for linkage disequilibrium (PLINK software) and filtered for 2% minor allele frequency and heterozygotes (TASSEL software), resulting in 54,185 SNPs for the GWAS using GAPIT software. The best fit model in GAPIT was an Enriched Compressed Mixed Linear Model (ECMLM) with P covariate from PCA and K* kinship matrix from the EMMA method. The negative log(p) was used to establish a significance threshold. (provided by Jennifer Wilker)

Session 8b: Genetic Resources

Chaired by Clare Coyne[1] and Sanjeev Gupta[2]

This session consisted of six presentations on topics related to genetic resources in pulse crops.

Hari Upadhyaya (ICRISAT) gave a talk on the enhanced use of germplam to accelerate genetic gains in food legumes. Identification of genetically diverse and agronomically beneficial germplasm offers breeders the opportunities to develop breeding populations combining multiple resistances into desirable agronomic backgrounds, delivering high-yielding climate resilient cultivars that can deliver greater genetic gains. Grain legumes germplasm were used to identify new sources of variation for resistance to various stresses and for agronomic and nutritional traits. Resequencing of these collections provides insight into allelic variation associated with important agronomic and nutritional traits. *Cajanus platycarpus*, a species from the tertiary gene pool, possessing several desirable agronomic traits, shows a range of novel traits such as resistance to phytophthora blight, fusarium wilt, pigeonpea sterility mosaic virus and legume pod borer. Using wild relatives, introgression lines with enhanced resistances and agronomic traits have been developed.

Jens Berger (Australia) talked about new opportunities for chickpea improvement by the exploitation of wild Cicer. Wild Cicer populations were identified at flowering, and leaves were collected on a single plant basis to facilitate population genetics. Mature seeds were similarly collected, site seasonal climates and soils characterized. The world collection has been increased by >1200 single plant accessions from 84 locations. These materials are the basis of an international effort to phenotype adaptive traits and introgress these into domesticated chickpea. Marker-trait associations are being explored, and trait-based domestic by wild crosses planned to complement the current base-broadening hybridization in Canada, USA, Turkey, Ethiopia and Australia.

Ramakrishna Nair (WVC) gave an overview of the International Mung bean Improvement Network (IMIN) which was established with partners from India, Bangladesh, Myanmar and Australia and is coordinated by the World Vegetable Center (WorldVeg). A mung bean mini-core collection (296 accessions) of World Vegetable Center, a genetically diverse resource, was provided to project partners, and is coordinating multi-location evaluation to identify and characterize desired traits that confer biotic and abiotic stress resistance, among others, including resistance to Mung bean yellow mosaic disease (MYMD) and a range of other diseases such as anthracnose and powdery mildew. The resistant accessions are being utilized to introgress the resistance genes into adapted varieties Mung bean mini-core collection: a treasure trove for resistance to pests and diseases.

Eric von Wettberg (USA) gave a talk on development new collection of chickpea wild relatives with thorough documentation of their ecological setting, because there is limited germplasm the crop wild relatives. This also provides insight into how domestication has reshaped cultivated legume responses to nitrogen.

Cengiz Toker (Turkey) studied *Pisum sativum* L. and *P. fulvum* Sibth. Et Sm. Reciprocal interspecific crosses aiming at (i) obtaining hybrid vigor, (ii) finding transgressive segregations and (iii) selecting of early-podded progeny for earliness. For yield and yield-related characteristics such as plant height, number of pods per plant, number of stems per plant, biological yield and 100-seed weight, considerable hybrid vigour in F1 and transgressive segregations in F2 populations were found in reciprocal interspecific crosses. *P. sativum* and *P. fulvum* interspecific crosses brought the hidden genes together responsible for earliness via transgressive segregations despite the fact that neither *P. sativum* nor *P. fulvum* species express that level of earliness.

The last speaker, **Faheem Shehzad Baloch** (Turkey), gave a talk about the diversity, characterization, inter-gene pool hybridization and breeding of *P. vulgaris* in Turkey. They collected 188 Turkish common bean landraces from 19 different Turkish geographic regions under the national project (TOVAG=215O630). Using whole-genome DArTseq markers they recognized two gene pools, the Mesoamerican and the Andean, and also a higher level of hybridization in the former. The prevalence of Andean gene pool (56.9% of the accessions) was observed, more purity and less diversity as compared to the Mesoamerican gene pool. Genetically distinct landraces were also found, that can be used as candidate parents for the common bean breeding.

[1] USDA Agricultural Research Service, USA
[2] IIPR, India

Overview of the workshops

Chickpea

Moderated by Pooran Gaur (ICRISAT, Hyderabad, India)

The Chickpea Workshop had 16 presentations, which included eight country reports on chickpea breeding and six on specific research topics. The workshop was moderated by **Pooran Gaur** from ICRISAT, Hyderabad, India. He also made the first presentation on “Global scenario of chickpea research and development”. This was followed by country presentations from India (**GP Dixit**), Ethiopia (**Asnake Fikre**), Iran (**Homayoun Kanouni**), Turkey (**Cengiz Toker**), Spain (**Juan Gil**), USA (**George Vandemark**), Canada (**Bunyamin Tar’an**) and Myanmar (**Mar Mar Win**). The research topic-specific presentations were on QTL mapping for ascochyta blight resistance (**Aladdin Hamwieh,** ICARDA), whole genome resequencing based trait mapping (**Mahendar Thudi,** ICRISAT), genome-wide association study of carotenoids concentration (**Mohammad K Rezaei**, Canada), herbicide tolerance (**Sushil K Chaturvedi**, India), nematode resistance (**Rebecca Zwart**, Australia), improvement of nutritional quality traits (**Ravi Chibbar**, Canada), and water use patterns in wild *Cicer* species (**Pushpavalli Raju**, Australia). The highlights of these presentations are given here.

The global scenario of chickpea production revealed that the global chickpea production increased by 43% During the past decade (2006-2016) because of 21% increase in area and 18% increase in yield. Over the years, about one-third of the chickpea area has shifted from cooler long-season environments to warmer short-season environments. In addition, the area under late-sown crop is continuously increasing. Thus, development of short duration varieties with enhanced tolerance to terminal drought and reproductive stage heat stresses is an important breeding priority in chickpea. Fusarium wilt (FW) and dry root rot (DRR) are the major root diseases in dry areas, whereas Ascochyta blight (AB) is a major foliar disease in areas where humidity is high and temperatures are low during the crop season.

In India, chickpea is the most important pulse crop with a share of 40 to 45% to the total production of pulses in the country. The research efforts have largely focused on development of varieties adapted to rainfed growing conditions. Over 210 varieties suited to varying agro-ecological conditions have been released. The key traits used in selection were grain yield under rainfed conditions, heat tolerance, desired maturity duration, resistance to Fusarium wilt, market-preferred seed traits (large seed size in Kabuli), and suitability to machine harvesting. This has helped the country in expanding chickpea area in central and southern India and compensating the loss in chickpea area that occurred earlier due to expansion of wheat in irrigated areas of northern India. Transgenic technology is being exploited to improve resistance to Helicoverpa pod borer.

The key challenges to chickpea production in Ethiopia include wilt-root rot complex, ascochyta blight, pod borer and terminal drought. A total of 23 varieties of desi and kabuli chickpea have been released from the local collections and the breeding lines received from ICRISAT and ICARDA. The chickpea productivity has increased substantially due to adoption of these varieties. Efforts are being made to exploit wild *Cicer* species and molecular markers in breeding programs.

In Turkey, chickpea is traditionally sown in spring and subjected to drought and heat

Pooran Gaur (ICRISAT) at chickpea workshop

stresses. Chickpea can be sown in autumn with new cultivars but winter-sown chickpea cultivars are not available for highlands. Some abiotic stresses (drought, heat, freezing etc.) and some biotic stresses (ascochyta blight, Fusarium wilt and weeds) are common and important stresses, whereas nutrient imbalance including salinity are localized challenges. More than 30 varieties have been released. Most of the area is occupied by large-seeded Kabuli chickpeas. Introgression of genes from *C. reticulatum* and *C. echinospermum* with integration of MAS and novel biotechnological approaches to enhance biotic and abiotic stresses offer future potential to increase chickpea yields.

The main chickpea breeding objectives in Spain include resistance to major diseases (Ascochyta blight and Fusarium wilt) and to increase yield and yield stability. The breeding program has used donor for resistance to Ascochyta blight from ICARDA and for wilt from ICRISAT. Recently, genotypes combining large seed size and resistance to Ascochyta blight and wilt have been developed using both classical and marker assisted selection.

Chickpea breeding in the USA focuses on developing large seeded Kabuli type varieties for canning and whole consumption, and smaller seeded desi type varieties for processed foods. Improving resistance to Ascochyta blight and emerging diseases, such as seed rot caused by *Pythium ultimum*, is a critical focus of breeding programs. Developing early maturing chickpea varieties that can be harvested without using desiccant herbicide is also a priority for breeding programs. Other emerging traits of importance to chickpea breeding in the U.S.A. include improving nutritional qualities and effective symbiosis with nitrogen-fixing *Mesorhizobium ciceri.*

The chickpea breeding program in Canada focuses on development of varieties with high yield potential, improved resistance to ascochyta blight, early maturity, herbicide tolerance, visual and nutritional seed quality. The research program has put more emphasis on breeding for medium to large seeded Kabuli with acceptable canning quality. For the desi, the focus is on small to medium seed size with improved seed coat colour and shape. High dehulling and milling efficiency are the desirable traits for the desi type. Acceleration of the breeding through the use of molecular tools has been routinely done to assist in selection for several traits.

Chickpea is an important pulse crop in Myanmar, largely grown in the Central Dry Zone (CDZ). Two-third of the chickpea area is in rice-chickpea cropping sequence, where chickpea sowing is delayed due to late harvest of rice. The breeding programs are focusing on development of varieties with high yield potential, early maturity, large-seed size (in kabuli type), drought and heat tolerance, resistance to root diseases, and suitability to machine harvesting. Department of Agricultural Research (DAR) has a strong collaboration with ICRISAT and has benefitted from receiving breeding materials and support in capacity building. DAR has so far released ten chickpea varieties, nine from the breeding materials supplied by ICRISAT and one from the breeding material developed by DAR. The improved chickpea varieties are covering about 96 percent of the total chickpea area and have led to several-fold increase in chickpea production.

For mapping quantitative trait loci (QTLs) for AB resistance, ICARDA developed a high-resolution genetic map (1244 markers spanning 2503 cM on eight linkage groups) from FLIP98-1065 (R) × ILC1929 (S) RILs. Three major conserved QTLs conferring AB resistance were identified: two on linkage group 2 (LG2-A and LG2-B) and one on linkage group 4 (LG4). These QTLs explained, respectively, 18.5%, 11.1% and 25% of the total variation. In total, 18 predicted genes were located on LG4, 9 on LG2-A and 10 on LG2-B. Th SNP markers located within genes associated with AB resistance could be used in marker-assisted breeding for AB resistance.

ICRISAT used skim sequencing-based bin mapping approach to narrow down the "QTL-hotspot" which spans 29 cM and harbours several QTLs for drought tolerance related traits, into two smaller regions viz., "QTL-hotspot_a" (139.22 kb) and "QTL-hotspot_b" (153.36 kb). Further QTL- seq, MutMap and TILLING by sequencing approaches are being employed to identify the causal SNPs, candidate genes and their functional validation for traits like heat tolerance, FW, AB and dry root rot resistance. Resequencing of reference set provided 207 significant marker trait associations for drought and heat tolerance related traits.

Chickpea is a rich source of provitamin A carotenoid. Genome wide association study conducted at the University of Saskatchewan identified 17 SNP markers significantly associated with provitamin A (β-carotene and β-cryptoxanthin) and zeaxanthin. SNPs associated with the cytochrome P450 gene family, 1-deoxy-D-xylulose-5-phosphate and genes involved in biosynthesis and/or transport of abscisic acid and gibberellin were identified. These markers can be used in breeding programs after validation.

In India, several sources of tolerance to herbicides Imazethapyr have been identified and being used in development of herbicide tolerant varieties. Mapping populations are being developed to identify gene(s)/QTLs controlling herbicide tolerance and linked molecular markers for use in breeding programs.

Higher levels of resistance to root-knot nematodes (*Meloidogyne artiella*), root-lesion nematode (*Pratylenchus thornei*) and cyst nematode (*Heterodera ciceri*) have been identified in wild *Cicer* species as compared to the cultigen. Barriers to interspecific hybridization restrict the use of sources of nematode resistance to *Cicer* species belonging only to the primary gene pool (*C. reticulatum* and *C. echinospermum*). Australian chickpea breeding program has successfully introgressed nematode resistance from the wild species to the cultivated species.

Chickpea has a relatively high concentration of proteins (13 to 30%). Starch is the predominant seed storage carbohydrate and contributor to seed weight and grain yield, as well as the main source of energy in human diet. Chickpea seeds also contain lipids (6-9%), minor quantities of vitamins, minerals, and bio-active phytochemicals. Seed quality improvement has mainly focused on increasing protein concentration and bio-availability in the human food. Opportunities exist for improving carbohydrates which are the major storage constituent (51-71%) and so far have not been the target of chickpea seed quality improvement.

Over 130 wild *Cicer* genotypes were evaluated for their response to changing vapour pressure deficit. There were significant differences across wild genotypes for diurnal transpiration patterns (P<0.001) that were not explained by habitat: responses varied both within and between collection sites. Thus, some wild *Cicer* genotypes conserve water at high VPD, while others do not; collection sites typically contain a wide range of responses. This result is important as water conserving wild *Cicer* lines can be further exploited for the development of elite drought tolerant chickpea cultivars, while more profligate types may lift yield potential in higher rainfall areas.

Lentil and grasspea

Moderated by Ashutosh Sarker (ICARDA)

Fernand Lambein described the history of grasspea cultivation, its adaptation, utilization, and advances in strategies to address lathyrism. **M. Carlota Vaz Patto** described genetic resources in *Lathyrus,* particularly Iberian landraces. Their group has generated mapping populations segregating for many traits of agricultural importance. **S. Gupta** provided an Indian perspective on lentil and grasspea breeding. Short duration and biofortification of iron and zinc are key goals for lentil. Breeding low neurotoxin grasspea has resulted in the release of improved cultivars. **M.O. Ali** described lentil and grasspea breeding in Bangladesh which has similar breeding objectives as mentioned for India. High uptake of new cultivars is a promising development. **R. Darai** provided a breeding update for lentil and grasspea in Nepal. Lentil is the most popular pulse crop in Nepal and production has increased, but yields remain relatively low (1.2 t/ha). Breeding objectives are similar to those in India and Bangladesh and further include breeding for Stemphylium blight resistance. **G. Nigussie** indicated that resistance to foliar and root diseases are key breeding objectives for lentil in Ethiopia where yields can exceed 2 t/ha. **Kevin McPhee** described substantial increases in lentil production in USA in the past two decades, due to benefits as a nitrogen fixing cash crop. **O. Idrissi** indicated progress on improving rust and ascochyta resistance in lentil in Morocco. **D. Wright** described an international effort to characterize the time to flowering in diverse e lentil germplasm, including extensive phenotyping and genotyping. **S. Singh** updated on progress in disease resistance breeding in lentil, with emphasis on rust, ascochyta, Fusarium, and Stemphylium. **H. Dikshit** described biofortification research, with emphasis on iron and zinc. **M. Subedi** described research on milling efficiency in lentil, with seed diameter and seed plumpness being key determinants. **J. Kumar** is using *L. orientalis* for development of new populations segregating for key adaptation traits. **S. Shirtliffe** is using drone imaging to describe canopy architecture in diverse lentil populations and found significant correlations with ground data. **B. Chandrashekhar** is using satellite imagery to produce big data for describing agronomic landscapes in India.

Faba bean

Moderated by Donal O'Sullivan (University of Reading, Reading, U.K.)

The faba bean research community was out in force at a well-attended faba bean workshop which packed in 14 short talks covering all corners of the globe where faba bean is grown and a range of scientific topics from pest and diseases to reproductive biology.

Fouad Maalouf gave a scene-setting talk covering ICARDAs work breeding faba bean for dryland areas including impressively large-scale screens for (amongst other things) resistance to ascochyta and rust, and heat tolerance. Our tour of the faba bean growing world continued with a fascinating overview of Chinese faba bean production given by **Xuxiao Zong** from CAAS, where the diversity of end uses, agroecologies and cropping systems (including faba bean under pear trees!) requires the full repertoire of faba bean botanical types and seasonal adaptations. In this context, CAAS has recently initiated a shuttle breeding programme giving two generations and selection environments per year at 25 and 41 degrees N, the fruits of which we look forward to seeing at IFLRC-8 in Nairobi in 4 years time!

Zain Fatemi from local co-hosts INRA opened the batting for a Moroccan perspective of faba bean productivity, reporting on breeding achievements including two synthetic varieties due for release in 2019 and a renewed effort to collect and exploit local landraces. **Lamiae Ghouti**, from IAV-Hassan II (Rabat) too up the landrace theme with a critical appraisal of the agricultural innovation model in Morocco and a compelling argument that participatory breeding of landrace faba beans can significantly enhance resilience. **Noura Benyoussef** from INRA-Tunisia completed our view of North African breeding efforts with good news of a series of variety releases with high levels of tolerance to Orobanche, which as many speakers in the session reminded us, remains the number one constraint on faba bean production in North Africa and the Nile Valley.

Heat and cold tolerance were the respective subjects of contributions from **Zayed Babiker** (ARI, Sudan) and **Jinghuo Hu** (WSU) respectively, further increasing the geographic range and sense of wonderment at the diverse environments to which faba bean can be (just about) made to adapt.

The topic then switched to pest and diseases with a roundup of work on the characterisation of resistance to major fungal diseases and Orobanche given by **Diego Rubiales**, including welcome news of a new line 'Quijana' that has been developed to carry both low germination stimulation and the more established 'Baraca'-derived tolerance. The excitement was not over as **Tadesse Negussie** from EIAR, Ethiopia described a new gall disease of faba bean and work to identify the causal agent, probably *Olpidium viciae*, to which, fortunately, some moderate resistance has been identified in preliminary screening trials. Talks focussed on biotic constraints were rounded off by a pair of talks from ICARDA colleagues **Moustafa El-Bouhssini** from ICARDA reporting *inter alia* promising levels of resistance to stem borer weevil (*Lixus algirus*) based on an antibiosis mechanism and **Safaa Kumari** covering results of aphid-transmitted viral resistance screens.

Taking us into some of the research upstream of breeding were **Ana Maria Torres** (IFAPA, Cordoba) with a review of the significant recent progress in markers, maps and ever more precise location of

QTLs for important traits, which has important implications for marker-assisted breeding. Ana Maria also introduced a new project looking at lines showing high and low levels of autofertility under the electron microscope. The endless challenge and fascination that faba bean's partially allogamous mating habit holds for all of us who work on faba bean genetics and breeding was addressed from a different angle by **Lisa Brünjes** from Goettingen, who in working out the paternity of thousands of progeny in a polycross was able to quantify the differing contributions of different genotypes to diversity and heterosis.

All-in-all, the session was the knowledge exchange equivalent of a satisfying 'bissara' soup, enhanced with many delectable and subtle aromas but with a single dominant ingredient – faba bean.

Pigeonpea

Moderated by Rao Rachaputi (The University of Queensland, Queensland, Australia)

Pigeonpea is a mandate crop of ICRISAT and as such several researchers from that ICRISAT provided updates on their research activities on this crop including a research overview from **C. Sameerkumar**, breeding update for southeast Africa from **R. Ganga**, utilization of wild species from **S. Sharma**, hybrid breeding from **C. Kumara**, breeding for disease resistance from **M. Sharma**, breeding for insect resistance from **J. Jaba**, prospects for super early varieties from **A. Hingane**, and genomic achievements from **R. Saxena**. Chairperson **Rao Rachaputi**, University of Queensland, provided a breeding update for Australia. Improvements in pest resistance, photoperiod/temperature insensitivity, and hybrid breeding are expected to boost yields from the current world average of 0.7 t/ha, and allow expansion of the crop in Asia, Africa, and Australia.

Pea

Moderated by Tom Warkentin (University of Saskatchewan, Saskatoon, Canada)

This session consisted of nine diverse and exciting presentations covering topics related to breeding, wild *Pisum* species, abiotic stress tolerance, weed and disease management, nutritional quality, and characterization of mutants.

Dengjin Bing (Canada) summarized activities in pea breeding at Agriculture and Agri-Food Canada. Canada produces approximately 30% of the world's dry pea crop and accounts for 50-60% of world dry pea exports. Pea has become an important crop in the western Canadian and northern USA wheat-canola crop rotations. Dengjin's program emphasizes increased biomass, grain yield and grain protein concentration.

Rebecca McGee (USA) described breeding activities in vegetable pea. Of the world total of 2.6 million hectares of production, 2 million is in Asia, primarily China and India. Vegetable pea production is increasing in the Americas and Oceana. Broadly three types of vegetable pea occupy markets: shelling type, edible pod type, and shoots. Breeding objectives for the shelling type include organoleptic properties (flavour, texture, colour, size) and ease of mechanical harvest. The edible pod type includes snow pea and snap pea (thick pods and stringless). Pea shoots are often grown in hydroponics in controlled environment conditions, with harvest after 2-3 weeks of growth, with end-use near the production facility.

Steve Shirtliffe (Canada) described his research on weed control in organically produced pea. Organic pea is typically xpriced at 2X the level of conventionally produced pea. Increased seeding rate (130 plants/m^2) improved competition with weeds. Mechanical weed control strategies provided >70% control and increased grain yield. Various inter-row tillage systems were evaluated including robotic/camera controlled approaches. Success with mechanical weed control was on the order of that required for deployment of a new herbicide.

Petr Smykal (Czech Republic) described prospects for using wild *Pisum* accessions in pea breeding. The primary gene pool includes *Pisum sativum* subspecies *sativum* and subspecies *elatius*. The secondary gene pool includes *Pisum fulvum* and *Pisum abyssinicum*. The tertiary gene pool includes *Vavilovia formosa*. International germplasm collections are lacking in the wild *Pisum* accessions (<1500) and should be a priority for future collection missions. Wild pea accessions have great potential in terms of harbouring alleles related to disease resistance, maturity, and seed quality. Petr developed introgression lines from a *P. fulvum* X *P. sativum* cross which have been extensively genotyped and are currently being phenotyped at international locations.

Rosalind Bueckert (Canada) described the work of her group on aspects of heat tolerance in pea both in the reproductive tissues and the vegetative tissues. Greater flowering duration and pollen viability are beneficial to yield under heat stress. The semileafless trait was found to be beneficial in improving lodging resistance which led to a cooler canopy.

Jagroop Kahlon (Canada) summarized her PhD research at the University of Alberta on using a transgenic approach in an attempt to mitigate Fusarium root rot in pea. The work was conducted under the supervision of Linda Hall at University of Alberta and Hans-Jorg Jacobsen at Leibniz University, Hannover, Germany. Transgenic pea lines carrying individual or stacked genes coding for chitinase, beta-glucanase, polygalacturonase, and stilbene synthase were developed and evaluated in confined field trials under permit from Canadian Food Inspection Agency. Assessments were made on many aspects of plant growth and disease symptoms. The soil was infested with *Fusarium avanaceum*, *Fusarium, solani*, and other*Fusariums*. No consistent pattern of benefit was observed in the transgenic lines compared to the controls for emergence or disease resistance indicating the complexity of the interaction.

Md Shahin Uzzaman (Australia) described research conducted in collaboration with Willie Erskine on waterlogging tolerance at germination in pea.

Waterlogging is an important abiotic constraint in Bangladesh where pea is planted 2-3 weeks prior to rice harvest in a relay cropping scenario. Significant variation in waterlogging tolerance was detected in both field (Bangladesh) and controlled environment conditions (University of Western Australia). The mechanism of tolerance is under investigation at the phenotypic (electrical conductivity increase due to leakage) and genotypic (differentially expressed genes) levels. Kaspa, a field pea cultivar with pigmented seed coats, was more tolerant than a cultivar with non-pigmented seed coats, which was more tolerant than a garden pea cultivar.

Claire Domoney (UK) described research on improving nutritional quality of pea. Pea and other pulse crops have slowly digestible starch, including some resistant starch and these properties are beneficial in human diets, especially in the diets of people susceptible to type II diabetes. Investigations were conducted on mutants in a starch branching enzyme in diverse *Pisum* germplasm. Seed protein profiles were examined in a pea fast-neutron population. Potentially beneficial traits identified include low vicilin proportion and low trypsin inhibitor activity.

Noel Ellis (New Zealand) described research related to the 'stipules reduced' mutant identified using the pea fast-neutron population developed at the John Innes Centre and described above. Fifteen genes have been characterized related to leaf morphology in pea. Frame shift or stop codons were typical causes. In some cases, stipules are reduced to 30% or even 10% of their normal size.

Harmonization of data management systems and big data analytics

Moderated by Abhishek Rathore and Brian King (ICRISAT and CIAT, respectively)

The importance of data science has been recognized by different national and international institutions. **A. Rathore** described the different data solutions that ICRISAT is starting to implement to facilitate researchers in making data driven research decisions, highlighting the present big data analytic challenges. **B. King** on the other hand, talked about the necessary keys to unlock powerful new data-driven capabilities for building resilient agri-food systems world-wide explaining the CGIAR platform for Big Data in agriculture. The CGIAR's geospatial data management was introduced by **J. Koo** that also talked about the tools that are currently being developed for providing FAIR-enabled open data and knowledge products in geospatial datasets. In addition, the particularities of the CGIAR´s socio-economic data management were introduced by **C. Azzarri**. The Breeding Management System analytic pipeline developed within the Integrated Breeding Platform, which allows breeders electronic crop data storage, retrieval, analysis, sharing, interpretation and utilization was illustrated by **J.M. Ribaut**. Next **P. Shelby** introduced the specialized data management tools, such as GOBii, Cassavabase and BrAPI that can help to implement effective genomic selection. The PHIS open source information system was described by **P.E. Alary** for semantics and plant phenotyping data structuration for data analytics. Also, a novel tool developed by CIP, to support accelerated breeding scheme in clonal crops, the GTDMS, was described by **J. Molano**. Finally, **J. Wilgenbusch** described a novel agroinformatics data sharing and analysis platform called G.E.M.S(TM) that combines the analyses of socio-economic with GxE datasets.

Workshop: Data Management Systems & Big Data Analytics

IFLRC-VII Field visits and Photographic overview

Approximately 75 participants attended the tour of field research trials at the INRA and ICARDA research farm at Marrakech on May 9, 2018. The tour was well organized and the field trials were in good condition. We were updated on research related to breeding of pulses (lentil, chickpea, faba bean) and cereals (durum wheat and barley), as well as disease and pest management research and genetic resources of food legumes crop. Shiv Agrawal, food legumes coordinator at ICARDA gave an overview of the field trials of chickpea, lentil, faba bean and grass pea, followed by visit to individual trials on machine harvestable and herbicide tolerant lentils, ascochyta blight tolerant chickpea, orobanche tolerant faba beans, and dual purpose grass pea. Participants showed keen interest in the MAGIC population of chickpea with wide genetic variation. Nice work on developing super early lentils for South Asia and heat tolerant lentils, chickpea and faba bean were also shown to interested participants. Sufficient time was available for interaction with key researchers, as well as for a nice lunch.

Participants at the field trial

Participants at the IFLRC-VII

Fernand Lambein from Ghent University (Belgium) receiving a life-time achievement award for his "lifetime support to Lathyrus research"

PhD Student awardees for best presentations:

(A) José Parreira Salvado, ITQB NOVA, Portugal
(B) Endale Geta Tafesse, University of Saskatchewan, Canada
(C) Deepti Angra, University of Reading, U.K.
(D) Abdallah Insaf, INRA-Morocco (received by Ms. Hasnae)
(E) Younes Nahli, INRA-ICARDA, Morocco

The International Legume Society and the Polish Academy of Sciences cordially invite you to join us at the **Third International Legume Society Conference**, scheduled from 21-24 May 2019 at the Novotel Poznań Centrum in Poznań, Poland.

In a world urgently requiring more sustainable agriculture, food security and healthier diets, **the demand for legume crops is on the rise**. This growth is fostered by the increasing need for plant protein and for sound agricultural practices that are more adaptable and environmentally sensitive. Food, feed, fiber and even fuel are all products that come from legumes – plants that grow with low nitrogen inputs and in harsh environmental conditions.

The conference will address the following themes: Legume Biodiversity and Genetic Resource Exploitation; Advances in Legume Genetics, Genomics and other -omics; New Strategies and Tools for Legume Breeding; Legume Contribution to Sustainable Agriculture; Legumes for Human and Animal Nutrition and Health; Legume Biochemistry and Systems Biology, Legume Physiology, Plant Development and Symbiosis; and Biotic and Abiotic Stresses in Legumes. The health and environment benefits, as well as, the marketing of legumes will be transversal topics throughout the conference. Special attention will be given to foster the interaction of researchers and research programs with different stakeholders including farmers and farmer associations, seed/feed and food industries, and consumers.

Please join us in beautiful Poznań, Poland from 21-24 May 2019! Plan now to include the Third ILS Conference in your busy agenda. Kindly share this information with any colleagues dealing with legumes.

Kevin McPhee, on behalf of the Scientific Committee and
Bogdan Wolko, on behalf of the Organizing Committee

Legume Perspectives is an international peer-reviewed journal aiming to interest and inform a worldwide multidisciplinary readership on the most diverse aspects of various research topics and use of all kinds of legume plants and crops.

The scope of *Legume Perspectives* comprises a vast number of disciplines, including biodiversity, plant evolution, crop history, genetics, genomics, breeding, human nutrition, animal feeding, non-food uses, health, agroecology, beneficial legume-microorganism interactions, agronomy, abiotic and biotic stresses, agroeconomy, sociology, scientometrics and networking.

The issues of *Legume Perspectives* are usually thematic and devoted to specific legume species or crop, research topic or some other issue. They are defined by the Editorial Board, led by the Editor-in-Chief with the help from Assistant Editors, who select and invite one or more Managing Editors for each issue. Having accepted the invitation, the Managing Editor agrees with the Editorial Board the details, such as the deadline for collecting the articles and a list of the tentative contributors, from whom he, according to his own and free choice, solicit the articles fitting into the defined theme of an issue. A possibility that every member of the global legume research community, with a preference of the International Legume Society members or established authorities in their field of interest, may apply to the Editorial Board to be a Managing Editor and suggest a theme for his issue is permanently open and can be done simply by contacting the Editor-in-Chief by e-mail, with a clearly presented idea, structure and authors of the potential issue.

Since one of the main missions of *Legume Perspectives* is to provide as wide global readership with the insight into the most recent and comprehensive achievements in legume science and use, the articles published in *Legume Perspectives* are usually concise, clear and up-to-date reviews on the topic solicited by the Managing Editor from each author. Managing Editor is solely responsible for collecting the articles from the authors, anonymous peer-review, communicating with the Technical Editor and providing the authors with the proofs of their manuscript prior to the publication.

Apart from review articles, *Legume Perspectives* is keen on publishing original research articles, especially if they present some preliminary results of an outstanding significance for legume research and before they are published in their full volume, as well as brief reports on already held and announcements about the forthcoming national and international events relating to legumes, descriptions of the projects on legumes, book reviews, short articles on legumes in popular culture or everyday life, fiction stories on legumes and obituaries. The authors of such contributions are advised to contact the Editor-in-Chief first, in order to present the draft of their idea first and receive a recommendation if it is appropriate.

Regardless of the article category, *Legume Perspectives* prefers a clear, simple and comprehensive writing style that would make its articles interesting and useful for both academic and amateur audience. Your article is expected to assist in the exchange of information among the experts in various fields of legume research.

Legume Perspectives welcomes either longer (900-1,100 words + up to 3 tables, figures or photos + up to 10 references) or shorter (400-500 words + 1 table, figure, photograph or drawing + up to 4 references) manuscripts. The Editor-in-Chief, depending on the opinion of the Managing Editor, may allow any variation in length or structure, from case to case.

The manuscripts for *Legume Perspectives* should be prepared in Microsoft Office Word, using Times New Roman font, 12 points size and single spacing. Please provide each manuscript with a 100-word abstract and 4-6 key words listed alphabetically. The references should follow the style of the published papers in this issue, be given in full and listed alphabetically. The tables may be incorporated in the manuscript, while figures, photographs or drawings should be submitted separately as jpg files with a resolution of at least 600 dpi. The authors whose native language is not English are strongly advised to have their manuscripts checked by a native English speaker prior to submission and be persistent in following only one of all the variants of English they themselves prefer.

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