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10-YEAR RESEARCH STRATEGY FOR PULSE CROPS

Review Draft

Note: Development of this 10-Year Research Strategy for Pulse Crops builds on earlier scoping work including a global survey of pulse research funding and relies on collaborative engagement with pulse research stakeholders. In September, interviews were held with thirty-three researchers working across many different scientific disciplines, geographic areas, and pulse crop types. In October at the Second International Legume Society conference in Portugal, a write-shop brought together seventeen scientists to review a preliminary draft report.

This Review Draft of the 10-Year Research Strategy for Pulse Crops has been distributed to a broad set of pulse research stakeholders to invite their insights. **Please send written comments to Christine Negra at *Christine@emergingag.com.*** A final draft will be reviewed by pulse research leaders and funders in mid-November and the final Research Strategy will be published in early December.

With funding support by the International Development Research Centre (IDRC) of Canada, this initiative is led by Emerging Ag, Inc. on behalf of the Global Pulse Confederation, which has sponsored a wide array of activities for the International Year of Pulses. It is motivated by the large gap between the potential of pulse crops for meeting global sustainability challenges and the current capacity to seize this potential. The 10-Year Research Strategy report will be used to set an agenda for global discussion and mobilize champions to advocate for accelerated pulse research investments.

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INTRODUCTION

Pulses have been essential for the development of agriculture over millennia and they are essential to any future scenario of sustainable global agriculture.

The UN Food and Agriculture Organization has declared 2016 the International Year of Pulses (IYP) to encourage connections throughout the food chain that would better utilize pulse-based proteins, further global production of pulses, increase the efficiency of crop rotations, and address trade challenges. The International Year creates a unique moment to showcase research investments that would allow pulse crops to deliver on their full potential as a critical player in the global food system.

Significant increase in global production and consumption of peas, beans, chickpeas, lentils, and other pulses is an important part of meeting international challenges and delivering on commitments such as the Sustainable Development Goals. As the agriculture sector wrestles with rising competition for land and resources, climate change, growing food demand, and complex commodity markets, pulses are a sustainable part of the food system that needs more research attention. Confronted by dual epidemics of malnutrition and overnutrition, the world needs to see increased representation of high-protein, low-fat, high-fiber pulse grains in human diets.

In April 2016, the Morocco Declaration shone a spotlight on the unmet potential of pulse crops to deliver food and nutrition security, agricultural sustainability, and reduced climate change risks, while contributing to economic empowerment of the rural poor, especially women and youth. The 13 pulse crops receive just USD 175 million in research funding annually, a significant shortfall compared to so-called major crops.[i] This represents a tiny fraction of the USD 61 billion directed toward public and private food and agriculture research.[ii]

The potential of pulses

Contribution of pulse crops to sustainability and well-being

The potential global impact of pulses for human nutrition and health is significant. Pulse grains have been cited for their role in nourishing children at risk of stunting during the first 1000 days of life, in reducing chronic diseases such as diabetes and heart disease, in combating obesity, and in building a diverse microbiome. More focused evidence gathering will reveal the importance of pulse consumption in reducing malnutrition and obesity and will provide data to support national dietary guidelines and the emerging medical arena of 'prescription food' and to inform policies that better incentivize farmers to grow pulses. Across the many different types of pulses, suitable varieties that can deliver a high-protein crop with potential for household consumption or income generation can be identified for most agricultural systems.

Pulses can improve the efficiency and resilience of cropping systems. Adding pulses to a cropping system can significantly boost total productivity of all crops in a rotation by increasing availability of nitrogen and other mineral nutrients, augmenting system diversity, disrupting pest and disease cycles, and improving soil quality.[iii] Pulses consistently provide nitrogen benefits under very different nitrogen-limiting growth conditions.[iv] By fixing atmospheric nitrogen, they reduce fertilizer needs and lower greenhouse gas footprints.[v] Pulses have a low water and energy footprint compared to most other protein sources and they can increase overall water use efficiency in crop rotations. Many pulse crops are well adapted to semi-arid conditions globally and can tolerate drought stress better than most other crops.

Diversity among pulse crops is a key advantage for agricultural sustainability.[vi] Pulse crops are suitable for a range of uses including human consumption, livestock feed, and soil improvement.[vii] To avoid yield loss or crop failure in a context of increasingly volatile weather, producers can make use of natural variety among pulse crops to match plant traits to growing conditions. Diversifying crop rotations by adding pulses helps farmers to reduce the impacts of pests, diseases, and weeds and may mitigate environmental and financial risks.[viii] The tremendous genetic diversity among pulse species is an asset for effective breeding and genetic improvement.

Challenges for pulse production and consumption

Solidifying a cornerstone of sustainable diets. Pulses are central to culinary traditions around the world and, in many countries, they are a cornerstone of food and nutritional security. Several such countries have a 'pulse deficit' in that their populations consume more pulses than they produce (e.g. India, European Union). Several countries, where pulses are not currently a major component of diets, have rapidly expanded pulse production and become net exporters (e.g. Canada, Australia, USA, Ethiopia). With rapid increases in global food needs on the horizon, the role of pulses will become even more significant especially with regard to dietary protein and micronutrients. Future projections of pulse consumption suggest a 23% increase globally by 2030, with much more rapid increases in Africa (~50%), making significant price rises likely.

Re-integrating into sustainable agriculture. Prior to the 1940s, when invention of the Haber-Bosch process led to the production of nitrate fertilizers, pulse crops were integral to most cropping systems due to their ability to deliver atmospheric nitrogen to soils. While the benefits of nitrogen fertilizers are well-known, we now understand the significant problems associated with excess nitrogen use (e.g. water and air pollution; energy use in fertilizer production) and recognize the need to re-integrate pulses back into cropping systems. Adding pulse crops can increase the diversity of on-farm biota, of household food, of livestock feed, and of income sources. However, the agronomic and environmental benefits of pulses vary considerably across growing conditions and farmers currently have few tools for to assist them in optimizing the management of these crops.

Bridging yield gaps. Actual yields of pulse crops vary greatly from field to field and from country to country due to biophysical, agronomic, supply chain, policy, and other factors. Overall, increases in average pulse yield have not kept pace with cereal crops and, with some exceptions, pulse productivity in developing countries has either held its ground or declined.[ix] Recent pulse production gains in some countries demonstrate the opportunities to markedly increase pulse production within farming systems of many different sizes and types. As pulse producers seek to bridge the gap between potential and on-farm yields, climate change raises new challenges including increased pest and disease pressure and heat and moisture stress. As with all forms of agricultural production, climate change will require researchers and producers to be prepared for more extreme and more variable local growing conditions (e.g., both wetter and drier periods).

Pathways to increased pulse production and consumption

Strengthening delivery pipelines. Supply chains that effectively deliver high-quality pulse seeds to producers and harvested pulse crops to markets and processing plants are essential to increasing pulse production consumption. While there have been notable successes, breeding of improved pulse varieties has been insufficient relative to the needs of pulse producers. In many places, new cultivars lack viable pathways to farmers' fields given fragmented pulse seed multiplication and distribution systems. This requires stimulation of appropriately scaled agri-enterprise systems that provide tangible links between breeding programs and producers, including providing high-quality, disease-free pulse seeds and supporting differentiated markets for pulse crops (e.g. local consumption, commodity export, manufacturing).

Diversifying pulse markets. To see significant increases in pulse production and consumption, farmers will need to have stronger price (or subsidy) signals and consumers will need to be offered appealing pulse-based products. In the coming years, the global food system is likely to encompass a range of pulse value chains including:

- **Pulses as commodity crops**. In these value chains, pulse varieties will be tailored to local and regional consumer preferences (and livestock feed needs) and also to inter-regional trade (e.g. existing and new exporters to India). Given basic commodity prices, producers will look to maximize yield and yield stability and minimize production costs (with modest emphasis on pulse quality). Consumers will include traditional pulse-consuming cultures and affordability will be an important driver. National governments and global donors will focus on these value chains as central to food and nutritional security.
- **Local value addition of pulses**. Local and regional food industries can offer new niche markets for pulse crops, especially where commercially viable uses can be found for all pulse fractions (i.e. protein, starch). Focus will be on consistent, high-quality production of specific pulse varieties with tailored properties (e.g. protein content, ease of processing). Producers will look for preferred market conditions and higher prices in exchange for more careful attention to quality parameters. 'Consumers' will be small and medium sized food product manufacturers (e.g. baby food, breweries) and parallel industries (e.g. aquaculture). Government economic development agencies may catalyze partnerships among companies, pulse producers, and research institutions as well as incentivize establishment of processing facilities (for de-hulling, milling, fractionation, etc.)
- **Pulses as ingredients in major food brands**. Large food companies have growing incentives to demonstrate the nutritional value of their products as well as the social and environmental sustainability of their supply chains. Increasing the representation of pulses as ingredients in major regional and global brands can help. While product development will be complex (e.g. validating nutritional and sustainability benefits; evaluating sourcing and processing feasibility), there is high potential for large-scale impact. Producers in large, structured supply chains would need to meet expectations for sustainability reporting. Consumers will value food product appeal, convenience, and price (e.g. pulse protein fractions in ready-to-eat dishes).

Converging on pulse research priorities

International agreement on strategic research priorities is needed, specifically, convergence among pulse research stakeholders regarding priority research gaps and transformative scientific investments.

Despite significant potential to improve food security and agricultural sustainability, global pulse crop production has remained relatively stagnant in yield per acre, acres planted, and total volume produced. The science of pulse agriculture is markedly underdeveloped compared to other staple crops, including cereals. While genome sequences are becoming available for some pulse species, they have lagged behind cereal crops in the genomics revolution. Similarly, early scientific advances regarding the effects of pulses in human diets suggest an important role combating malnutrition and non-communicable diseases, but the body of knowledge has not expanded at a rate necessary to catalyze change in dietary guidelines and clinical practice.

State of knowledge for pulses

In recognition of the significant opportunities offered by pulse crops, in 2014, the Global Pulse Confederation convened a Productivity and Sustainability thematic committee, composed of representatives from research, farmer groups, and industry (see Appendix 1). This committee undertook scoping exercises on the state of knowledge and current research capacity internationally. These studies highlighted major unmet knowledge needs including:

- Cost-effective ways to increase pulse crop productivity and resilience through a combination of genetics, breeding, and agronomy;
- Context-specific options for profitably integrating pulses into crop systems and agricultural landscapes;
- Strategies for reducing the gap between developed and developing countries in pulse crop yields;
- Mechanisms for making pulse markets and supply chains more efficient and equitable;
- Tools for anticipating and mitigating climate change effects at relevant scales for pulse production decisions; and
- Full quantification of pulses' contribution to farm systems, to soil quality, and to nutrition.

Investing for impact

Investing in research can increase pulse productivity, quality, and resilience. Improved germplasm, agronomic management, seed and marketing systems, and other interventions have generated tangible impact in farming systems around the world. In the last decade, meaningful improvements in productivity have been seen for chickpea, lentil, and faba bean in North America, chickpea in Ethiopia and Australia, and faba bean in Europe. Despite modest funding, researchers have demonstrated the potential to significantly improve smallholders' pulse productivity and resilience (e.g. biological control of podborer in cowpea in West Africa; testing of a high-yielding, disease-resistant, waterlogging-tolerant faba bean variety in Ethiopia).[x] Pulse crops are rich in micronutrients and an excellent vehicle for biofortification (e.g. high-iron lentil in response to anemia in India and Rwanda).

Engaging research stakeholders

To develop a holistic understanding of major needs and opportunities for pushing back critical knowledge frontiers, this initiative has consulted with a diverse set of individuals representing expertise in: (i) yield and resilience, including breeding and agronomy; (ii) health and nutrition; (iii) integrated agricultural management; (iv) social dimensions; (v) value chains; (vi) modelling / forecasting, including economists and crop modelers; and (vii) research networks. In addition to diverse disciplinary expertise, consultations were designed to achieve balanced representation across developed and developing countries and world regions (see Appendix I for a list of contributors).

In September 2016, interviews with thirty-three experts informed development of an early working draft report. On October 15, as part of the Second International Legume Society conference in Troia, Portugal, a write-shop brought together seventeen pulse researchers for a structured discussion of a preliminary draft. This revised report has been circulated to a broader group of pulse research stakeholders. Drawing on comments received, a final draft version of the report will be presented at a mid-November verification meeting (TBD). A final version of the 10-Year Research Strategy for Pulse Crops will be prepared in early December.

Building a 10-year research strategy

This report presents an internationally coordinated strategy designed to increase investment in strategic pulse research including work with transformative potential that is not underway or planned within existing funding and implementation mechanisms. It takes a global view and encompasses many dimensions including breeding, genetics, agronomy, nutrition, and land use. Its purpose is to articulate the cumulative potential of all pulse research domains and to increase their visibility among public and private sector stakeholders in government, agriculture, health, the food industry, foundations and funding agencies, research institutions, and consumer groups (see Appendix 2 for a list of major institutional stakeholders).

This initiative seeks to promote more impactful, prominent, and efficient scientific progress globally by establishing a shared research agenda across international and national scientific efforts as well as foster global and regional networks of leading scientists and industry players collaborating toward improved productivity and sustainability of pulses.

CHAPTER 1. BREEDING AND GENETICS FOR IMPROVED PRODUCTIVITY AND RESILIENCE

Research objectives

Unlike major cereal crops, which have had massive investment, many urgent pulse breeding goals that would increase productivity, reduce producer risks, and expand uses of pulse crops remain unrealized.

Investments in genetics and breeding should be informed by agricultural constraints (e.g. biotic and abiotic stresses) and opportunities (e.g. enhanced nitrogen fixation; reduced nitrous oxide emission) as well as uses on-farm (e.g. multiple uses for food, feed, soil fertility) and beyond (e.g. market and consumer preferences) through collaboration with agronomists, producers, food scientists, and others. Importantly, introduction of improved cultivars requires careful attention to market and price dynamics as well as farmers' cost of production to avoid perverse outcomes from yield increases (e.g. price drops; reduced profitability; increased labor demand).

Optimizing for yield, resilience, and other agricultural production objectives

Pulse breeding programs balance multiple objectives for improving field or 'input' traits including:

1. Realization of full potential for **yield** and **yield stability** through increased resistance to biotic (e.g. diseases, pests, parasitic weeds)[xi] and abiotic stresses (e.g. extreme temperature, drought, excess moisture, soil anoxia).[xii] Variable field performance and risk of catastrophic losses create a major impediment to farmers including pulses in their cropping systems.
2. Enhancing **biological nitrogen fixation**, through manipulation of plant and / or microbial genetics, particularly for varieties intended for low-input agriculture (noting that, in high-input agriculture, enhanced nitrogen fixation could divert carbon away from plant growth, reducing yield).
3. Improving **nutrient** and **water use efficiency**, which can expand the range of production conditions suitable for pulse production and reduce costs and risks. Relatedly, improved nitrogen efficiency in cropping systems can contribute to climate change mitigation by reducing the greenhouse gas emissions associated with nitrogen fertilizer production and use.
4. Increasing suitability for **specific farming contexts**, such as reduced time-to-maturity to allow integration into cereal-fallow systems, optimal plant architecture for mechanized and non-mechanized systems, tolerance to agri-chemicals (e.g. dwarf pigeonpea varieties that facilitate chemical control of podborer and podfly), and optimizing for intercropping with specific cereals.
5. Exploiting the potential of **'orphan' pulse crops** (e.g. grass pea, tepary bean, marama bean) to fill ecological niches (e.g. arid conditions, marginal lands) and social needs (e.g. food and feed crops; healthcare) in specific regions through improved traits (e.g. plant architecture).

Field performance of pulses is highly dependent on environmental factors (e.g. estimated to be 70% or more). Genotypes must be tested under a range of cropping systems and breeding programs need better selection tools to account for the intersecting effects of plant genetics, growing environment, and management practices.

Optimizing for end uses

Increasingly, pulse breeding programs will integrate objectives related to end uses, optimizing for market or 'output' traits such as:

1. Improving content, quality, and bioavailability of **protein** and **micronutrients** and biofortification for enhanced micronutrient (e.g. iron, selenium, zinc) content. In addition to growing importance in pulse marketing, these traits have significant health implications in South Asia and sub-Saharan Africa and may have relevance in developed countries as well (e.g. selenium deficiency as a disease risk factor).
2. Aligning with **consumer preferences** and cultural and market expectations for acceptable and preferred pulse characteristics (e.g. taste, color). Sub-regional preferences may affect marketing potential (e.g. preference in eastern India for pigeonpea and lentil and preference in North and Southern India for blackgram). A key trait is shorter cooking time, which has implications for energy use and household labor (especially for women) and which can build on existing variation among pulse species and cultivars.
3. Adapting for **multiple on-farm uses** including household consumption, forage, fodder, fuel, and soil amendment. While generally of secondary importance relative to food uses, feed and fodder quality can be important for integrating pulses into some farming systems.
4. Increasing **suitability for processing** can emphasize diverse traits related to low-waste milling, fractionation, protein behavior during baking, gelatinization properties of pulse starches, and growing and processing cereal and pulse grains together. Biomaterial applications include adjusting seed properties and starch and sugar fractions.

Exploiting synergies and resolving tradeoffs

While pulses are grown in many different areas and can seem dissimilar, there are core similarities (e.g. nitrogen fixation, role in cropping systems, common ancestry) that can be better exploited based on fundamental biology (i.e. biochemistry, physiology, and molecular biology) of phenomena such as nodulation, nitrogen fixation, flowering time, plant architecture, and grain and fodder quality. This can include use of existing knowledge and similar gene sequences to accelerate research in other pulse species. Combining desired traits is of interest for optimizing pulse cultivars to specific regions. This can include development of pulses with resistance to multiple diseases as well as optimization of yield volume and quality (i.e. protein content).

In seeking priorities for research investment, there may be some logic to investing in a few major pulse types, however this approach could miss out on the advantages that emerge from the large diversity among pulse species. Proportionate investments determined by the value of the crop based on a socio-economic assessment is one way of dealing with this. Another is the development of basic-science understanding, tools and technologies in a model species in the near term before applying widely to several pulse crops. Development of hybrid varieties is important to the seed industry (which seeks control of seed marketing to achieve profits and which could deliver more consistent seed quality), although the potential for greater yield improvement is unclear. Transgenic approaches (i.e. combining traits through gene editing) may be necessary to develop traits not present in cultivated germplasm (e.g. Aphanomyces, podborer resistance).

Tools and approaches

Development of improved pulse cultivars relies on characterization of germplasm collections (e.g. greenhouse and field testing; imaging and chemical analytic techniques) to identify sources of desired traits, gene discovery (e.g. genome sequencing, genotyping), and integrated breeding for genetic enhancement.[xiii] Assembling the tools for genome-wide association studies (GWAS) and genomic selection will set the stage for accelerated genetic gain. Such tools include interlinked molecular and phenotypic analyses. While significant natural variability remains to be tapped for pulse crops, big yield gains are possible by traditional breeding even now, provided that breeding processes are streamlined. Molecular breeding increases the pace of breeding through improved precision.

Conserving genetic resources

Breeding programs are fundamentally dependent on genetic resources (e.g. germplasm collections, *in situ* wild relatives, landraces, public and privately owned breeding lines). Conserving genetic collections (such as those held by ICARDA, CIAT, ICRISAT, ECPGR, Svalbard seed vault, national collections such as at VIR, USDA or EMBRAPA) and ensuring accessibility is a high priority. Protection for 'hotspots' of wild relatives is important for maintaining a broad base of genetic variation for future crop improvement. Wild relatives can be better exploited through appropriately targeted efforts, recognizing that these are reserves of very large genetic diversity that are likely dominated by deleterious mutations (i.e. will not offer desired alleles).

Utilizing genetic resources

Pulse germplasm collections are large, but this does not necessarily mean germplasm is utilized in breeding programs as, in addition to gaps in breeding capacity, not all germplasm collections have been properly characterized. This includes development and characterization of populations, including mutants, for allele mining, forward genetics, and reverse genetics for modifying plant growth, yield and quality traits. To facilitate greater utilization of genetic resources, both simple (e.g. genetic mapping) and more involved (e.g. phenotyping; molecular tools) analyses are needed. Genetic collections need to be characterized by phenotyping (e.g. for resistance to stresses; efficient nitrogen fixation, protein content) as well as new molecular tools.

Genome sequencing and effective use in breeding programs

Diversity panels and sequenced genomes allow researchers to identify genotypes that provide desired traits and then breed, enhance, and stabilize these traits. With a genomic approach, molecular markers are developed from diversity panels through association mapping. Markers enhance the precision and efficiency of breeding. Identification of genetic markers can reduce the need for extensive germplasm screening. Genetic knowledge varies across pulse species. Recent genome sequencing efforts (i.e. chickpea, lentil, pigeonpea) offer opportunities in comparative genomics. Genetic improvement needs to be a priority including use of new genomics tools as accelerators toward defined objectives (i.e. not driven by available tools).

Crop simulation modeling and foresight

Pulse performance, as with any crop, results from the interactions of many factors and it is experimentally difficult to understand which factors are dominant. Crop simulation can be more consistently used for priority-setting in breeding programs to understand plant traits controlling desired performance and to run scenarios, informed by weather data. Breeding programs informed by crop simulation models that capture spatial variation (including in agronomic practices) can re-focus from broadly adapted 'mega varieties' to a broader set of varieties optimized for climate variability and diverse farming conditions.

While it can never be fully predictive, foresight planning is an important part of setting appropriate objectives for pulse breeding programs. This can include yield gaps, farmers' risk perceptions and desired pulse traits, etc. Ex ante and marker research assessment (with modeling and other cross-cutting tools) is necessary to identify the desired traits for improved pulse varieties targeted to yield gaps in specific geographies and production environments (e.g. optimal pulses to include in rice fallow systems based on modeling, comparative genomics).

Current capacities and competencies

Regional capacity

In many regions, current levels of breeding work are not sufficient to meet pulse production needs. For example, work by the CGIAR and other development-focused research organizations on genomics and new variety development is targeted to providing material to national partner breeding programs. While many national programs have gained improved scientific capacity, they commonly lack funding sources. Relatedly, as core funding sources for the CGIAR and its counterparts have dwindled, funding for genetics research and breeding programs has become inconsistent and there is increased reliance on donor-funded projects.

In developing countries, where the need for resistant varieties is most compelling, few programs are actually using marker-assisted selection to develop improved varieties. To achieve the necessary precision for guiding breeding programs, crop simulation models need to be built and strengthened significantly with continuous addition of location- and context-specific data. Importantly, many locations in developing countries lack GIS infrastructure, weather data, and scientific and technical staff needed for crop simulation.

Genetic resources and knowledge

Robust capacity for manipulating pulse genetic diversity to develop improved varieties for different growing conditions and objectives (e.g. food, fodder, intercropping, stress resistance, adaption to different zones; enhancing ecosystem services) is of central importance. Effective delivery of this function will rely on global capacity to identify potential sources of stress resistance and other desired traits and this requires coordinated efforts to maintain and screen germplasm collections and diversity panels. Researchers have found molecular markers for most of the key biotic stresses, but markers are needed for abiotic stress (e.g. drought). While some traits of interest are simple, drought tolerance is a complex trait and reliance on a single or few markers will retard achievement of breeding objectives.

Given the thousands of pulse germplasm lines, rapid throughput mechanisms are needed to assess pulse populations for desired traits. Phenotyping is expensive and labor intensive and facilities should be designed for both: (i) high throughput screening, which requires precise assessment to arrive at a selection decision; (2) moderate or low throughput screening for product characterization, which is a necessity for understanding basic mechanisms, or in some cases for product deregulation. Facilities can be established as centers of excellence for specific traits of regional importance. There may be potential for collaboration on phenotyping with cereal crops (e.g. wheat) grown in association with pulses and interdisciplinary collaboration across plant breeders, physiologists, and food scientists is needed to optimize for nutrition objectives (i.e. linking high throughput screening tools with animal studies, nutrient absorption trials, and efficacy studies).

Private sector role

The private sector role in genetics and breeding varies. In some places (e.g. Canada, Australia, European Union), producer associations gather levies to support impact-focused research. India mandates that 2% of corporate profits are directed to social works, representing a potential source of research investment. The relatively small market size of pulses and intellectual property issues have limited investment by the seed industry. The food industry makes use of public sector research to develop new products to bring to the marketplace. Larger companies may invest customize publicly funded research to their needs.

Academic capacity

Maintaining and enhancing the pool of pulse geneticists is an essential task given that many pulse scientists are approaching retirement and cultural barriers and low public sector funding inhibit younger scientists from entering the field. To make real headway on major pulse breeding objectives, better core support is needed for academic researchers to dedicate committed, consistent effort toward critical challenges (e.g. focused evaluation of a few traits per year).

CHAPTER 2. PULSES IN INTEGRATED CROP SYSTEMS AND AGRICULTURAL LANDSCAPES

Research objectives

Rapid integration of pulse crops has occurred in large-scale farming systems that are well-served by locally relevant research and extension and operate within high-functioning value chains.[xiv] Especially for smallholder farmers, integration of pulse crops into farming systems can be inhibited by uncertainties regarding specific benefits, labor requirements, pulse marketability, and price signals,[xv] indicating the need for a holistic research agenda that encompasses socio-economic as well as biophysical and technological dimensions.

Optimizing production methods for agricultural systems

Farmers can achieve production objectives by choosing management strategies that promote full expression of beneficial genetic traits.[xvi] Appropriate agronomic management is a central pillar of pulse production that relies on developing options suited to local contexts (i.e. carefully matching feasibility and opportunity with context). Key research areas include:

1. **Crop rotations**, **intercropping**, and **relay cropping** with cereals. This includes issues such as replacing fallow with short-season pulses, prescribing systems for particular growth types (e.g. staking options for climbing beans), and defining complementarities among cereal and pulse varieties (e.g. species proportion in intercropping) and optimal position of pulses in rotations.
2. **Pest, disease, and weed management** that strategically combines crop and varietal selection (e.g. resistant cultivars; diversification), cultural practices (e.g. soil preparation, disease-free seeds; timing of planting, irrigation), monitoring, mechanical and biological control, and chemical application.[xvii] This approach relies on research to understand the biology of pests, diseases, and weeds (e.g. interactions with other biotic and abiotic stresses) as well as farmer training, decision support (e.g. warning services), and access to necessary inputs.
3. **Nutrient** and **agrichemical management** (e.g. foliar application of fertilizers; seed treatment) including soil test-based fertility management (e.g. phosphorus, micronutrient availability; soil rehabilitation). To develop fertilizer recommendations, soil test-crop response studies are needed (i.e. adequate and efficient application of fertilizers and manures).
4. **Soil and water management** including conservation agriculture (e.g. low / no tillage) and sowing methods (e.g. line vs broadcast) and water use efficiency and rainwater conservation, with emphasis on methods suitable for pulse production.
5. **Mechanization** including appropriately scaled equipment that lowers cost of production and accounts for social / demographic (e.g. gender, youth) implications.
6. **Post-harvest management** including storage (e.g. pest-resistant bags) and seed saving (i.e. guarding viability and quality).

Facilitating pulse adoption by farmers

Adoption of pulses by individual producers will be influenced by access to high-quality, affordable seeds and extension services as well as potential uses (e.g. cash crop, household consumption, livestock feed) and socio-cultural factors (e.g., farmer preference for cash crops).[xviii] In developed countries, agricultural support systems and cultural factors encourage adoption of new varieties and technologies. In developing countries, there are multiple possible barriers to production efficiency (e.g. handling, storage, marketing). In addition, there are adoption barriers such as lack of access to inputs including seeds and knowledge about new technologies.

Different technologies are appropriate for farmer 'segments' with different access to knowledge, finance, and market opportunities, as well as risk tolerance. Research is needed to better understand:

- Factors driving **yield gaps** between potential and actual on-farm yield (e.g. physical, ecological, systems constraints). This includes access to management information and tools as well as cost and availability of agri-chemicals.
- **Farmer decision making** including estimating profit and risk and weighing tradeoffs among yield, resilience, and labor requirements. This includes understanding opportunity costs for resource-poor farmers (i.e. diverting biomass from fodder, fuel and building material to crop residue for conservation agriculture) and time dimensions including current season vs multi-year risks and benefits.
- Farmer **variety selection** and **demand for technologies**. This includes market size and preferences as well as socio-economic drivers, impacts, and beneficiaries (women, youth), with attention to potential for unintended effects of interventions.

Quantifying impacts of pulses in farming systems

To inform farm-scale decision making and agricultural policy, better knowledge is needed about the full set of impacts resulting from integration of pulses into cropping systems including:

- Nitrogen budgets including interaction with soil type and climatic condition and environmental effects (e.g. nitrogen leaching; ammonia acidification; nitrous oxide emissions).
- Pre-crop and intercrop effects (e.g. protein content of cereals following pulse crops in rotations).
- Disruption of pest and disease cycles (e.g. break crop in monoculture cereals).
- Water use efficiency over a full crop cycle.
- Multiple services in farming systems including human food (e.g. dietary diversity), livestock fodder, and crop residues as well as soil quality, agrobiodiversity, and other ecological dimensions including effects on microbial populations.
- Greenhouse gas footprints (e.g. reduction in fossil fuel use in manufacturing nitrogen fertilizer; carbon sequestration).

Yield and environmental benefits of pulse production are spatially and temporally variable and producers need management tools that account for major sources of variation (e.g. variety, management, crop mix). For example, most growers do not have farm-scale tools for estimating pulsederived nitrogen benefits in crop rotations. Quantification of pulse-related benefits in farm system should be done on a multi-year basis as producers can improve management decisions if they can estimate multi-year economic returns from integrating pulses with other crops and livestock. Quantification and should seek to understand which benefits provide rewards to producers (e.g. on-farm ecosystems services) and which benefits are public goods (e.g. off-site ecosystem services) which require mechanisms for compensating farmers for their delivery.

Tools and approaches

Innovation pipelines

To anticipate and respond to production challenges, pulse-growing regions need effective pipelines for improved pulse varieties, technologies, and methods that accommodate a broad range of value chain considerations (i.e. from production to end use). This is particularly challenging for small, disaggregated markets which require assistance in coordinating supply and demand.

Effective innovation pipelines can make use of information and communication technologies to share information about markets, weather, and emerging pests and diseases. They can also use farmer participatory research modes such as ICT-based farmer survey systems. Functional Extension services are necessary to disseminate knowledge and promote innovation including locally-tailored varieties, technologies, and production strategies and estimated return on investment. Extension is also important for linking farmers to input and credit sources. Field demonstrations and farmer field days are key venues for comparison of new and old varieties, cultivation practices and other production technologies.

Input services

Investments in improved genetic resources are wasted if new varieties cannot be distributed through profitable seed systems that produce benefits for companies, farmers, and the institutes that develop improved varieties. Improving high-quality seed availability is key and this involves establishment of seed multiplication mechanisms and seed quality maintenance and assessment. Dissemination of improved pulse varieties should be paired with appropriate agronomic packages (i.e. fertilizer, fungicide) to maximize productivity. Optimal agronomic packages may be particularly important for short season varieties. Availability of inputs to farmers should be considered (i.e. do suppliers stock the specified chemicals?)

In developing country contexts, farmers are commonly unaware of newly improved varieties, reducing the potential for adequate market volume, therefore creating seed demand is an essential function (e.g. outreach programs and events). This can include engaging companies, NGOs, traders, and farmer groups to elicit feedback (e.g. seed coat / color / sheen; taste preferences) and to undertake local testing (i.e. to confirm suitability). Some countries have national schemes that rank varieties by location type.

Markets for pulse seeds are comparatively small, lowering potential profit margins. In some areas, this may indicate a key role for smaller companies in seed production and distribution (possibly supported by training, infrastructure support, and incentives by the public sector or NGOs). Innovative seed multiplication systems can include companies contracting with progressive farmers to ensure quality and access. A combination of formal (e.g. national programs) and informal (e.g. organized through villages or farmer groups) seed systems will be useful in many cases depending on their relative efficiency (i.e. in assessing varietal performance and controlling quality), responsiveness to seed buyers (e.g. small seed packs that allow smallholders to test new varieties), and existing local market knowledge. Differentiated markets (i.e. demand for particular varieties) may incentivize development of seed systems.

Current capacities and competencies

Regional R&D

Regional R&D systems are needed to anticipate local and regional risks and to develop cost-effective responses to emerging problems (e.g., pests; disease; drought) and market expectations (e.g., processing suitability; grain quality standards; reduced pesticide use). In the context of climate change and dynamic food systems, participatory, multi-actor, multi-disciplinary research modes that integrate social science (e.g. gender dimensions) are particularly important. Multi-criteria research and modeling capacity are needed to best inform producer decision making, which integrates yields, prices, costs (e.g. inputs, equipment), and risks (e.g. disease, drought).

Translating knowledge

While successful innovations in one location are not necessarily viable in other areas, knowledge translation is nevertheless a central function for pulse agronomy. Translational research programs are 'patchy' (i.e., stronger in some areas than others) and training and mentoring is needed to cultivate a new generation of pulse agronomists. Funding is needed to fill geographic and training gaps and to ensure knowledge sharing. In some countries, where universities have traditionally undertaken basic research and regional agriculture departments led breeding and systems agronomy work, funding for research by regional agriculture departments has been declining. It is important to clarify the role of publicly funded research and expectations regarding the private sector role in knowledge delivery.

CHAPTER 3. INTEGRATION OF PULSES INTO FOOD SYSTEMS

Research objectives

Understanding contexts and drivers

A food systems approach recognizes the interdependencies among agricultural production systems, value chains, and consumers and emphasizes diversification as a source of sustainability.[xix] Efforts to increase pulse production and consumption occur in the context of dynamic, interconnected global and regional food systems and should be informed by an understanding of how these systems work. For example:

- **Production**. Pulses should be looked at in the context of the availability of arable lands for food production and locally retained income from pulse production as well as the effects of agricultural policies (e.g. lock in; subsidies; minimum support prices).
- **Demand**. While overall global demand for pulses rose from 42 million tons in 1980-81 to 66 million tons in 2009-11, annual per capita consumption declined from 10 kg to 6.5 kg in that same period. In developing countries, 80% of pulses are consumed by people; in developed countries only 40% go to human consumption and 50% goes to animal feed. Future projections of pulse consumption suggest a 23% increase globally by 2030, with much more rapid increases in Africa (~50%), making significant price rises likely. Socio-cultural dimensions (e.g. food habits; taste and species preferences) and affordability influence which social groups consume pulses.
- **Food and nutrition**. Pulses should be looked at in the context of human protein supply (animal vs vegetable). Pulse crops (as well as other legumes) can feed a higher population than can be supported with animal protein (given land and natural resource limits for food production such as water use).
- **Markets, prices, and trade**. Soybean is inexpensive and dominates international markets, whereas most pulses are consumed where they are produced. Deficits in pulse production are growing in some regions. In many areas, traders control prices received by farmers inhibiting market signals for increased production. Optimizing production season and harvest timing with high market prices has to be balanced with production constraints (e.g. water availability in rainfed systems, pest or disease cycles). Multi-national food companies face risks to stable, continuous sourcing of required quantity and quality of pulse crops in the context of climate change (e.g., higher pest or disease damage; drought; extreme heat events).
- **Value chains**. Fragmented, inefficient value chains affect pulses (and many other agricultural products) including input supply, post-harvest storage and transport, processing, and marketing.

Understanding value chain actors

To foster mutual awareness, increase alignment, and improve coordination across different parts of the pulse research enterprise, it is important to identify and describe major pulse value chain actors.

- Breeders manipulate genetic variation to produce pulse varieties with enhanced traits.

- Input suppliers manage inventory and supply of pulse seeds, agri-chemicals, and equipment as well as farmer credit programs.
- Farmers manage land, resources, and inputs to produce pulses and other crops (and livestock) and, in some cases, participate in cooperatives that provide some value chain services.
- Aggregators and wholesalers collect crops from farmers, store and transport them, and broker sale with focus on paying low prices and selling at high prices.
- Processors (small, medium, and large) acquire pulses from aggregators and wholesalers, manufacture them into various products, and sell these to retailers.
- Retailers (e.g. supermarkets, small outlets) sell pulse grains and food products to final consumers.
- Consumers prepare and consume pulse-containing products.

Information barriers among value chain actors can create bottlenecks (e.g. as breeders develop diverse varieties optimized for different end uses, they may be unaware of seed traders' potential bottlenecks in distribution of multiple varieties). If the benefits from research innovations are not allocated equitably across value chains, perverse outcomes may arise.

Implications for women and youth

Interventions in value chains will produce a combination of positive and negative effects and it is not always possible to predict the magnitude or recipients of these effects. Social norms, such as gender roles in different aspects of food production and marketing, will influence the nature of these effects. For example, in West Africa, men commonly produce cereal crops and women produce 'sauce' for household consumption, therefore pulses are seen as 'women's crops.' Interventions that alter production (e.g. mechanization) or marketing (e.g. higher prices) could disrupt these roles with unknown consequences for household nutrition. Therefore, research projects predicated on shifts in pulse productivity (e.g. increased yield) or markets (e.g. integration of pulses into regional or global food brands) should undertake ex ante assessment of potential social and nutritional security impacts (e.g. pulses diverted from households and local markets to manufactured food products).

Such assessments should also evaluate the capacity of supply chains to handle increased total production without losses (e.g. storage, preventing aflatoxin, post-harvest handling) and to deliver local benefits. For example, youth unemployment is a major problem in many developing countries and livelihood opportunities in agri-enterprise (e.g. post-production handling, pre-processing, food product manufacture for regional markets) can be part of pulse value chain interventions.

Baseline and scenario analysis and ex ante impact assessment should include questions such as:

- Who currently depends on pulses for food, income, and value addition? What is known about household decision making (e.g. control over resources including land, income, equipment, livestock; access to capacity building and information sources)?
- Which social segments are likely to experience positive and negative effects under different pathways for increasing pulse production (e.g. labor and time allocation for sowing, weeding, harvesting, cleaning, seed selection / storage) and marketing (e.g. income)?

- How can value chains be shifted without negative effects on local diets and pulse access? Can educational programs mitigate against negative effects?
- What are likely net effects under alternative intervention scenarios? How do these relate to larger social needs and policy objectives?

In developing research proposals, gender considerations can be best integrated by a rigorous review of assumptions underlying a project's theory of change that focuses on specific actors that would be required to change their behavior. For example, a new pulse variety with high-yield potential is intended to improve nutrition and income for smallholder families, yet this assumes that farmers will pay for new seeds, adhere to agronomic recommendations, and retain crops with income-generating potential for household consumption. Pragmatic assessment involves understanding the incentives and capacities of these actors. To enable research teams to hold themselves accountable to wider sociological impacts, research funders should provide seed funds to support partner-based exploration of assumptions in pre-proposal phases.

Implications for diet and health

Globally, there are ~2 billion people with micronutrient deficiency and ~2 billion people with overweight or obesity. Diet is a huge factor in morbidity and mortality on a global scale, across all countries (high and low income). There is a constant demand for hard evidence about pulses and health outcomes, but most research papers can only indicate association. While some evidence is emerging on pulse consumption, glycemic index, and prevention of Type 2 diabetes, proving the contribution of pulses to human health is a large, expensive question. Pulses offer high protein bioavailability (e.g. 84-94% in beans, cowpeas) and can be a major source of protein in carbohydrate-dominated diets. They can also play a role in addressing micronutrient deficiencies (e.g. Fe, Zn, Vit A) and are linked to anti-inflammatory effects, lipid metabolism, satiety, reduced cancer risk, and other effects.

There is high prevalence of malabsorption and stunting among children in sub-Saharan Africa and gut health is central (i.e. poor diet, nutrient absorption increases susceptibility to common infections). Studies are investigating the potential of pulse consumption to reduce enteric pathogens with attention to alteration of microbiome and child growth. Evidence is emerging about the intersection between pulses and gut health related to: (i) nutrient absorption; (ii) barriers to pathogenic microbes; and (iii) appropriate immune response. This includes 'pre-biotic' effect of pulse consumption (i.e. resistant starch stimulates commensal bacteria) as well as anti-inflammatory effects.

Documenting clinical health benefits involves two major dimensions:

1. **Health outcomes (risk factors):** Randomized, controlled studies of the role of dietary pulses with regard to major NCD risk factors (i.e. cholesterol level, blood glucose, blood pressure). The need is to build a large body of knowledge that spans diverse demographic groups (e.g. age, health status) through a broad base of 'workmanlike' efforts rather than 'frontier' science.
2. **Hard outcomes (mortality, morbidity)**: Large, long-term trials that evaluate the role of dietary pulses with regard to actual mortality and morbidity (especially for cancer, diabetes).

Should the body of evidence supporting medical benefits of pulses grow, clinical guidelines can be informed and strengthened so that medical professionals consistently recommend pulses in the diet. Relatedly, a larger evidence base would inform and strengthen how pulses are represented in government dietary guidelines, translating into public health messaging. This is important to shifting public attitudes toward pulses (e.g. alternative protein source to red / processed meats to reduce risks of NCDs). Note that foods, rather than nutrients, are being discussed as the basis for dietary recommendations.

Value addition

While pulses are commonly consumed as whole grains, there is growing interest and experience with pulse ingredients in manufactured food products. As novel foods with pulse-based ingredients (e.g. baked goods, snack bars, infant complementary foods) are developed, there are opportunities to improve nutrition by lowering glycemic index and increasing protein and micronutrient content (e.g. combining bean with potato which has higher iron bioavailability than bean with rice). If a broad and credible research base is built for the health benefits of pulses, food manufacturers can utilize this to inform their decisions about including pulses in product lines and how they market and advertise pulse-containing products to the public.

Fractionating pulse grains into various components can add value (e.g. pulse proteins have some processing properties that make them attractive in the food industry[xx]), but it is important to pursue commercial viability for all pulse fractions (e.g. protein, starch) with a focus on higher value end uses (i.e. direct human consumption, aquaculture feed, biomedical applications). Food manufacturing processes could result in loss of pulse micronutrients (as well as undesirable components). Collaboration between researchers and the food industry is needed to ensure that manufacturing (e.g. fractionation, heating, grinding) does not reduce nutritional value (i.e. investigating which processing steps remove nutrients; testing processing technologies for minimal nutrient removal) and to better identify the quality parameters required for food products.

Whether in the home or a commercial process, the mode of preparation of pulse grains for consumption (e.g. de-husking, soaking, roasting, puffing, flattening, germinating, splitting, grinding, fermenting, cooking) can influence protein availability and digestibility; levels of micronutrients, minerals and anti-nutrients; physical properties (e.g. oil and water absorption, foaming, emulsification, viscosity, gelling); and aroma, taste, and texture.[xxi] For globally marketed food products, research will include automated manufacturing technologies, globally appealing flavors and textures, combining multiple protein sources, methods for reducing fat content, value chain assessments, and food prototype development.

Valorizing traditional or underutilized pulse species (e.g. horsegram, mothbean, lupins) represents another research area that can combine nutrition and agricultural sustainability (e.g. diversify seasonality of maturity; agrobiodiversity at species and genetic level) objectives. Value addition, including efforts focused on food security, that is directed toward on local markets can potentially accommodate a more diverse set of pulse species and varieties (e.g. nutritious, fortified, locally flavored foods designed for vulnerable populations such as pregnant women and babies).

Sustainability and safety

Markets for pulse crops vary dramatically with some national markets holding a high bar for food safety (e.g. pesticide residues; toxins in chickpeas) and sustainability as a condition for access and other markets focused almost exclusively on price considerations. Pulses produced in some regions can reliably be shown to be safely and sustainably produced, while in other regions it is difficult to elicit information about production practices, socio-economic impacts, or product safety (e.g., pesticide residues). In addition to health implications, this inhibits global trade and restricts sourcing options for traders and manufacturers who would benefit from increased supply chain traceability and transparency as well better harmonized food safety rules (e.g., Maximum Residue Limits). Relatedly, research attention may be needed for potential allergens, toxicity, and anti-nutritional factors (e.g. tannins; phytate).

Tools and approaches

Biofortification and nutrient bioavailability

Bioavailability of nutrients varies demonstrably in pulse grains. Research is needed to understand (i) the factors and mechanisms of bioavailability (i.e. not just nutrient concentration), (ii) approaches for exploiting these factors for enhanced nutrition, and (iii) absorption and efficacy studies. Measuring bioavailability (e.g. through a cell culture model) should include factors such as amino acid composition and digestibility. It is particularly important to understand which pulse varieties have higher nutrition as key information for breeding and biofortification efforts to enrich pulses with micronutrients (e.g. to support micronutrient-deficient populations in southeast Asia and Africa). Given that many pulses are already high in micronutrients and may exceed biofortification targets (e.g. HarvestPlus), simply fortifying foods with pulses (e.g. adding pulse flour to breads; pulses in baby food; combining animal and vegetable protein) can improve diet quality.

'Whole of diet'

The whole of diet approach evaluates locally available and affordable food components and investigates what people are producing and consuming, what is available in local markets, influences on what people eat, and what constitutes a higher or lower quality diet. While it is universally recommended to consume more pulses, there are context-specific reasons (e.g. replace consumption of animal sources with plant protein; provide a vegetable protein where animal sources are needed, but unaffordable). Diet interventions can be tested through participatory engagement with community to present options for diet improvement and understanding the interventions that they are willing to take on.

Data and metrics

FAOSTAT data provide estimates of per capita availability, but information about actual consumption of pulses is needed (i.e. dietary intake data such as 24-hour recall, FFQ or food diaries). For consumption and diet, metrics can include food groups in the diet and minimum diet diversity (e.g. for women, children). Funding is needed to better exploit potential data sources such as demographic and health surveys, which collect information about children. Aggregate food categories can obscure assessment of pulse consumption (e.g. reported in combination with nuts and seeds). There are a growing body of pulse-specific case studies conducted in both developing and developed countries. Develop monitoring and evaluation (M&E) [CH: Pulse-based nutrition education has been proven to change the dynamics of pulse consumption and diet diversity, thereby improved child and mother's health and nutritional status (i.e. studies in Ethiopia, India, Kenya, Malawi).

For monitoring and evaluation, activity metrics (e.g. number of farmers served) can have perverse results. Outcome metrics (e.g. adoption percentages; kilograms of pulses; anthropometric measures) take time to show progress and funded programs may end up pushing for high numbers even though many are 'light adopters' of new technologies or methods. It is useful to look at 'costs per adoptee or beneficiary' and there may be benefit in studying the effect of different types of reporting metrics on program outcomes. To understand knowledge, attitude, and practice related to pulse, 'market orientation index per pulse types' measures the level of acceptability of different pulses.

Current capacities and competencies

Documenting nutrition and health benefits

To better support dietary recommendations related to pulses, FAO and the Global Pulse Confederation are developing a database of scientific studies on the nutritional value of pulses. This process has revealed that necessary information is scarce and that more data-gathering is needed for characterizing nutritional composition (e.g. vitamins, minerals, protein). For work to document clinical health benefits, there is ample capacity in terms of high-quality laboratories, but very little funding is available for either of these research needs. Collaboration with the medical community is an important pathway.

Bioavailability and biofortification

Research on bioavailability and biofortification can be done cost-effectively at existing centers of excellence (e.g. University of Saskatchewan; CIAT, Michigan State University, Cornell University, University of Manitoba). In general, there is low capacity for bioavailability science at food manufacturers (e.g. labs focus on measuring content) so they commonly approach universities to undertake basic research (i.e. more cost-effective). Pulse producer groups in developed countries could undertake valuable studies on commercial scale biofortification, given strong capacity to bring research into cropping systems. National pulse crop associations, universities, research organizations, NGOs, and researchers in developing countries can be used as a catalyst in the process.

CHAPTER 4. INTEGRATION ACROSS AGRICULTURAL, NUTRITIONAL AND SOCIAL SCIENCES

Research objectives

Expanding multi-disciplinary research

Significant shifts toward multi-disciplinary approaches have already occurred in pulse crop science and this trend will continue as many challenges require the application of diverse expertise (e.g. breeding, agronomy, nutrition, markets, trade, policies, consumer trends, environmental quality). Multi-disciplinary research programs should be focused on clearly delineated research needs and questions (rather than simply linking up sets of research tools) informed by assessment of past and present pulse research investments.

To develop an integrated understanding of the functions, constraints, and opportunities for pulses within specific geographies (e.g. regions; soil and climate regimes), multiple research modalities will be needed to characterize the net effects of economic performance, social benefits, and ecosystem service provision by pulses. This includes estimating net effects of pulses on value chains and nutritional balance and health as well as assigning economic values under current conditions and feasible scenarios. It also includes research to describe transition paths for overcoming 'lock in' (i.e. preference for cereals enforced by policy and market structures). Quantifying ecosystem services provided by pulses in cropping systems (at field, local, regional, larger scale) can provide a clearer picture of the added value provided by pulse crops (e.g. crop competitiveness, nitrogen efficiency, greenhouse gas emission reductions, nitrogen leaching, agrobiodiversity).

Collaboration with cereal researchers

Some pulse research objectives could potentially be best achieved as 'nested' components of research programs working on major sustainability challenges in cereal systems (e.g. rice, wheat, barley), which generally receive a much larger proportion of global R&D spending. This is particular relevant for cereal systems work for which integration of pulse crops represents a meaningful solution to production challenges. There are several 'success stories' including integration of improved chickpea in the Pacific Northwest, pigeonpea (and bean) in maize systems in Tanzania, and cowpea with sorghum and millet as well as pending opportunities such as integrating pulses in rice-fallow in India. There may be potential for collaboration on phenotyping with cereal crops (e.g. wheat) grown in association with pulses and interdisciplinary collaboration across plant breeders, physiologists, and food scientists is needed to optimize for nutrition objectives (i.e. linking high throughput screening tools with animal studies, nutrient absorption trials, and efficacy studies).

Tools and approaches

Networks

As with any research area, regional and global multi-disciplinary networks can be powerful accelerators for pulse crop research. Potential functions of networks include:

- Increasing mutual awareness among scientists (e.g. molecular biologists, breeders, agronomists, nutrition experts) and practitioners (e.g., producers, extension advisors, agribusiness technicians), exchanging information and expertise, and helping researchers to strategically prioritize scientific objectives and tailor their research designs to align with 'real world' knowledge needs (e.g. identifying traits that are applicable to growers; evaluating technology).
- Forming consortia to tackle complex sustainability issues that within and across production, processing, and consumption components of pulse supply chains (e.g. the Ascochyta Group has been a platform for developing an organized global view of sources of resistance).
- Coordinating access and sharing of germplasm material and genomic information and harmonizing issues around intellectual property.
- Fostering multi-location trials (see current efforts by CORAF and CIRAD in West Africa as well as Mars' BECA project) and sharing of field and laboratory facilities.

New R&D modes

Participatory engagement with farmers is an important component of pulse research to understand what is happening in production systems and to learn about innovative practices (e.g. though farmer networks working with different pulse types). User-engaged research can bring scientists together with producers, food industry, medical scientists, development agencies, policy makers with a focus on real world knowledge needs (e.g. methods for full commercial viability of pulse fractions). Social scientists can assist with design of participatory research especially in overcoming gender barriers.

Research organized toward 'challenge-based topics" (as in the EU's Horizon 2020 program) represents a viable approach to mobilizing multi-disciplinary and / or multi-sector R&D (e.g. through public-private-research partnerships). Such approaches can be relevant for meeting region-specific pulse crop research needs as well as cross-regional challenges (e.g. international, multi-disciplinary engagement over ten years related to *Ascochyta*). Cross-regional modes can also be used to adapt existing knowledge (e.g. genome sequencing tools) generated in developed countries to programs focused on pulse crops important in developing countries.

Current capacities and competencies

Diverse funding opportunities

Different funding entities present different expectations and opportunities. As a result, researchers working in different places can encounter funding mechanisms that emphasize either basic (e.g. fundamental biology; agroecology) or applied (e.g. urgent regional concerns such as response to terminal drought) studies. There is potential for more cross-regional collaborations (e.g. working on nitrogen fixation, disease resistance, biofortification), but funding is limited.

In addition to maximizing near-term impact, research efforts will benefit from funding allocated to integration across disciplinary silos. For example, diverse research teams that develop well-integrated scientific approaches and are capable of ex ante impact assessment (including socio-economic and gender implications) and multi-criteria assessment (e.g. stress resilience, market expectations, nutritional value) will be best able to generate innovations that are distributed through complete value chains and that account for nutrient absorption and health outcomes (i.e. not just consumption).

To promote better integration, multi-disciplinary expertise (breeders, social scientists, nutritionists, animal models, human studies, etc.) is important in funded programs. Research projects need social scientists and economists who can develop baseline surveys and understand production and consumption patterns to complement development of new pulse varieties. Research teams benefit from "integrators" who bring different disciplinary threads together especially at the proposal development stage given the additional complexity of preparing multi-disciplinary research proposals.

Cross-sectoral partnership

Seizing the full potential of pulse crops for agricultural sustainability and human well-being requires a coherent international research community with strong cooperation across academic, government, and private sector research systems. This requires recognizing and accommodating differences in research objectives, approaches to intellectual property, technical capacity, and resources. There are opportunities for increasing engagement such as collaboration on improved seed systems or pulse-based food products (e.g. research institutes and development agencies partnering with SMEs). In India, the requirement that companies direct 2% of their revenues to CSR creates a potential funding mechanism for pilot research projects that become prototypes for private-public-academic partnerships in agri-food production innovation.

Capacity and available partners

There is an overall need for expansion in the number of scientists working on many dimensions of pulse production and consumption. Interactions among geneticists, breeders, agronomists, and social scientists are essential to developing new pulse cropping systems that reduce pesticide use, better manage diseases / pests, optimize fertilizer use, and build agrobiodiversity. There are too few socio-economic scientists working on pulses and more are needed. In some countries, agriculture research institutes may not have robust social science and economic counterparts to partner with. Importantly, multi-disciplinary focus should not come at the expense of support for work on pulse genetics and breeding. There is a real risk of lost capacity in these areas in the absence of consistent and adequate funding.

Integration across disciplines relevant to pulses (e.g. agronomy, rural development, health and wellbeing) is inhibited by relatively weak, underfunded Extension institutions, which would otherwise be well-positioned to lead integrative socio-economic approaches. In a context focused on specialization, there is a need for good farming systems skills and production of farmer-relevant information (beyond promoting new varieties). New Extension models, or revival of previously successful ones (e.g. close alliance between Agricultural Offices providing training and advisory services and Block Development Offices arranging for farming inputs that used to function coordinately at the district level in India), may be needed. Strengthening support for Extension institutions requires building political will across sub-national jurisdictions.

CHAPTER 5. SPATIALLY-EXPLICIT ANALYSES RELATED TO GLOBAL CHALLENGES

Research objectives

Contribution to global and national challenges

Pulses have high potential to contribute to global and national targets related to sustainable development and climate change. To support policy development and integrated land use planning, it is necessary to improve the capability for quantification of potential and actual benefits for meeting the Sustainable Development Goals (SDGs)[xxii] and Nationally Determined Contributions (NDCs) for greenhouse gas mitigation and climate change adaptation. Understanding the potential for domestic pulse production is relevant to ensuring national food and nutritional (e.g. protein, micronutrient) security. A number of developed countries have surplus production, while many developing countries have a pulse deficit, especially in West and South Asia.[xxiii] Europe also has a significant pulse deficit, which is currently met through soybean imports.

To more fully incorporate pulses into global sustainable development and climate finance programs, international agencies would benefit from access to integrated, spatially-explicit analysis of the potential contribution of pulses. This would enable strategic targeting of 'public good' investments to maximize food and income security, natural resource integrity, and greenhouse gas emission reductions, while minimizing negative effects on local communities. For national agencies to identify biophysically and socio-economically suitable areas for investment in sustainable pulse production (e.g., infrastructure; locally-relevant R&D and Extension), they will benefit from spatially-explicit analysis of the potential contribution of pulses to agricultural productivity, livelihood and nutrition improvement, and national targets (e.g. low-carbon development).

Risks and opportunities in specific geographies

Risks associated with pulse production are spatially variable at multiple scales. Where risks are few (e.g. high water-holding capacity soils), pulse crops are more readily adopted by producers given nitrogen and other benefits to cropping systems. In other regions that face numerous risks (e.g. variable in-season rainfall; significant pest, disease, or weed burden), producers are less likely to integrate pulses into their farming systems.

To support increased productivity and sustainability of pulses in the context of land competition and degradation (e.g. integrating into cereal-dominated farming systems; optimizing production on marginal lands), sufficiently granular assessment of major risks and opportunities across diverse farming systems is needed. To understand which cropping systems will be amenable to inclusion of pulses as a mixed or rotation crop, work is needed to:

- Simulate rainfall (for defined crop water requirements) and temperatures (for defined heat tolerances) to estimate the probability of pulse crop failure.

- Anticipate climate change effects (e.g. disease; pests; drought) at scales relevant to production decisions.
- Forecast the potential success (accounting for costs, labor, and socio-cultural factors) of improved varieties, new technologies, and / or alternative farming systems (e.g. integrated crops and livestock).

Success factors

Pulses are ancient crops and pulse crop domestication was required for the development of arable agriculture. They are 'traditional' crops in many parts of the world that have lost ground to cereal production. In other areas, pulses are relatively recent additions to cropping systems (i.e. Canada, Australia, USA). In the last fifty years, while there has been some increase in production of warm-season pulses (e.g. cowpea, common bean, pigeonpea), the amount of land dedicated globally to producing many temperate region pulse crop types (e.g. pea, faba bean, vetches, lupin) has declined.[xxiv] Acreage dedicated to lentil production has increased globally and chickpea production area has held constant.

Recent pulse production gains in countries such as Australia, Canada, Ethiopia, and USA demonstrate that there are opportunities to markedly increase pulse production within farming systems of different sizes and types. Research is needed to construct a clear understanding of where pulse crops are being adopted and succeeding or failing and why (e.g. policies; producer support; socio-economic benefits), so that interventions are well-targeted. A central focus will be understanding how pulses compete with other crops in terms of producer profitability.

Tools and approaches

Crop simulation models

Crop simulation models draw on global circulation models, weather data, maps of soil fertility and growing period, and demographic data (e.g. poverty, stunting) to predict outcomes (e.g. yield, health improvement) under alternative conditions (e.g. growing pulses in new areas; altered genetic architecture; intercropping; change in cultivation method, timing, or plant density). Crop simulation models can inform development of breeding objectives and this should be complemented by assessment of production value to farmers. To increase the likelihood of farmer adoption (and value chain development) for improved varieties, more integrated research packages are needed that bring GIS, crop simulation models, and socio-economic expertise into breeding and agronomy programs.

Spatially-explicit models can be used to evaluate crop suitability across heterogeneous areas, estimate climate change impacts (e.g. using standard standard scenarios) and production constraints, and assess the effects of alternative management approaches (e.g. different crop mix, soil management, fertilization, water use) on yield and environmental parameters (e.g. nutrient status, water use, soil carbon). Model outputs depend on realistic, accurate parameterization, which requires long-term field trial data for well-described pulse cultivars and management (e.g. planting and harvesting dates; intensity of fertilization and irrigation; other species in rotation).[xxv]

Life Cycle Analysis

Policy makers seeking to achieve sustainable food supply systems need to answer questions about which foods should be imported or produced domestically and how agricultural land should be used. The Life cycle analysis (LCA) approach can be combined with land use models to address these issues. With growing interest in dietary transitions away from animal toward plant protein sources, LCA becomes a useful tool for exploring the full suite of effects that might result from shifting pulses to the 'center of the plate.' Implications can range from environmental effects (e.g. nitrogen use and pollution; water use and quality), food waste (i.e. pulses are less vulnerable to waste), processing efficiency, and affordability of food products re-formulated to include pulses (i.e. can pulses deliver nutrition similar to meat, fruit, and vegetables at a cheaper price?) LCA requires attention to multi-year, multi-criteria, and cross-supply chain effects (including health benefits) and land use options (e.g. arable and grasslands) and should account for pulses that are directly consumed by people and indirectly consumed (i.e. pulses as animal feed).

Sustainability reporting

Increasingly, food manufacturers and producers will encounter demands for comparative sustainability data for animal, plant, and insect protein (e.g., water demand; cost of production; agrichemical and energy use; GHG footprint). Producers will need feasible strategies for monitoring and reporting on sustainability improvements to their farming system. Improving pulse supply chain transparency (i.e. increasing capacity for markets to deliver signals about food safety and sustainability expectations) can reduce market barriers for small-scale producers and expand sourcing options for international pulse traders and manufacturers.

Development agencies and research institutions are working to develop more integrated sustainability metrics (e.g. for 'climate-smart' agriculture) that look beyond area, yield, and volume of production to accommodate profitability (costs and prices at farm and firm level), nutrition, value addition and processing, gender, and resilience to environmental variability.

Current capacities and competencies

While relevant crop simulation modeling tools exist (e.g. Simple Simulation Modeling, SSS), they need to be calibrated and validated (e.g. for chickpea). Further work is needed so that models are more routinely used for important pulse species and growing regions. This involves scavenging from the literature base to develop appropriate coefficients for additional pulse species and testing through case studies. Although important for areas affected by malnutrition, nutrition signatures have not yet been incorporated into crop simulation models for pulses. This requires better understanding of the effect of genetic changes on nutritional characteristics. The community of pulse crop modelers is quite small and clustered in groups at ICARDA, ICRISAT and in North Carolina, Montpellier, and Iran. Global efforts to improve agricultural models are essential for navigating emerging to challenges to crop production systems. For example, the Agricultural Model Intercomparison Project (AgMIP) is an important platform for building capacity for modeling integration of pulses into cereal based systems and impacts of pest and disease.

Many global-scale LCA studies are undertaken (with pulse crops embedded in the analysis), but there is a need for national scale studies which produce results relevant for agricultural and food policies.

Robust public sector agricultural data systems are an important foundation for investing strategically to maximize food security, community development, and natural resource integrity (i.e. basis for designing of research strategies, programs and activities). Higher temporal and spatial resolution data can improve spatially-resolved scenarios and predictions. Opportunities for data improvement may existing through recent advances in crowdsourcing information, big data, and ICT. Building constituencies for robust data and models involves communicating benefits of spatially-explicit evaluation of investments.

RECOMMENDATIONS

A vision for pulse crop research

This Research Strategy shines a light on areas of broad international agreement for strategic research priorities for pulse crops. It is clear that now is not the time for simply applying available tools to narrowly scoped problems. Rather, there is strong support for integrated approaches that emphasize sustainability and transformative potential of scientific investments. Key outcomes for agriculture, value chains, and consumers include:

- **Sustainability in the face of global challenges** including agricultural systems that can meet growing global protein and micronutrient needs and are resilient to weather extremes, increased pest and disease burdens, and other climate change threats.
- **Natural resource sustainability** including cropping systems with higher soil fertility, water use efficiency, and microbial diversity and reduced greenhouse gas emissions and environmental impacts.
- **Diversification as a source of sustainability** for agriculture (e.g. increasing overall productivity of cereal-based systems) and human well-being (e.g. combatting health problems associated with under- and over-nutrition).
- **Economic sustainability at the farm scale** including reduced risks and improved farm income and dietary diversity, supported by better agronomic management tools and input supply systems.
- **Sustainable value chains** that better utilize whole grain pulses and pulse fractions and offer consumers healthy and appealing pulse-based products through expanded public and private sector coordination and investment in agri-enterprise and food manufacturing.
- **Sustainability of research capacity, knowledge, and infrastructure** (especially in developing nations) including model-informed, farmer (especially women and youth) participatory research and pipelines for regionally-tailored varieties, technologies, and management practices.

Investing in global and regional priorities

The need for research investments that are focused on end-user needs and targeted at multiple scales is widely recognized. Consistent and significantly expanded investment in pulse research should focus on:

Global and cross-regional scale

To fill gaps and increase coordination of research functions that serve many or all pulse-growing regions (i.e. fundamental research capabilities, tools, and technologies), global platforms should emphasize:

- Undertaking gap analysis of genetic resources (e.g. sources of resistance to emerging stresses);
- Compiling evidence for where greater integration of pulses is appropriate and can provide benefits (e.g. diversification; reduction of inputs);
- Linking different disciplines and forging connections to work on cereal systems and ecosystem services;
- Providing context for research networks that provide training and ensure quality control; and
- Taking the lead in identifying and developing research partnerships with the private sector.

Regional and local scale

Agricultural systems and public health challenges vary dramatically across major regions of the world so, while the same basic research functions are needed in all regions, the structure and focus of research activities will vary based on regional characteristics. To establish or enhance delivery of 'universal' research functions in regionally-adapted ways (i.e. focused on region-specific challenges and opportunities in production, nutrition, health, markets, and supply chains), integrated research programs will need to address a wide range of issues such as:

- breeding and use of relevant pulse species and cultivars for specific growing conditions and uses;
- new types of sustainable, diversified cropping systems;
- socio-economic dimensions of production and consumption;
- value chain / market conditions and consumer preferences;
- national level capacity to undertake research.

The table below summarizes major research functions that require investment at **global** (or cross-regional) and **regional** (or local) scales.

Research priorities	Global and regional functions
Germplasm resources	Global. Acquisition, maintenance, and access for germplasm collections.
	Global. Characterization (using molecular tools; phenotyping) to understand potential sources of desired traits.
	Global. In situ conservation of genetic variation among wild relatives.
Genetics and genomics	Global. Tool and technology development (e.g. adapting work on other plants / biota to pulse species).
	Global. Development and maintenance of publicly available databases (i.e. genome sequences; diversity panels; markers).
Modeling and analysis	Global. Adaptation of existing modeling tools to pulse species including model intercomparison.
	Regional. Use of crop simulation models to better integrate geographic variability and risks into priority-setting for breeding and agronomic interventions.
	Regional. Use of foresight and ex ante assessment (e.g. yield gaps, farmers' risk perceptions; desired pulse traits; market expectations; potential for nutrition / health; supply chain needs) to inform agriculture and value chain interventions.
Crop improvement	Regional. Breeding regionally-adapted varieties that optimize for growing conditions and objectives including yield, resilience, water / nutrient use efficiency, suitability within farm systems (e.g. plant architecture amenable to mechanization; animal feed) and value chains (e.g. market requirements; processing suitability; uses of pulse fractions), nutrition challenges (e.g. high-iron cultivars to address anemia), and valorizing under-utilized pulse species.
Innovation pipelines	Regional. Establish or improve farmer participatory research (e.g. farmer levy supported projects; international development funded studies; company funded work in key sourcing regions).
	Regional. Establish or improve pipelines for improved pulse varieties (i.e. pulse seed multiplication, distribution, and quality assurance systems) and agronomic packages.

Research priorities	Global and regional functions
Integrated cropping systems	Regional. Maximize integrated management of crops, pests / diseases, and weeds including innovation in mechanization (e.g. sowing, harvesting, threshing equipment) and post-harvest technologies (e.g. storage bags).
	Regional. Exploit the potential of pulse-cereal systems (e.g. diversification of cropping systems and diets to meet regional targets for food / nutritional security, soil health and environmental integrity, climate change mitigation and adaptation).
Producer support programs	Regional. Establish or improve producer support programs including rural advisory services and ICT platforms (e.g. pest and disease early warning).
Value chains	Regional. Maximize value addition through quality enhancement (e.g. targeted to specific end uses), aggregation (e.g. storage, transport), processing (e.g. cleaning, de-hulling, milling) facilities, and market development (e.g. manufactured products).
	Regional. Develop commercially viable uses and cost-effective processes for novel food (e.g. protein concentrate) and biomedical applications.
	Regional. Establish or improve sustainability reporting and food safety systems.
Nutrition and health	Global. Solidify the evidence base for contribution to malnutrition and non-communicable diseases.
	Global. Improve understanding and capacity for enhancing micronutrient bioavailability including biofortification.
	Regional. Evaluate the potential for nutritional / diet transitions (e.g. diversification, plant-based protein) and 'whole of diet' approaches.
Quantification	Regional. Quantify the impacts of pulses in cropping systems on nitrogen, water, soil biology, greenhouse gas emissions, and socio-economic dimensions (e.g. income, gender, food and nutritional security) and use to develop farm-level management and accounting tools (e.g. nitrogen, multi-functionality).
	Regional. Evaluate the contribution of pulses to national targets (e.g. health and nutrition, climate adaptation and mitigation) and policies (e.g. subsidies, minimum support prices, agriculture / rural development).
Scientific capacity	Global. Replenish ranks of retiring pulse scientists through training and core funding of academic positions mandated with consistent effort toward critical challenges (e.g. focused evaluation of genetic traits).
	Global. Establish or improve cross-regional, multi-disciplinary 'challenge-focused' exchange platforms (e.g. sources of potential pest / disease resistance, water use efficiency) and food technology exchange platforms (e.g. methods for full commercial viability of pulse fractions).
	Global. Bring pulse-specific concerns into broader scientific platforms (e.g. intellectual property; spatial data; dietary studies; scientific capacity in developing countries).

Investing in the pulse research community

The mandate for the International Year of Pulses is to encourage connections throughout the food chain that would better utilize pulse-based proteins, to further global production of pulses, to increase the efficiency of crop rotations, and to address trade challenges. The pulse research community plays several critical roles in meeting this mandate. A strong, multi-scale global pulse research community that integrates work across all countries and regions, is capable of meeting local to global needs, and is well-linked to the broader agricultural science community is central to the vision described here. Collaboration anchored in global and regional networks of scientists, government partners, and industry players is necessary for improved productivity and sustainability of pulses.

Call to action

Increased production and consumption of pulses is essential if global agriculture and food systems are to stay within planetary boundaries. In the coming decade, collective action toward a shared vision for investing in pulse crops research can deliver impactful, efficient scientific progress that unlocks the potential of pulses for agricultural sustainability and human well-being. This Research Strategy calls for a level of research investment that is in line with the scale of global challenges and opportunities faced by pulse crops.

These recommendations are directed at public and private sector stakeholders in government, agriculture, health, the food industry, foundations and funding agencies, research institutions, and consumer groups. Industry groups, such as the Global Pulse Confederation, can play a critical role in promoting value addition pathways for pulse-based products (e.g. by engaging SMEs, regional partners, and major food companies). National governments can promote pulse production and consumption as part of climate-smart economic development (e.g. for export as well as in-country pre-processing and value addition for local markets) and public health (e.g. dietary diversification). Research institutions will be the engines of knowledge and innovation. All stakeholders can work to ensure that pulses are included in major policies and sustainability finance mechanisms (e.g. Green Climate Fund).

APPENDIX 1 LIST OF CONTRIBUTORS

	Name	Affiliation	Advisory committee	Interview / early input	Write-shop	Bilateral input / review	Verification meeting
1.	Shoba Sivasankar	CGIAR Research Program on Grain Legumes, ICRISAT (*Organizing Author*)	Author	X	X		
2.	Noel Ellis	IYP Productivity and Sustainability Committee, Global Pulse Confederation (*Lead Author*)	Author	X	X		
3.	Robin Buruchara	Pan Africa Bean Research Alliance, CGIAR-CIAT (*Lead Author*)	Author	X			
4.	Carol Henry	University of Saskatchewan (*Lead Author*)	Author	X			
5.	Diego Rubiales	Spanish National Research Council (*Lead Author*)	Author	X	X		
6.	Jeet Singh Sandhu	Indian Council of Agricultural Research (*Lead Author*)	Author	X			
7.	Christine Negra	Versant Vision LLC (*Coordinating Author*)	Author	X	X		
8.	Steve Beebe	CGIAR CIAT	Committee	X			
9.	Jens Berger	CSIRO	Committee	X			
10.	Gerard Duc	INRA	Committee	X			
11.	Jeff Ehlers	Bill and Melinda Gates Foundation / University of California, Riverside	Committee	X			
12.	Todd Scholz	US Dry Pea & Lentil Council	Committee				
13.	BB Singh	Texas A&M University / G.B. Pant University	Committee	X			
14.	Denis Tremorin	Pulse Canada	Committee				
15.	Rajeev Varshney	CGIAR ICRISAT	Committee	X			
16.	Tom Warkentin	University of Saskatchewan	Committee	X			
17.	Irv Widders	Michigan State University - Legume Innovation Lab	Committee	X			
18.	Frederic Marsolais	Agriculture and Agri-Food Canada			X		
19.	Tomas Nemecek	Agroscope - Institute for Sustainability Sciences		X			
20.	Ping Wan	Beijing University of Agriculture				X	
21.	Gina Kennedy	CGIAR Bioversity		X			
22.	Glenn Hyman	CGIAR CIAT		X			
23.	Shiv Kumar Agrawal	CGIAR ICARDA		X			
24.	Seid Ahmed Kemal	CGIAR ICARDA			X		
25.	Mahmoud Solh	CGIAR ICARDA		X			
26.	Michel Ghanem	CGIAR ICARDA -		X			
27.	Esther Njuguna-Mungai	CGIAR-ICRISAT				X	
28.	Vincent Vadez	CGIAR ICRISAT		X			
29.	Alan de Brauw	CGIAR IFPRI - Markets, Trade, and Institutions		X			
30.	Boukar Osumane	CGIAR IITA		X			
31.	Christian Fatokun	CGIAR IITA / University of Ibadan		X			
32.	Dilrukshi Thavarajah	Clemson University		X			
33.	Flavio Breseghello	EMBRAPA - Arroz e Feijao		X			
34.	Thiago de Souza	EMBRAPA - Arroz e Feijao		X			
35.	Laurent Bedoussac	ENFA/INRA			X		
36.	Teodardo Calles	FAO-AGPM		X			
37.	Mike Dickinson	Fera Science Ltd.				X	
38.	Juraj Balkovic	IIASA, Agro-Environmental Systems Group				X	
39.	Christian Folberth	IIASA, Agro-Environmental Systems Group				X	

	Name	Affiliation	Advisory committee	Interview / early input	Write-shop	Bilateral input / review	Verification meeting
40.	Judith Burstin	INRA		X			
41.	Abderrahim Bentaibi	INRA - Morroco		X			
42.	Guinet Maé	INRA / AgroSup Dijon			X		
43.	Marie-Laure Pilet	INRA-Rennes			X		
44.	Claire Domoney	John Innes Centre		X	X		
45.	Charlie Riches	McKnight Foundation, Collaborative Crop Research Program (retired)		X			
46.	Phil McClean	North Dakota State University				X	
47.	Christine Watson	Scotlands Rural Use College			X		
48.	Marta Santalla	Spanish National Research Council			X		
49.	Erik Steen Jensen	Swedish University of Agricultural Sciences		X	X		
50.	Frederic Muel	Terres Inovia, France		X	X		
51.	Pete Iannetta	The James Hutton Institute		X			
52.	Branko Cupina	University of Novi Sad - Agriculture			X		
53.	Bert Vandenberg	University of Saskatchewan		X			
54.	David Jenkins	University of Toronto - Nutritional Science		X			
55.	Kadambot Siddique	University of Western Australia		X			
56.	Ray Glahn	USDA Research Service / Cornell University		X			
57.	Ken Giller	Wageningen University		X			
58.	Mark Manary	Washington University in St. Louis - Pediatrics		X			
59.	Ram Nair	World Vegetable Center, AVRDC - South Asia		X			
60.	Fred Stoddard	University of Helsinki			X		

APPENDIX 2 MAJOR PROGRAMS AND STAKEHOLDER INSTITUTIONS

Major pulse research programs and funding sources[xxvi]

Funders / programs / projects	Pulse types	Focus areas
CGIAR Research Program Grain Legumes	chickpea, dry bean, cowpea, faba bean, lentil and pigeonpea	Developing countries
World Vegetable Centre (AVRDC)	mungbean	South & Central Asia
Bill & Melinda Gates Foundation: Tropical Legumes III, CGIAR, N2Africa	chickpea, dry bean, cowpea, pigeonpea	Africa
Kirkhouse Trust	cowpea, dry bean, 'orphan' legumes	Africa; South Asia
Australian Centre for International Agricultural Research (ACIAR)	lentil, pea, chickpea, mung bean	Asia; Africa
Australia: Grains Research & Development Corporation (GRDC), Commonwealth Scientific and Industrial Research Organization (CSIRO)	pea, lentil, chickpea, mung bean, dry bean, cicer milkvetch	Australia
Brazil: Embrapa, Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG), Instituto Agronômico de Pernambuco (IPA), Universidade Federal de Lavras (UFLA), Universidade Federal de Viçosa (UFV), IAC, IAPAR, Universidade Estadual de Maringá	carioca bean, dry bean, cowpea	Brazil
Canada: International Development Research Centre (IDRC) - Canadian International Food Security Research Fund (CIFSRF)	lentil, chickpea	Ethiopia
Canada: Agriculture & AgriFood Canada (AAFC), Saskatchewan Pulse Growers (SPG), Agriculture Development Fund (ADF)-Saskatchewan Agriculture, Alberta Crop Industry Development Fund (ACIDF), Alberta Pulse Growers (APG), Manitoba, Ontario	pea, lentil, chickpea, dry bean, faba bean	Canada
Central & South America: Zamorano University- Honduras, ICTA-Guatemala, INTA-Nicaragua,	dry bean	Central & South America
China	(unknown)	China
Europe: FP7 (Legato, Eurolegumes, Legume Futures), Institut National de la Recherche Agronomique (INRA), other programs	pea, lentil, chickpea, dry bean	Europe
India: Indian Agriculture Research Institute (IARI), Indian Institute for Pulse Research (IIPR)	pea, lentil, chickpea, pigeonpea, dry bean, cowpea, 'orphan legumes'	India
Mexico: state programs	dry bean	Mexico
Turkey: Turkish General Directorate of Agricultural Research (GDAR), Scientific and Technological Research Council of Turkey (TUBITAK), universities, state and private seed companies	lentil, chickpea, dry bean	Turkey
US Agency for International Development (USAID): Feed the Future	dry bean, chickpea, cowpea	Africa
USA: Department of Agriculture (Agriculture Research Service-ARS, National Institute of Food and Agriculture-NIFA), commissions, universities, state programs	pea, lentil, chickpea, dry bean, cowpea	USA

Major pulse research stakeholder groups

Stakeholder groups	Examples
CGIAR	CRP on Grain Legumes, IITA, ICRISAT, ICARDA, CIAT, Bioversity, IFPRI, CCAFS.
International research consortia	Leverhulme Centre for Integrative Research on Agriculture and Health, New Alliance on Food Security and Nutrition, International Union of Food Sciences and Technology, Institutes of Pulse Research; Pea and Lentil Genome Sequence projects.
Regional regional consortia	Pan Africa Bean Research Alliance (PABRA); Association for the Advancement of Agricultural Sciences in Africa; Inter-American Institution for Cooperation in Agriculture.
Sub-regional research platforms	Center For Coordination of Agricultural Research and Development for Southern Africa (CCARDESA); Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA); (West and Central African Council for Agricultural Research and Development (CORAF/WECARD).
National research centers	Zambia Agriculture Research Institute; Ethiopian Institute of Agricultural Research, Indian Institute of Pulses Research (IIPR/ICAR) , Brazilian Agricultural Research Institute (Embrapa), Institut National de la Recherche Agronomique (INRA); Morocco, Institut National de Recherches Agronomiques (INRAT); Tunisia, Agricultural Research Center (ARC); Egypt, Central Research Institute For Field Crops; Turkey, Ethiopian Institute of Agricultural Research; Bangladesh Agricultural Research institute; Chinese Academy of Agricultural Science (CAAS); Agriculture Research Corporation of Sudan (ARCo); Lebanese Agricultural Research Institutes (LARI); Jordanian National Center for Agricultural Research and Extension (NCARE), CSIRO; USAID Legume Innovation Labs.
Global donors	International Development Research Centre (IDRC); UN Food and Agriculture Organization; USAID; Bill and Melinda Gates Foundation
Societies and NGOs	International Legume Society; ASA-CSSA-SSSA; SAI Platform; Sustainable Food Lab; International Life Sciences Institute
Farmer groups	World Farmers Organization, Pulse Canada; Pulse Australia; Northern Pulse Growers USA; US Dry Pea and Lentil Council; UNIP-France; BEPA-UK, Ugandan Farmers Federation
Industry	Global Pulse Confederation; India Pulses and Grains Association; BASF; DowDupont; Syngenta; Bayer; Novozymes; Panner; Advanced Seed

APPENDIX 3 EXAMPLES OF PULSE RESEARCH ISSUES AND CAPACITY

Major centers for pulse genetic resources[xxvii]

- Global Gateway to Genetic Resources (GENESYS)
- Asian Vegetable Research and Development Center (Taiwan; http://www.avrdc.org)
- Australian Temperate Field Crops Collection (Australia; http://agriculture.vic.gov.au)
- Banco de Germoplasma – Departamento de Recursos Genéticos e Melhoramento; Estação Agronómica Nacional, Instituto Nacional de Investigaçã Agrária (Portugal; https://www.genesys-pgr.org/wiews/PRT005)
- Centro de Investigación Agraria Finca La Orden – Valdesequera (Spain; https://www.genesys-pgr.org/wiews/ESP010)
- Centro Internacional de Agricultura Tropica, CIAT (Colombia; http://www.ciat.cgiar.org)
- Crop Germplasm Resources Information System (China; www.cgris.net/cgris_english.html)
- Crop Germplasm Resources Platform, Ministry of Science and Technology (China)
- Institute of Crop Sciences, Chinese Academy of Agricultural Science (China; http://www.cgris.net/cgris_english.html)
- International Centre for Agricultural Research in Dry Areas, ICARDA (Syria; http://www.icarda.cgiar.org)
- International Crop Research Institute for the Semi-Arid Tropics, ICRISAT (India; http://www.icrisat.org)
- International Institute of Tropical Agriculture, IITA (Nigeria; http://www.iita.org)
- International Livestock Research Institute, ILRI (Ethiopia; http://www.ilri.cgiar.org)
- Junta de Extremadura. Dirección General de Ciencia y Tecnología (Spain; http://centrodeinvestigacionlaorden.es)
- Leibniz Institute of Plant Genetics and Crop Plant Research (Germany; http://www.ipk-gatersleben.de)
- N.I. Vavilov Research Institute of Plant Industry (Russia; http://www.vir.nw.ru)
- National Bureau of Plant Genetic Resources (India; http://www.nbpgr.ernet.in)
- National Plant Germplasm System (USA; http://www.ars-grin.gov/npgs/index.html)
- NIAS Genebank (Japan; https://www.gene.affrc.go.jp/databases_en.php)
- Ustymivka Experimental Station of Plant Production (Ukraine; https://www.genesys-pgr.org/wiews/UKR008)

Major pulse pests affecting different regions[xxviii]

- North and South America: Ascochyta blights; Wilt / root rots; Stemphylium blight; Anthracnose; Chocolate spot; Rusts
- North Africa and Mediterranean: Ascochyta blights; Wilt / root rots; Rust; Chocolate spot; Parasitic weeds; Pod and stem borers; Leaf miner; Aphids; Bruchids
- Sub-Saharan Africa: Ascochyta blights; Rusts; Chocolate spot; Wilt / root rots; Pod borers; Aphids; Powdery mildew; Bruchids; Viruses; Faba bean gall
- West Asia: Ascochyta blights; Rusts; Parasitic weeds; Sitona weevils; Wilt / root rots; Leaf miners; Viruses; Bruchids
- South Asia: Ascochyta blights; Wilt / root rots/ Rusts; Botrytis gray mold; Stemphylium blight; Pod borers; Bruchids
- China: Chocolate spot; Rusts
- Australia and New Zealand: Ascochyta blights; Chocolate spot; Botrytis gray mold; Rusts; Pod borers; Viruses; Root rots; Nematodes

[i] Murrel D. 2016. Global research and funding survey on pulse productivity and sustainability. Global Pulse Confederation. http://iyp2016.org/resources/documents/technical-reports/124-pulses-global-research-and-funding-survey/file

[ii] Pardey et al. 2015. Long-run and global R&D funding trajectories: the U.S. Farm Bill in a changing context. Paper presented at: 2015 Allied Social Sciences Association Annual Meeting; Boston, Massachusetts.

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[iv] Miller et al. 2002. Pulse crop adaptation in the Northern Great Plains. Agronomy Journal 94: 261-272. Sharma et al. 2005. Rice establishment method affects nitrogen use and crop production of rice-legume systems in drought-prone eastern India. Field Crops Research, 92: 17–33.

[v] Jeuffroy MH et al. 2013. Nitrous oxide emissions from crop rotations including wheat, rapeseed and dry peas. Biogeosciences, 10, 1787–1797. Nemecek T et al. 2015. Designing eco-efficient crop rotations using life cycle assessment ofcrop combinations. Europ. J. Agronomy 65 (2015) 40–51. Lupwayi NZ, Kennedy AC. 2007. Grain legumes in Northern Great Plains: Impacts on selected biological soil processes. Agronomy Journal, 99: 1700-1709.

[vi] While soybeans (as well as groundnut and forage legumes) can deliver similar benefits as pulse crops, the latter can provide additional benefits for nutrition (e.g. micronutrient, dietary fiber) and diversification of agricultural systems and diets.

[vii] The scope of the Research Strategy is defined as pulse species (which can be optimized for a range of uses including human consumption, livestock feed, and soil improvement) rather than a more narrow definition of pulse crops as food crops only. The rationale is that: (a) it is not easy to separate pulses by uses as different cultivars can be adapted to different purposes (animal feed, green or dry seeds, ingredients, immature pods, leaves) and growing conditions (e.g. intensive vs extensive); (b) in food systems context, the multi-functional nature of pulses is important for meeting diverse needs and challenges.

[viii] Deytieux V. 2012. Is integrated weed management efficient for reducing environmental impacts of cropping systems? A case study based on life cycle assessment. Eur. J. Agron, 36, 55–65.

[ix] Siddique et al. 2012. Innovations in agronomy for food legumes: a review. Agron. Sustain. Dev, 32:45–64.

[x] Tamo M. 2016. Farmers in Benin adopt new natural enemies to fight pod borers in cowpea. http://iyp2016.org/news/173-farmers-in-benin-adopt-new-natural-enemies-to-fight-pod-borers-in-cowpea ICARDA. 2016. A new faba bean variety replenishes soils and raises hope in Ethiopia. http://iyp2016.org/news/146-a-new-faba-bean-variety-replensihes-soils-and-raises-hope-in-ethiopia

[xi] In the European Union, for example, interest in breeding approaches to pest, disease, and weed management may increase as more restrictive chemical regulations encourage alternatives to pesticide use.

[xii] In setting priorities among breeding objectives, focusing on tolerance to extreme temperature may be supported by the more solid predictions for extreme temperature as opposed to predictions for drought occurrence, however drought-resistance will be a critical trait.

[xiii] Foyer CH et al. 2016. Neglecting legumes has compromised human health and sustainable food production. Nature Plants, 2. 16112. ISSN 2055-026X.

[xiv] Siddique et al. 2012. Innovations in agronomy for food legumes: a review. Agron. Sustain. Dev, 32: 45–64.

[xv] Ebanyat P et al. 2010. Impacts of heterogeneity in soil fertility on legume-finger millet productivity, farmers' targeting and economic benefits. Nutrient Cycling in Agroecosystems, 87:209–231. Snapp SS et al. 2002. Sustainable soil management options for Malawi: can smallholder farmers grow more legumes? Agriculture, Ecosystems and Environment, 91: 159–174.

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[xvii] While intensive agronomic management can reduce risk of heavy losses, the labor cost can be a barrier for some practices in some regions.

[xviii] Lawal AF, Omotesho OA, Adewumi MO. 2010. Land use pattern and sustainability of food crop production in the fadama of Southern Guinea Savanna of Nigeria. African Journal of Agricultural Research, 5(3): 178-187. Shiferaw BA, Kebede TA, You L. 2008. Technology adoption under seed access constraints and the economic impacts of improved pigeonpea varieties in Tanzania. Agricultural Economics, 39 (3): 309-323.

[xix] IPES-Food. 2016. From uniformity to diversity: a paradigm shift from industrial agriculture to diversified agroecological systems. International Panel of Experts on Sustainable Food systems.

[xx] Fractionation can put pulse crops in direct competition with soybean (proteins are similar), which has high market value for non-protein fractions (i.e. oil).

[xxi] Laurette Dube. 2016. Building synergy between global-national Pulse Innovation Platforms and with other agricultural commodities. Paper presented at: Global and National Pulse Innovation Platforms (PIPs) and Health Innovation Platform Canada-Food (HIP-Canada-Food), Montreal, Canada.

[xxii] Pulse crops have particular relevance for: Goal 2: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture; Goal 3: Ensure healthy lives and promote well-being for all at all ages; and Goal 13: Take urgent action to combat climate change and its impacts.)

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