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10-YEAR RESEARCH STRATEGY FOR PULSE CROPS

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Increased production and consumption of pulse crops is essential if global agriculture and food systems are to stay within planetary boundaries. Yet, the 13 pulse crops receive just USD 175 million in research funding annually.

This report presents an internationally coordinated strategy designed to increase investment in five major arenas of scientific activity, each of which is essential to achieving the potential of pulse crops. 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.

Advances in breeding and genetics enable development of improved varieties that, when paired with improved management, will increase productivity and resilience of integrated cropping systems. Improvements in production require counterpart food system shifts that increase demand for and value addition to pulse crops, while improving the nutrition and well-being of all social groups. Given the complex, interconnected biophysical, socio-economic, and policy context for increasing pulse production and consumption, dedicated efforts to build multi-disciplinary pulse research capacity are essential. Finally, spatially-explicit data and models are foundational for guiding interventions and quantifying the impact of pulses on human well-being and agricultural sustainability. Balanced investment in research and development across these five priority scientific arenas can deliver holistic, realistic transformation.

> *Increased pulse production and consumption can contribute to achieving the UN Sustainable Development Goals.*
>
> **Goal 2: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture.** Pulses are a global crop that provides income for farm families and nutrition for the hungry and malnourished. Greater integration of pulse crops into farming systems can contribute to food and nutritional security and natural resource integrity.
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> **Goal 3: Ensure healthy lives and promote well-being for all at all ages.** Pulses provide good nutrition – including protein, fiber, vitamins and minerals. They are low in saturated fat, reduce the risk of some chronic diseases, and support better diets to maintain healthy body weights. With two to three times as much protein as many cereals, pulses can have particular benefits for communities with protein-deficient diets.
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> **Goal 13: Take urgent action to combat climate change and its impacts.** Pulses are a low carbon footprint food. Pulses can help to cost-effectively reduce risks to farming from climate change, such as disease, drought, and extreme temperatures. Farmers can adapt to changing weather patterns by choosing from a wide array of pulse varieties to match plant traits to altered growing conditions.

Breeding and genetics for improved productivity and resilience. Effective breeding and genetic improvement of pulses, that harnesses their tremendous genetic diversity to match location-specific growing conditions and the needs of households and local and global markets, is required to increased production and consumption. Investments should be informed by agricultural constraints (e.g. biotic and abiotic stresses) and opportunities (e.g. inclusion in cereal-based systems; enhanced nitrogen fixation and yield) as well as uses on-farm (e.g. food, feed, soil fertility) and beyond (e.g. market demands; novel food products) through collaboration with agronomists, producers, food scientists, and others. Climate change is an important driver for genetic improvement that anticipates future shifts in temperature and precipitation.

Pulses in integrated cropping systems and agricultural landscapes. The declaration of the consecutive years 2015 and 2016 as the International Year of Soils, and that of Pulses, respectively, by the UN General Assembly, signifies the strong alliance between soils and pulses in sustainable agriculture. Adding pulses to a cropping system can boost total productivity of all crops by increasing the availability of nitrogen and other mineral nutrients, disrupting pest, weed, and disease cycles, enhancing nutrient and water use efficiency, reducing the impact of weather extremes, and augmenting system diversity. There are many different cultivated pulse crops that support a range of uses including human consumption, livestock feed, and soil improvement with potential benefits for income and household nutrition. For large- and small-scale farmers, integration of pulse crops into farming systems can be inhibited by uncertainties regarding specific benefits, labor requirements, pulse marketability, and price signals. Research that provides farmers with options for long-term, integrated management of their pulse-based cropping system can sustainably and profitably increase productivity.

Source: http://iyp2016.org/

Integration of pulses into food systems. Pulses are central to many culinary traditions around the world and, in many countries, they are a cornerstone of food and nutritional security. 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. Confronted by the dual epidemics of malnutrition and overnutrition, the world needs to see greatly increased representation of high-protein, low-fat, high-fiber pulse grains in human diets. 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.

Integration across agricultural, nutritional and social sciences. Relevant, effective innovation for increasing pulse production and consumption requires multidisciplinary approaches that combine well-targeted breeding and agronomy with socio-economic and market knowledge and builds on scientific advances made in other crop types. Multiple research modalities will be needed to develop an integrated understanding of the functions, constraints, and opportunities for pulses within specific geographies (e.g. regions; soil and climate regimes). Coordinated research among pulse and cereal crop researchers can focus on development of production practices and technologies for holistic management of cropping systems as well as efficient seed system models (e.g. multi-seed availability to farmers) and manufacture of cereal- and pulse-based foods. Interdisciplinary collaboration across plant breeders, physiologists, agronomists, and food scientists is needed to optimize for nutrition objectives (e.g. linking high-throughput screening tools with animal studies, nutrient absorption trials, and efficacy studies).

Spatially-explicit analyses related to global challenges. Pulses have strong potential to contribute to the Sustainable Development Goals (SDGs) and Nationally Determined Contributions (NDCs) for greenhouse gas mitigation and climate change adaptation. To support policy development and integrated land use planning, improved capability for quantification of potential and actual benefits of pulses for meeting global and national targets is essential. Also, estimating the potential for domestic pulse production is relevant to ensuring national food and nutritional (e.g. protein, micronutrient) security. 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 can be well-targeted.

Recommendations

There is broad international agreement on strategic research priorities for pulse crops, that emphasize sustainability, transformative potential, and end-user needs. Consistent and significantly expanded investment in pulse research should be targeted to multiple scales.

Global and cross-regional scale. To fill gaps and increase coordination of research functions that serve many or all pulse-growing regions, global platforms should emphasize: gap analysis of genetic resources; evidence of pulse crop benefits; forging linkages with cereal crop researchers; establishing challenge-focused networks; and developing research partnerships with the private sector.

Regional and local scale. While the same basic research functions are needed in all regions of the world, the structure and focus of research activities will vary based on region-specific challenges and opportunities in production, nutrition, health, markets, and supply chains. To deliver 'universal' research functions in regionally-adapted ways, integrated research programs will need to address a wide range of issues such as: optimizing pulse breeding and cropping systems for specific growing conditions and end uses; socio-economic dimensions of production and consumption; value chain conditions and consumer preferences; and national level research capacity.

Major research functions at global (or cross-regional) and regional (or local) scales.

Research priorities	Global and regional functions
Germplasm resources	Global. Acquisition, maintenance, and availability of germplasm and mutant collections.
	Global. Evaluation (genotyping; phenotyping) to understand potential sources of desired traits (e.g. stress resistance; nutrient bioavailability).
	Global / regional. *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; phenotyping; 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, agronomic, and policy interventions.
	Regional. Baseline data collection and *ex ante* or *ex post* impact assessment of agriculture and value chain interventions (e.g. yield gaps, farmers' risk perceptions; desired pulse traits; market expectations; potential for nutrition / health; supply chain needs) with emphasis on women (e.g. income; household nutrition) and youth (e.g. agri-enterprise).

Research priorities	Global and regional functions
Crop improvement (including climate resilience)	Regional. Breeding regionally-adapted varieties that are optimized for growing conditions and objectives including yield, multiple stress resistance, water / nutrient use efficiency, suitability within farming 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 across production pipelines and value chains (e.g. farmer levy supported projects; international development funded studies; company funded work in key sourcing regions; gender-sensitive research modes).
	Regional. Establish or improve production pipelines to deliver improved pulse varieties (i.e. pulse seed multiplication, distribution, and quality assurance systems) together with location-specific agronomic packages.
Integrated cropping systems for sustainable production	Regional. Maximize integrated management of crops, weeds, pests, and diseases including innovation in mechanization (e.g. multi-crop systems; sowing, harvesting, threshing equipment) and post-harvest technologies (e.g. hermetic 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 for inclusive growth	Regional. Establish or improve producer support programs including rural advisory services and ICT platforms (e.g. pest and disease early warning; weather and market information).
Value chains and poverty reduction	Regional. Maximize value addition through quality enhancement (e.g. targeted to specific end uses), reduced loss (pre- and post-harvest), aggregation (e.g. storage, transport), processing (e.g. cleaning, de-hulling, milling) facilities, and market development (e.g. manufactured products; novel uses).
	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.
Sustainable consumption for nutrition and health	Global. Solidify the evidence base for contribution of pulses 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 / nutritional security, health) to support 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; incomes; climate adaptation and mitigation) that can feed into policy guidelines (e.g. subsidies, minimum support prices, agriculture / rural development).

Research priorities	Global and regional functions
Scientific capacity and partnerships for development	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).

A strong, multi-scale global pulse research community that integrates work across all countries and regions and is well-linked to the broader agricultural science community is central to the vision described in this Research Strategy. This requires investment in the regional and global pool of scientists capable of addressing critical needs in pulse breeding and genetics, agronomy, nutrition and health, socio-economic dimensions, and spatial analysis. Collaboration anchored in networks of scientists, government partners, and industry players is key to improved productivity and sustainability of pulses.

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. Recommendations are directed at public and private sector stakeholders in government, agriculture, health, the food industry, consumer groups, funding agencies, foundations, and research institutions. Pulses are the future of food and the future starts now.

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 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 pulses is an important part of meeting international challenges and delivering on commitments such as the Sustainable Development Goals. The agriculture sector is wrestling with rising competition for land and resources, climate change, growing food demand, and complex commodity markets. With more research attention, pulses can make major contributions to sustainable food and agricultural systems. 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.

> Pulses are annual and perennial leguminous crops harvested solely for dry grain. They include dry beans (including *Phaseolus and Vigna* species), dry peas, dry broad beans, chickpeas, lentils, dry cowpeas, pigeon peas, Bambara beans, lupines, vetches, and pulse nes (e.g. *Sphenostylis stenocarpa; Mucuna pruriens*). Legume species when used as vegetables (e.g. green peas, green beans), for oil extraction (e.g. soybean, groundnut), and for sowing purposes (e.g. clover, alfalfa) are not considered pulses.
>
> All pulse species merit research investment based on their unique importance in local, regional and global contexts (e.g. diversification and resilience; local dietary preferences).
>
> *Source: FAO. 1994. Definition and classification of commodities: 4. Pulses and derived products. (www.fao.org/es/faodef/fdef04e.htm*

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.[i] The 13 pulse crops receive just USD 175 million in research funding annually, a significant shortfall compared to so-called major crops[ii] and a tiny fraction of the USD 61 billion directed toward public and private food and agriculture research.[iii] This low level of investment undermines the sustainability and coherence of the pulse research community.

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[iv] and heart disease,[v] in combating obesity,[vi] and in building a diverse microbiome.[vii] More focused evidence gathering will clarify the importance of pulse consumption in reducing malnutrition and obesity and will provide data to inform national dietary guidelines and the emerging medical arena of 'prescription food' and to support policies that better incentivize farmers to grow pulses. Across the many different types of pulses, suitable varieties that can deliver a high-protein, micronutrient-rich 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, with minimal negative environmental impact, significantly boost total productivity of all crops in a rotation by increasing availability of nitrogen and other mineral nutrients, enhancing nutrient and water use efficiency, augmenting system diversity, disrupting pest, weed, and disease cycles, and improving soil quality.[viii] Pulses have a strong strategic alliance with soils in that they help maintain and improve soil health while reducing soil degradation[ix]. Pulses consistently provide nitrogen benefits under very different nitrogen-limiting growth conditions.[x] By fixing atmospheric nitrogen, through biological nitrogen fixation, they reduce fertilizer needs across the whole crop cycle and lower greenhouse gas footprints.[xi] Pulses have a low water and energy footprint compared to most other protein sources[xii] and they can increase overall water use efficiency in crop rotations.[xiii] Many pulse crops are well adapted to semi-arid and dry conditions globally and can tolerate drought stress better than most other crops, an important trait in a changing climate.[xiv]


Source: http://iyp2016.org/

Diversity of pulse crop species and varieties is a key advantage for agricultural sustainability.[xv] There are many different cultivated pulse crops that support a range of uses including human consumption, livestock feed, and soil improvement.[xvi] To avoid yield loss or crop failure in a context of changing weather regimes, small- and large-scale producers can make use of natural variation among pulse crop types to match plant traits to growing conditions. Adding pulses to cereal-based cropping systems can help farmers to reduce the impacts of pests, diseases, and weeds as well as weather extremes.[xvii] This can also add new sources of income and household nutrition, while mitigating environmental and financial risks.[xviii] The tremendous genetic diversity of pulse species and varieties 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 many culinary traditions around the world and, in many countries, they are a cornerstone of food and nutritional security. Some regions have a 'pulse deficit' in that their populations consume more pulses than they produce (e.g. India, Europe, Middle East, North Africa). 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, Turkey, 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.[xix]

Re-integrating into sustainable agriculture. Prior to the 1940s, when invention of the Haber-Bosch process led to the production of nitrogen fertilizers, pulse crops were integral to most cropping systems due to their role in converting atmospheric nitrogen to plant-available forms. While the benefits of nitrogen fertilizers are well-known, we now understand the significant problems associated with excess fertilizer use (e.g. water and air pollution; energy use in fertilizer production; greenhouse gas emissions) and recognize the need to re-integrate pulses back into cropping systems. Re-integration of pulses also offers promise for cereal-dominated cropping systems in regions such as sub-Saharan Africa which commonly lack sufficient nitrogen sources. Adding pulse crops can increase the diversity of on-farm biota, of household food, of livestock feed, and of income sources while improving ecosystem services. However, the agronomic and environmental benefits of pulses vary considerably across growing conditions and farmers currently have few tools 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 mostly remained stagnant.[xx] 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).[xxi]

Pathways to increased pulse production and consumption

Supporting research for productivity enhancement. To match the productivity gains made in cereal crops in recent decades, steady investment in systematic, streamlined pulse breeding programs is urgently needed and can build on existing scientific progress. Mature breeding technologies for accelerated genetic gain have already been proven in cereals and should be incorporated into pulse breeding efforts. The practical implications of packaging crop varieties with optimal management practices are better understood and expanded capacity for location-specific adaptation testing is needed.

Strengthening delivery pipelines. Supply chains that effectively deliver high-quality pulse seeds to producers and harvested pulse crops to markets or processing plants are essential to increasing pulse production and consumption. While there have been notable successes, breeding of improved pulse varieties alone has been insufficient to meet the needs of pulse producers and value chains. In many places, new cultivars and agronomic packages lack viable pathways to farmers' fields given fragmented pulse seed multiplication and distribution systems and rural advisory services. Stimulation of appropriately scaled agri-enterprise systems that provide tangible links between breeding programs and producers is required, including the provision of high-quality, disease-free pulse seeds, region-specific breeding, and support of differentiated markets for pulse crops (e.g. local consumption, commodity export, processing).

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 or Europe). 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.

Source: http://iyp2016.org/

- **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 cooking and 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) in both local and export markets. 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 (e.g. marketing messages anchored in credible environmental and health claims). While product development will be complex (e.g. validating nutritional and sustainability benefits; evaluating sourcing and processing feasibility), there is high potential for substantial 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 to maximise efficiency and synergy.

Despite significant potential to improve food security and agricultural sustainability, global pulse crop production has remained relatively stagnant in yield per hectare, hectares planted, and total volume produced. The science of pulse agriculture is markedly underdeveloped compared to other staple crops, including cereals. While genome sequencing information is becoming rapidly available, pulse crops have lagged behind cereal crops in the practical application of molecular breeding techniques despite technological advances and reduced costs. The role of pulses in farming systems with other crops (e.g. rotation, relay, and intercropping systems) is under-researched. Similarly, while early scientific advances regarding the effects of pulses in human diets suggest an important role in combating malnutrition and non-communicable diseases, this body of knowledge has not expanded at a rate necessary to catalyze change in dietary guidelines and clinical practice.[xxii]

State of knowledge for pulses

Source: http://iyp2016.org/

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 and secure pulse crop productivity and resilience through a combination of genetics, breeding, and agronomy;
- Context-specific options for profitably integrating pulses into cropping 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 and predictive capacity for pulses' contribution to farming systems, to soil quality, to the environment, and to nutrition and health.

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; faba bean in Europe; common bean in Argentina, China, and Central Asia; pea in Russia and Turkey; and mungbean in Myanmar, China, and Australia.[xxiii]

Despite modest funding, researchers have demonstrated the potential to significantly improve smallholders' pulse productivity and resilience (e.g. climbing bean in Rwanda; biological control of podborer in cowpea in West Africa; pigeon pea in east Africa; high-yielding, disease-resistant, waterlogging-tolerant faba bean variety in Ethiopia).[xxiv] Pulse crops are rich in micronutrients (e.g. high-iron common beans from northern Colombia)[xxv] and an excellent vehicle for biofortification (e.g. high-iron bean and lentil varieties).

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 large, 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) food systems; (vi) modeling and 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 1 for a list of contributors).

In September 2016, interviews were conducted with 33 experts and on October 15, as part of the Second International Legume Society conference in Troia, Portugal, a write-shop brought together 17 pulse researchers for a structured discussion of a preliminary draft. In November, comments were solicited from a broad set of pulse research stakeholders through distribution of a review draft and presentation at the IYP Global Dialogue held at the UN Food and Agriculture Organization in Rome. These comments have informed development of this final version of the 10-Year Research Strategy for Pulse Crops.

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 yet underway at the necessary scale within existing funding and implementation mechanisms. It takes a global view and encompasses many dimensions including genetics, breeding, 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, consumer groups, foundations, funding agencies, and research institutions (see Appendix 2 for a list of major institutional stakeholders).

Source: http://iyp2016.org/

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.

The following chapters describe key research objectives, tools and approaches, and capacities and competencies for five major arenas of scientific activity, each of which is essential to achieving the potential of pulse crops. Advances in breeding and genetics enable development of improved varieties that, when paired with improved management, will increase productivity and resilience of integrated cropping systems. Improvements in production require counterpart food system shifts that increase demand for and value addition to pulse crops, while improving the nutrition and well-being of all social groups. Given the complex, interconnected biophysical, socio-economic, and policy context for increasing pulse production and consumption, dedicated efforts to build multi-disciplinary pulse research capacity are essential. Finally, spatially-explicit data and models are foundational for guiding interventions and quantifying the impact of pulses on human well-being and agricultural sustainability. Balanced investment in research and development across these five priority scientific arenas can deliver holistic, realistic transformation.

To ensure that pulse producers and value chain actors have the evidence-based knowledge and technologies they need to increase global pulse production and consumption, a long-term vision supported by public and private sector investment and action is essential.

CHAPTER 1. BREEDING AND GENETICS FOR IMPROVED PRODUCTIVITY AND RESILIENCE

Effective breeding and genetic improvement of pulses, that harnesses their tremendous genetic diversity to match location-specific growing conditions and the needs of households and local and global markets, is foundational to increased production and consumption. Coherent breeding and genetic programs are a critical component of global efforts to boost yields and stress resistance of pulse crops.

Research objectives

Unlike major cereal crops, which have had massive investment, pulse crops have been weakly funded. As a result, many urgent pulse breeding goals that would increase productivity and profitability, reduce producer risks and environmental impact, and expand uses of pulse crops remain unrealized.

Investments in breeding and genetics should be informed by agricultural constraints (e.g. biotic and abiotic stresses) and opportunities (e.g. inclusion in cereal-based systems; 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. meeting market and consumer preferences; novel food products; applications in industry and medicine) through collaboration with agronomists, plant physiologists, producers, food scientists, and others. Climate change is an important new driver for genetic improvement that anticipates future shifts in temperature and precipitation. Pulse crops can also mitigate climate change through reduced greenhouse gas emission for the whole agri-food chain. 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:

- Realization of full potential for **yield** and **yield stability** through increased and durable resistance to biotic (e.g. diseases, pests, weeds)[xxvi] and abiotic stresses (e.g. extreme temperature, drought, excess moisture, soil anoxia, poor mineral availability, salinity, acidity).[xxvii] Variable field performance and risk of catastrophic losses create major impediments to farmers including pulses in their cropping systems and, in some regions, tightening regulation of pesticides amplifies the importance of breeding for resistance to biotic stresses.

Source: http://iyp2016.org/

- Enhancing **biological nitrogen fixation** by understanding and using plant and / or microbial genetics (e.g. investigating plant control of nitrogen partitioning or developing rhizobia strains capable of withstanding hotter and drier climates) to increase nitrogen availability for pulses and other crops while reducing reliance on chemical fertilizers.
- Improving **nutrient** and **water use efficiency**, which can expand the range of conditions suitable for pulse production while reducing costs and risks. Relatedly, improved overall nitrogen use efficiency in multi-crop systems can contribute to climate change mitigation by reducing greenhouse gas emissions associated with nitrogen fertilizer production and use.
- Tailoring pulse varieties to **specific farming contexts**, such as reduced time-to-maturity to allow integration into cereal-fallow systems, dormancy and overwintering in northern latitudes, optimal plant architecture (e.g. morphology; standing ability) for mechanized and non-mechanized systems, tolerance to agri-chemicals (e.g. facilitating chemical control of weeds or insect pests), and optimizing for intercropping with specific cereals and other field crops (e.g. cowpea-sorghum systems in West Africa; common bean-maize in meso-America).
- Exploiting the potential of **'orphan' pulse crops** (e.g. tepary bean, marama bean, horsegram, moth bean) through their introduction to fill ecological niches (e.g. arid conditions, marginal lands) and social needs (e.g. food and feed crops; health care; dietary preferences) in specific regions through improved traits (e.g. seed composition; plant architecture; photoperiod- and thermo-insensitivity to enable year-round production).
- Understanding control of **seed formation, biology, and quality** and, hence, nutritional functionality and yield.

Field performance of pulses is highly dependent on environmental factors (e.g. weather, soil microbes, pests and diseases). Genotypes must be tested under a range of cropping systems and climatic conditions and breeding programs need better selection tools to account for the intersecting effects of plant genetics, growing environment, and management practices. In turn, these need to respond to needs and market demand (whether for export, local markets, or home consumption) in specific growing regions.

Optimizing for end uses

The needs of farming households, local and global commodity markets, food manufacturers, and other value chain actors drive pulse production. Increasingly, pulse breeding programs will integrate objectives related to end uses, optimizing for market or 'output' traits such as:

- Improving content, quality, and bioavailability of **protein** and **micronutrients** (e.g. iron, selenium, zinc, folate) through biofortification as well as minimizing anti-nutritive compounds (e.g. trypsin inhibitors in pea; alkaloids in lupins). In addition to their growing importance in pulse marketing, nutrition-related traits have significant health implications in South Asia, Meso-America, and sub-Saharan Africa and may also have relevance in developed countries (e.g. selenium deficiency as a disease risk factor).
- Aligning with **consumer preferences** including cultural and market expectations for acceptable and preferred pulse characteristics (e.g. taste, color, fragrance). Sub-regional preferences may affect marketing potential (e.g. preference for pigeon pea and lentil in eastern India and for blackgram in North and Southern India). A key trait is shorter cooking time, which has implications for energy use

and household labor, especially for women, and which can exploit existing genetic variation among pulse cultivars.

- Adapting for **multiple on-farm uses** including household consumption, forage, feed, fuel, and soil improvement. While generally of secondary importance relative to food uses, feed and fodder quality are important for integrating pulses into many farming systems around the world (e.g. dual-purpose varieties suitable for both grain and forage uses).
- Increasing **suitability for processing** can emphasize diverse traits related to low-waste milling, grain integrity, efficient cooking, 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 trade-offs

While pulse species are grown in many different areas and can seem dissimilar, there are core similarities (e.g. nitrogen fixation; role in cropping and food systems; common evolutionary history). These can be better exploited based on their shared nutritional and agronomic roles as well as their fundamental biology (i.e. pulse growth and development; metabolism; response to environmental cues). If a process is understood in one pulse crop (or related legume), this knowledge can be readily adapted to another based on shared biology and evolutionary relatedness.

Combining desired traits is of interest for optimizing pulse cultivars to specific regions including development of pulses with resistance to multiple diseases as well as optimization of yield volume (which relates to numerous traits) and quality (e.g. protein content, stover digestibility). Careful and regulated transgenic approaches (i.e. introduction of foreign genes)[xxviii] and gene editing (i.e. engineering mutations or inactivating endogenous genes to confer a new trait) may help in developing important traits (e.g. resistance to specific biotic stresses) not present or easily identifiable in cultivated germplasm through phenotyping (and this may expand the set of available funding opportunities for pulse research). Development of hybrid varieties could potentially lead to yield improvement (i.e. in pulse species with suitable reproductive biology), though clear demonstration of this potential is necessary.

In seeking priorities for research investment, there may be some logic to investing in a few major pulse types, however this approach would miss out on the advantages that emerge from the large genetic diversity across pulse species and varieties, including those of high importance for regional growing conditions and consumers. Proportionate allocation of investments across pulse types should be informed by assessment of potential economic value as well as benefits to social groups and value chain actors. Investment in basic scientific understanding, tools, and technologies (e.g. genome sequencing, functional genomics) for a few pulse species should emphasize major traits common to many pulse species (e.g. nitrogen economy). Genetic improvement of pulse crops should draw strategically on the array of existing and emerging tools as accelerators toward defined objectives.

Tools and approaches

Development of improved pulse cultivars involves evaluation of genetic resources (e.g. genotyping, phenotyping) for identification of sources of desired traits, gene discovery, and knowledge-based breeding for genetic enhancement.[xxix] Across cultivated and wild pulse types, there are many genetic adaptations to a wide variety of stresses that can be detected and exploited through breeding programs. However, the extent of genetic knowledge varies across pulse species.

Conserving genetic resources

Breeding programs are fundamentally dependent on genetic resources (e.g. germplasm collections, *in situ* wild relatives, landraces, mutant repositories, analytical populations, public and privately owned breeding lines). Pulse germplasm collections are large though often much smaller than some cereal collections (see Appendix 3). Through an agreement with the International Treaty on Plant Genetic Resources for Food and Agriculture, genetic resources stored in participating genebanks are held in trust, under the auspices of FAO, and made freely available for research. Conserving pulse genetic resources such as those held in national and international collections and ensuring accessibility is a high priority to complement 'conservation in use' of those varieties perpetuated through representation in farmers' fields.

In situ protection for 'hotspots' of pulse 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 for introgression into domestic gene pools, recognizing that these are reserves of very large genetic diversity that can provide desired alleles as well deleterious mutations, requiring careful selection processes. Conservation of rhizobial genetic resources is also important for breeding to enhance biological nitrogen fixation.

Evaluating and utilizing genetic resources

Breeding of new pulse varieties relies on identification of genes that influence plant performance (i.e. useful allelic variation that contributes to phenotypic variation) so that desired traits can be bred, enhanced, and stabilized. To give breeders access to genotypes with the attributes they require (e.g. higher yield; resistance to stresses; efficient nitrogen fixation; protein content), screening techniques can be applied to different sources of genetic variation (e.g. germplasm collections, mutant populations) to detect traits of interest. To facilitate greater utilization of genetic resources, key areas for investment include:

- **Phenotyping**. This includes straightforward, but time-consuming phenotyping and the scientific capacity to undertake it at the regional level as well as centralized, high-throughput phenotyping platforms (which are more expensive to operate).
- **Genotyping**. Molecular markers, developed from diversity panels through association mapping and related methods, enhance the precision and efficiency of breeding, by enabling mapping of thousands of genes, and can reduce the need for extensive phenotypic screening of germplasm for traits of interest. (Alleles identified in domestic gene pools may be insufficient for identification of novel variants in wild gene pools.)
- **Genome sequences**. Recent genome sequencing efforts in pulses and related legumes offer opportunities in comparative genomics. Investments in pulse genome sequencing should be balanced by recognition that relevant allelic variation may be easily identified (i.e. not dependent on complete sequencing) or may not be present in germplasm collections.

While significant natural variability remains to be tapped for pulse crops, big yield gains are possible by conventional hybridization and selection methods even now, provided that breeding processes are effectively deployed. When underlying genetics is properly understood, molecular breeding has the potential to increase the pace of breeding through improved precision.

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 used for priority-setting in breeding programs to understand plant traits controlling desired performance and to run scenarios, informed, for example, by weather and soil data. Breeding programs supported by crop simulation models that capture spatial and temporal variation (including in agronomic practices) can re-focus from broadly adapted 'mega varieties' to a broader set of varieties responsive to diverse farming conditions and variability in climate and other key factors. Model-informed breeding is particularly relevant to anticipating and responding to climate change. For example, warmer temperatures that accelerate plant maturation could reduce yield (i.e. less time to capture light energy) and create a need for longer duration cultivars. Understanding relationships among allelic variation, plant performance, and future climate conditions can assist in developing 'climate ready' genebanks that can meet producers' needs in the coming decades.

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

Capacities and competencies

Regional capacity

In many regions, current levels of breeding research are not sufficient to meet pulse production needs (e.g. in Central and South America, North Africa, the Mediterranean Basin, and South Asia) that are sources of origin for numerous pulse crops. 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, in the CGIAR and its counterparts, funding for pulse genetics research and breeding programs has become inconsistent and there is increased reliance on a mix of donor-funded projects, which does not facilitate implementation of stable and coherent programs that deliver transformative results.

In developing countries, where the need for resistant varieties is most compelling, few programs are currently using marker-assisted selection to develop improved varieties. To achieve the necessary precision for guiding breeding programs, crop simulation models need to be built, linked to underlying genetic variation, and strengthened significantly with continuous addition of location- and context-specific data. Importantly, many locations in developing countries lack geographic information systems (GIS) infrastructure, key 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; multi-crop systems; 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 conserve different sources of genetic variation and to screen germplasm collections and diversity panels. Researchers have found molecular markers for some important biotic stresses; resistance to most stresses is complex and reliance on a single or few markers will retard achievement of breeding objectives. To deliver durable and sustainable resistance against biotic and abiotic stresses, greater investment is needed to discover genes controlling resistance mechanisms and to improve precision and efficiency of marker-assisted-selection. Development of genomic and post-genomic resources for pulses can benefit from recent methodological advances and reduced costs.

Given the thousands of pulse germplasm lines, rapid throughput mechanisms are needed to assess pulse populations for variant (or mutant) alleles related to desired traits. Phenotyping is expensive and labor intensive and facilities should be designed for: (i) high throughput screening, which requires precision for confidence in selections; (ii) moderate or low throughput screening for product characterization, which is a necessity for understanding basic mechanisms, or in some cases for product deregulation; (iii) efficient, traditional, large-scale field screening (e.g. disease nurseries have a continuing important role). Facilities can be established at centers of excellence for specific traits of regional importance. Development and maintenance of phenotype and ontology databases (which address landraces, wild forms, cultivars, breeding lines, and mutants), linked to genotyped data is an important resource for breeders, research, and farmers.[xxx] There may be potential for collaboration on phenotyping with cereal crops (e.g. wheat; maize; sorghum; rice; brassicas such as canola) grown in association with pulses. 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's role in genetics and breeding varies regionally. In some places (e.g. Canada, USA, Australia), producer associations gather levies to support impact-focused research. India mandates that 2% of corporate profits are directed to social works that companies could decide to invest in pulse crop research. There is a clear need for greater private sector involvement in breeding and seed systems in many regions, however the relatively small market size of pulse seeds tends to limit investment by the seed industry. The food industry makes use of public sector pulse research findings to develop new products to bring to the marketplace and some larger companies may customize publicly funded research to their needs.

Academic capacity

Maintaining and enhancing the pool of pulse scientists is an essential task given that many 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 breeding and genetics challenges. Pulse research needs to be prestigious to attract and retain excellence. Strong 'north-south' partnerships among centers of excellence and on-going support (e.g. mentoring of staff and graduates) are need to boost pulse research capacity in developing nations.

CHAPTER 2. PULSES IN INTEGRATED CROPPING SYSTEMS AND AGRICULTURAL LANDSCAPES

Adding pulses to a cropping system can boost total productivity of all crops by increasing the availability of nitrogen and other mineral nutrients, disrupting pest, weed, and disease cycles, enhancing nutrient and water use efficiency, reducing the impact of weather extremes, and augmenting system diversity. There are many different cultivated pulse crops that fit into a variety of production niches and support a range of uses including human consumption, livestock feed, and soil improvement with potential benefits for income and household nutrition. [xxxi] Holistic research that provides farmers with options for long-term, integrated management of pulses in cropping systems, linked to the genetic potential of pulse varieties, can sustainably and profitably increase productivity.

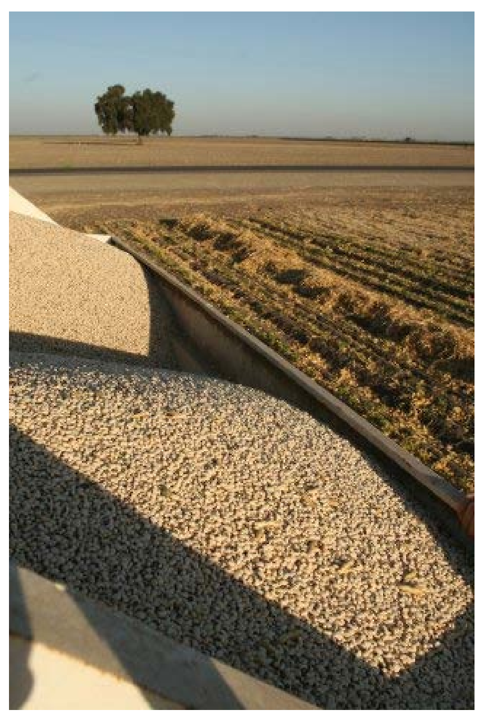
Research objectives

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.[xxxii] For large- and small-scale farmers, integration of pulse crops into farming systems can be inhibited by uncertainties regarding specific benefits, labor requirements, pulse marketability, and price signals,[xxxiii] 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 and production technologies that promote full expression of beneficial genetic traits.[xxxiv] 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:

- **Crop rotations**, **intercropping**, and **relay cropping** with cereals and other crops, including agroforestry systems. This includes practices such as replacing fallow with short-season pulses, prescribing systems for particular growth types (e.g. staking options for climbing pulses), and defining complementarities among cereal and pulse varieties (e.g. crop sequencing; optimal densities; species proportion in intercropping; seasonal cultivation).
- Integrated **pest, disease, and weed management** that strategically combines crop and varietal selection (e.g. resistant and weed-suppressive cultivars; diversification), cultural practices (e.g. soil preparation;



Source: http://iyp2016.org/

disease-free seeds; timing of planting and harvesting; seeding rate; irrigation), monitoring, mechanical and biological control (e.g. trap crops; botanical insecticides), and chemical application.[xxxv] 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 crop response paired with farmer training, decision support (e.g. warning services), and access to necessary inputs.

- **Nutrient** and **agrichemical management** including optimizing biological nitrogen fixation (e.g. seed inoculation) and soil nutrient availability (e.g. sulfur, phosphorus, potassium[xxxvi]) to meet the needs of pulses and other crops, while minimizing losses to the environment, as well as soil test-based fertility management (e.g. application of fertilizers; seed treatment).
- **Soil and water management** including conservation agriculture (e.g. low and no tillage; ridge planting; mulching), sowing methods (e.g. broadcast; frilling), soil rehabilitation, water use efficiency, and rainwater conservation, with emphasis on methods suitable for pulse production.
- **Mechanization** including appropriately scaled equipment that lowers cost of production and accounts for social and demographic (e.g. gender, youth) implications. This includes mechanical harvesting suitable for intercrop systems.
- **Post-harvest management** to reduce loss from insect pests and processing including storage (e.g. hermetic bags, bins, metallic silos), grain drying and milling technologies (including at local level), and seed saving (i.e. guarding viability and quality).

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 as well as environmental effects (e.g. nitrogen leaching and run-off; ammonia acidification; nitrous oxide emissions).
- Pre-crop and intercrop effects such as improved yield and protein content of cereals when grown in association with pulse crops, substitution of biological nitrogen fixation for chemical fertilizer, and increased plant-availability of soil nutrients.
- Disruption of weed, pest, and disease cycles in multi-crop systems (e.g. break crop when introduced into monoculture cereals[xxxvii]).
- Water use efficiency over a full multi-crop cycle.
- Multiple services in farming systems including human food (e.g. dietary diversity), livestock fodder, and nitrogen-rich crop residues (which can benefit subsequent crops) as well as soil quality and other ecological dimensions such as effects on microbial populations.
- Reduced greenhouse gas footprints (e.g. reduction in fossil fuel use in manufacturing nitrogen fertilizer; carbon sequestration).[xxxviii]
- Agrobiodiversity and ecosystem services and associated benefits for farming system productivity.[xxxix]

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 pulse-derived nitrogen benefits in crop rotations (or the associated financial return from adding pulses to cropping systems). Quantification of pulse-related benefits in farming 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. Efforts to identify and quantify those pulse-related benefits that provide rewards to producers (e.g. on-farm ecosystems services) and those that are public goods (e.g. off-site ecosystem services) will clarify which benefits will require compensating farmers for their delivery.

Facilitating pulse adoption by farmers

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

The relevance of different technologies will vary for farmer 'segments' with different access to knowledge, finance, and market opportunities, as well as production objectives and risk tolerance. Research is needed to better understand:

- Factors underlying **yield gaps** between attainable and actual on-farm yield (e.g. physical, ecological, and systems constraints). This includes access to management information and tools (e.g. integrated pest, weed, and disease management) as well as cost and availability of high-quality seeds, inoculants, and agri-chemicals.
- **Farmer decision making** including estimating profit and risk and weighing tradeoffs among yield, resilience, and labor requirements.[xli] 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), allocation decisions (e.g. across farm enterprises), and time dimensions (e.g. current season vs multi-year risks and benefits).
- Farmer **variety selection** and **demand for technologies**. This includes market size and trait preferences as well as socio-economic drivers, impacts, and beneficiaries (including women and youth), with attention to potential for unintended effects of interventions as well as future demand for traits and technologies (e.g. with shifts in market and climate).

To increase the competitiveness of pulses with other crop options, in addition to yield, research should focus on profitability, risk, labor and management requirements. In some developing countries, growing shortages of farm labor are increasing interest in affordable mechanization and chemical controls in pulse production.

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. Advances made for other crop types (e.g. cassava) may offer lessons for pulse innovation pipelines.

In addition to site-specific decision support, effective innovation pipelines can make use of information and communication technologies (ICT) 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 and training systems and farmer research and co-learning groups engaged in multi-environment trials. ICT programs need to be tailored to multiple languages and literacy levels and content should be created and approved by relevant experts. Functional outreach and extension services (including use of mobile ICT) are necessary to disseminate knowledge and promote innovation including locally-tailored varieties, technologies, and production strategies and estimated return on investment. Outreach and 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 and introduction to innovative production practices (e.g. disease and pest recognition) and technologies.

Input services

Investments in improved genetic resources are wasted if new varieties cannot be distributed through viable seed systems that produce benefits for farmers, institutes that develop improved varieties, and companies when they are involved. Improving high-quality seed availability is key and this involves establishment of seed multiplication mechanisms and seed quality maintenance and assessment. To maximize productivity, dissemination of seed of improved pulse varieties should be paired with appropriate inputs (i.e. inoculants, fertilizers, pesticides) and agronomic 'package of practices' recommendations developed based on adaptation, planting density, and soil test-crop response studies among other considerations. Optimal input packages may be particularly important for short-season varieties. Access to and availability of inputs to farmers should recognize that seeds and other inputs may be handled by different distributors (i.e. do suppliers stock the specified chemicals?) and that farmers may require financing support (e.g. are micro-credit facilities available?)

In developing country contexts, farmers are commonly unaware of newly improved pulse varieties and inoculants, reducing the potential for adequate market volume, therefore creation of demand for seeds and other technologies 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, and sheen; taste preferences) and to undertake local testing to confirm suitability. Some countries have national schemes that rank crop varieties by location type. In Ethiopia, which has one of the highest extension-to-farmer ratios in Africa, diversification of seed systems accompanied by wide-scale promotion of recommended packages has been impactful.

Capacities and competencies

Regional R&D

Regional R&D systems are needed to anticipate local and regional risks and to develop cost-effective and scaleable responses to emerging problems (e.g. pests; disease; drought) and market expectations (e.g. processing suitability; grain quality standards; reduced pesticide use). 'Mining' of soil and agronomic information is part of developing best practice information that can assist farm-scale decision making about whether and how to integrate pulses into their farming systems. 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 (see chapter 4). 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, weeds, drought).

Seed systems

Markets for pulse seeds are comparatively small as a result of low profit margins. In some areas, there is 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 pulse varieties) may incentivize development of seed systems, whose growth will depend on mechanisms for gathering market information.

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, including inter-generational transfer of regional expertise from retiring researchers to upcoming scientists. 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

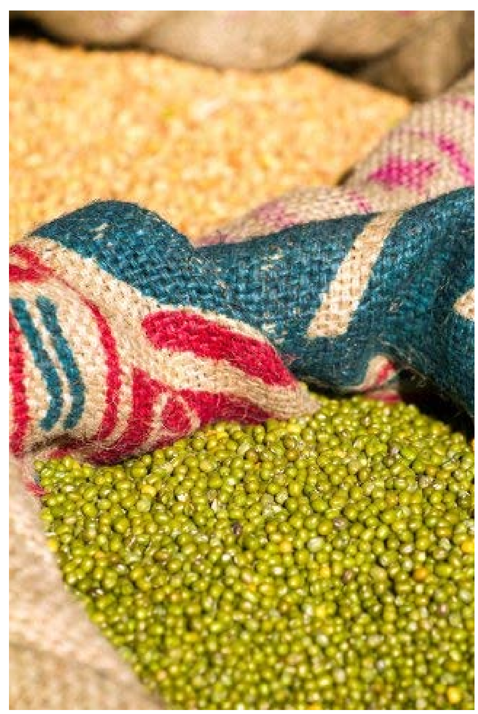
Pulses are central to many culinary traditions around the world and, in many countries, they are a cornerstone of food and nutritional security, including use for livestock and fish feed. With rapid increases in global food needs on the horizon, the role of pulses will become even more significant, especially with regard to dietary protein and micronutrients.[xlii] Confronted by the dual epidemics of malnutrition and overnutrition, the world needs to see greatly increased representation of high-protein, low-fat, high-fiber pulse grains in human diets.[xliii] Effective strategies for encouraging consumers to incorporate more pulses into their diets will need to be complemented by increases in pulse production, especially at the domestic level.

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.[xliv] 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.[xlv] 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 to 6.5 kilograms in that same period.[xlvi] 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 and the potential for increasing demand.
- **Food and nutrition**. The importance of pulses should be understood in the context of human protein sources (animal vs vegetable), micronutrient supply, and gut health. Pulse crops (as well as other legumes)



Source: http://iyp2016.org/

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**. Most pulses are consumed where they are produced (while soybean is the dominant legume in international commodity markets). 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**. Pulse value chains are highly diverse ranging from trans-national commodity export to local markets featuring traditional landraces. Where value chains are fragmented, input supply, post-harvest storage and transport, processing, and marketing may be inefficient.

Understanding value chain actors

In the coming years, the global food system is likely to encompass a range of pulse value chains and value chain actors will not operate in isolation. To foster mutual awareness, increase alignment, and improve coordination across different parts of the pulse research enterprise, it is important to understand the features of efficient, equitable value chains and to identify and describe major pulse value chain actors, such as:

- Breeders manipulate genetic variation to produce pulse varieties with enhanced or desired traits.
- Input suppliers manage inventory and supply of pulse seeds, agri-chemicals, inoculum, 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.

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, convenient pulse-based products. Improved production standards and reliable supply are important precursors to investment in pulse-based products by the food industry. Information barriers among value chain actors can slow advances (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 equitable across value chains, perverse outcomes may arise.

In many developing countries, pulse value chains are long with many middlemen, while large-scale production and vertical integration have contributed to shorter pulse value chains in North America and Australia. Low stockpiling of pulse grains, from farm level to national level, contributes to gaps between producer and consumer prices and seasonal fluctuations in retail prices.[xlvii] International trade and currency dynamics are a source of uncertainty for producers and other value chain actors and market prices will be affected by seasonal production volumes in importing countries.

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. increased demand and value-added products result in higher pulse prices) could disrupt these roles with unknown consequences for household nutrition.[xlviii]

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 market (e.g. price drop due to local oversupply) or 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. post-harvest handling; storage; preventing aflatoxin) 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, and storage) and marketing (e.g. income)?
- How can value chains be shifted to achieve net positive 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 and interventions required to change their behavior. For example, a new pulse variety with high-yield potential might be 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 needs, 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 coordinated stakeholder exploration of assumptions in pre-proposal phases.

Implications for diet and health

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. Pulses have direct nutritional benefits and can enhance the dietary benefit of other foods such as complementarity with cereals as recognised in diverse culinary traditions.

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. iron, zinc, vitamin 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 and low 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 non-communicable disease risk factors (i.e. cholesterol level, blood glucose, blood pressure) are needed to build a large body of knowledge that spans diverse demographic groups (e.g. age, health, socio-economic 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 and 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 for shifting public attitudes toward pulses (e.g. an alternative protein source to red / processed meats to reduce risks of NCDs). Importantly, foods, rather than nutrients, are increasingly being discussed as the basis for dietary recommendations.

Value addition

For pulses to take a more prominent place in global diets, efforts are needed to 'flip the script' toward increased awareness of the nutritious value and intrinsic appeal of pulses rather than their mere consideration as a low-cost substitute for animal protein. This is central to building value chains that deliver financial rewards to farmers for producing high-quality pulse crops.

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, extruded snacks, 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[xlix]), 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 can risk 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 for seed coat removal, roasting, puffing, flattening, germinating, splitting, grinding, fermenting, parboiling, pre-cooking, 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.[l] 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, tepary bean[li]) represents another research area that can combine nutrition and agricultural sustainability objectives (e.g. diversify seasonality of maturity; agrobiodiversity at species and genetic level). Value addition that is directed toward local markets can potentially accommodate a more diverse set of pulse species and varieties, with potential emphasis on food security (e.g. nutritious, fortified, locally flavored foods designed for vulnerable populations such as pregnant women and babies) as well as convenience foods targeted to urbanizing populations.

Sustainability and safety

Markets for pulse crops vary dramatically with some national markets holding a high bar for food safety 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.[lii] Research is needed to: (i) understand the factors and mechanisms of bioavailability (i.e. not just nutrient concentration); (ii) develop approaches for exploiting these factors for enhanced nutrition; and (iii) undertake 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 this information is key 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, 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 communities to present options for diet improvement and understand the interventions that they are willing to take on.

Pulse-based nutrition education has proven effective in changing the dynamics of pulse consumption and diet diversity and, consequently, child and maternal health and nutritional status (e.g. in Ethiopia, India, Kenya, Malawi). Research into the effectiveness of outreach methods should focus on communication (e.g. radio programs), school feeding programs, and other public education strategies.

Data and metrics

FAO has a global mandate for pulse crop data and FAOSTAT represents the best global data resource available to governments, international agencies, the food sector, researchers, and consumers. Pulse statistics published in FAOSTAT usually lag behind by one or two years. More real-time data collection and analysis of market developments and shorter-term market outlook (i.e. pulse production, utilization, trade, prices) would benefit pulse producers and purchasers. Other potential improvements include resolving regional definitional challenges for specific pulse crop types (e.g. bean and cowpea in West Africa) and complications in reporting on intercropped pulses. 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, food diaries, or food frequency questionnaires). Aggregate food categories can obscure assessment of pulse consumption (e.g. reported in combination with nuts and seeds).

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. There is a growing body of pulse-specific case studies conducted in both developing and developed countries.

For monitoring and evaluation of agronomic and dietary interventions, use of 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 beneficiaries are ‘light adopters’ of new technologies or methods. It is useful to look at ‘costs per adoptee or beneficiary’ and there may be merit in studying the effect of different types of reporting metrics on program outcomes. To understand knowledge, attitude, and practice related to pulses, ‘market orientation index per pulse type’ measures the level of acceptability of different pulses.

The concept of a nutrient productivity metric, which combines agricultural yield with nutritional composition and relates these to human nutritional needs, represents an important opportunity to more accurately evaluate the benefits of pulses in the diet relative to other types of food. It is also a nutrition-sensitive tool for breeding programs to develop varieties that optimize for nutrition as well as yield, stress resistance, and consumer preferences. Nutrient productivity would be expressed as the percentage of Dietary Reference Intakes (DRI) met for 10 adults per year from an agricultural product produced in one hectare per year, for one or more of nine nutrients (i.e. energy, protein, dietary fiber, Fe, Zn, Ca, vitamin A, vitamin C and folate). Data gaps would need to be filled for yield and nutritional composition in different settings and varieties.[liii]

Capacities and competencies

Documenting nutrition and health benefits

To better support dietary recommendations related to pulses, FAO (supported by contributions from the Global Pulse Confederation, IFAD, Colfiorito, and Turkey) is developing the INFOODS Global Food Composition Database for Pulses, which will contain data on the nutritional value of pulses, based on screening of more than 17,000 scientific articles. This process has revealed that necessary information is scarce (especially for minor pulse species) and that more data generation is needed for characterizing the complete nutrient profile (e.g. vitamins, minerals, protein) of all pulse species, as well as of different varieties and locations. For work to document clinical health benefits, there is ample capacity in terms of high-quality laboratories, but very little funding is available for these research needs. Collaboration with the agricultural sector as well as the medical community (e.g. contribution of pulses to nutritional outcomes; pulses as source of pharmaceutical compounds) is an important pathway. Some studies relating pulse composition with health outcomes exist, but significant further work is needed.

Bioavailability

Research on bioavailability 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 within food manufacturing companies (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 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

Given the complex, interconnected biophysical, socio-economic, and policy context for increasing pulse production and consumption, dedicated efforts to build multi-disciplinary pulse research capacity are essential. Relevant, effective innovation for increasing pulse production and consumption requires multidisciplinary approaches that combine well-targeted breeding and agronomy with socio-economic dimensions and market knowledge, and builds on scientific advances made in other crop types.

Research objectives

Strengthening 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 concurrent 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. 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 and water use efficiency, greenhouse gas emission reductions, nitrogen leaching, agrobiodiversity).

Source: http://iyp2016.org/

Cross-species collaboration with cereal crop researchers

Given the importance of complementary functions within diverse and complex agri-food systems, 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, maize, oat), which generally receive a much larger proportion of global R&D spending. This is particularly relevant for cereal systems work for which integration of pulse crops represents a meaningful solution to production challenges (e.g. adaptation to climate change). There are several 'success stories' including integration of improved chickpea in the Pacific Northwest, pigeon pea (and bean) in maize systems in Tanzania, cowpea with sorghum and millet in West Africa, lentil in rice systems in Bangladesh and Nepal, and mungbean in rice-wheat systems in India. There are also pending opportunities such as integrating pulses in rice-fallows in India and Bangladesh.

Coordinated research among pulse and cereal crop researchers can focus on development of production practices and technologies for holistic management of cropping systems as well as efficient seed system models (e.g. multi-seed availability to farmers) and manufacture of cereal- and pulse-based foods. Interdisciplinary collaboration across plant breeders, physiologists, agronomists, and food scientists is needed to optimize for nutrition objectives (e.g. linking high-throughput screening tools with animal studies, nutrient absorption trials, and efficacy studies). In addition to cereals, there are examples of beneficial collaboration with other crop types (e.g. pea and faba bean with canola in France and the UK and with sunflower in France and Russia; bambara groundnut with sorghum, maize and yam in Sub-Saharan Africa; common bean with cassava in South America).

Understanding policy context and enabling policy dialogues

The challenge facing policy makers and agricultural experts is how to produce sufficient nutritious food for a growing population without further degrading natural resources and contributing to climate change. Agricultural policies cannot be developed in isolation and need to be developed together with social, economic, and environmental policies and should bring farmers and consumers into the center of policy development.

Pulses will need to become more financially competitive if they are to become more prominent in farming systems. To overcome 'lock in' (i.e. preference for cereals in cropping systems imposed by policy and market structures), multi-disciplinary research on transition paths can investigate the potential of new value-added market outlets and innovative cropping systems with high yield and reduced environmental impacts.[liv] The environmental benefits of adding pulses to cropping systems (e.g. net reduction in greenhouse gas emission; improved agrobiodiversity) are not sufficiently valorized by markets. Cereal producers are the major beneficiaries of agricultural subsidies in many countries although European policy is now shifting toward diversification of agricultural production (e.g. hectares under pulse production has doubled in Germany). Food labeling rules and dietary guidelines that categorize pulses as either high-protein or high-starch limit the ability of food manufacturers to make full use of pulse fractions.

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, pathologists, breeders, entomologists, 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 preferred by growers; evaluating technologies).

- Forming consortia to tackle complex sustainability issues within and across production, processing, and consumption components of pulse supply chains. Examples include the Pan-African Bean Research Alliance (PABRA), the International Mungbean Network, and the International *Ascochyta* Workshop.
- Coordinating access and sharing of germplasm material and genomic information and harmonizing issues around intellectual property.
- Fostering multi-location, multi-crop agronomic field trials (see current efforts by CORAF and CIRAD in West Africa on the IAVAO project as well as the BeCA-ILRI Hub[lv]) and sharing of field and laboratory facilities.

New R&D modes

Participatory engagement with farmers is an important component of pulse research, especially for undertaking multi-crop research from a farming systems perspective. This has been a driving force within CGIAR research in coordination with National Agricultural Research Systems. It helps 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.

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 'upstream research' (e.g. fundamental biology; agroecology), applied science (e.g. urgent regional concerns such as response to major climate change scenarios), or 'downstream' development and scaling effort. There is potential for more cross-regional collaborations (e.g. working on nitrogen fixation, pest and disease resistance, and 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* and *ex post* impact assessment (including socio-economic, environmental, 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. Scholarships or fellowships could be designed to encourage more senior researchers to catalyze stronger collaboration among research groups and institutions enabling pulse researchers to better rely on one another and more freely exchange personnel, ideas, and material.

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 and partnerships across academic, government, and private sector research systems. This requires recognizing and accommodating differences in research objectives, approaches to intellectual property, technical and human 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 experienced scientists, especially in regional R&D programs, working on many dimensions of pulse production and consumption. Interactions among geneticists, pathologists, breeders, agronomists, environmental scientists, and social scientists are essential to developing new pulse cropping systems that reduce pesticide use, better manage diseases and pests, optimize fertilizer use, and build agrobiodiversity. There are too few socio-economic scientists working on pulses and more are needed if we are to understand drivers of demand for pulses. In some countries, agricultural research institutes seeking cross-disciplinary partnerships may not have robust social science and economic counterparts. Importantly, multi-disciplinary focus should not come at the expense of support for work on pulse genetics and breeding, rather a holistic approach is needed for integrated pulse crops into farming systems. 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 well-being) 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). Research program leaders need multi-disciplinary skills to lead integrated research programs that address issues across pulse value chains.[lvi] New Extension models, or revival of previously successful ones (e.g. in India, 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), 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

As researchers and other pulse stakeholders work to bridge yield gaps and develop options for profitably integrating pulses into cropping systems, agricultural landscapes, and food systems, most solutions will be context-specific. Progress will depend on spatially-explicit information to guide research investments and to increase the efficiency of research (e.g. share fixed costs and equipment within a region) and dissemination (e.g. multiple technology options to the same geographic area).

Research objectives

Contribution to global and national challenges

Pulses have high potential to contribute to the Sustainable Development Goals (SDGs)[lvii] and Nationally Determined Contributions (NDCs)[lviii] for greenhouse gas mitigation and climate change adaptation. To support policy development and integrated land use planning, improved capability for quantification of potential and actual benefits for meeting global and national targets is essential.

To more fully incorporate pulses into sustainable development and climate finance programs, international agencies would benefit from integrated, spatially-explicit analysis of the potential opportunities for pulses to improve agricultural productivity, nutrition, and livelihoods. 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. Such spatial analyses will enable 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).

While some pulses are grown across the world (e.g. chickpea, common bean, lentil, pea), other pulses are of high regional importance such as cowpea in sub-Saharan Africa, faba bean in East and North Africa and West Asia, pigeon pea in South Asia and East Africa, mung bean in South and South East Asia, urdbean in India, and grasspea in India, Bangladesh, Australia, and the Middle East. Better understanding of 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 Europe and many developing countries, especially in North Africa and West and South Asia, have a pulse deficit.[lix] To meet growing demands for pulses, it is important to systematically analyze production gaps.

Source: http://iyp2016.org/

Opportunities and risks in specific geographies

Opportunities and risks associated with pulse production are spatially variable at multiple scales, requiring improved capacity for targeting location-specific interventions. Where risks are few (e.g. moderate to high intensity of cultivation prevails; soil water-holding capacity is high), pulse crops are more readily adopted by producers given nitrogen and other benefits to cropping systems. In other regions where low-input agriculture is the norm and there are numerous risks (e.g. variable in-season rainfall; soil nutrient deficiencies; significant pest, disease, or weed burden), producers are less likely to integrate pulses into their farming systems. Notably, under the extreme agricultural environments of dry arid and semi-arid regions, more resilient crops, including some pulses like cowpea, remain primary options.

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 opportunities and risks across diverse farming systems is needed. Such assessment should be supported by up-to-date data repositories at the national level on demographics and agricultural conditions including predictable weather parameters, soil conditions, markets and consumer preferences, prices, trade, and prevailing policies. To understand which cropping systems will be amenable to inclusion of pulses as a mixed or rotation crop, work is needed to:

- Simulate pulse production under current and future climatic conditions, based on defined crop water requirements and heat tolerances, to estimate the probability of pulse crop failure and strategically design varietal traits in breeding programs.
- Anticipate climate change effects (e.g. disease; pests; drought; flooding; storm events) at scales relevant to production decisions.
- Forecast the potential success (accounting for costs, labor, and socio-cultural factors) of improved varieties, new technologies, and 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 (e.g. 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, pigeon pea), the amount of land dedicated globally to producing many temperate region pulse crop types (e.g. pea, faba bean, vetches, lupin) has declined.[lx] Acreage dedicated to lentil production has increased globally and chickpea production area has held constant.

Pulse crop productivity varies dramatically among countries and recent pulse production gains in countries such as Australia, Canada, Ethiopia, Myanmar, 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, are 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 as well as the role of pulses in integrated farming systems.

In India, for example, introduction of pulse crops into new areas and non-traditional production belts has been a major factor recent record-high production of chickpea, pigeon pea, and lentil.[lxi] Expansion of chickpea production in southern India was achieved through introduction into black cotton soils, utilization of rabi fallow lands, adoption of short duration varieties, and large scale mechanization (i.e. to cope with labor shortages). To continue increasing pulse production in India, combined efforts by policy makers, scientists and extension agencies will be needed to further integrate pulses into rice-fallow systems.

Tools and approaches

Crop simulation models

Crop simulation models can enable scientists to decipher the complexity of pulse production and simplify the choice of targeted interventions to maximize productivity and sustainability. Such 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).

Different models developed for different regions, scales, and farming systems can be linked to inform research questions. Spatially-explicit models can be used to: (i) evaluate crop suitability across heterogeneous areas; (ii) estimate climate change impacts (e.g. using standard scenarios) and production constraints (e.g. yield gap analysis); and (iii) 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; pests and diseases; soil carbon).

Crop simulation models can inform development of breeding objectives and of agronomic interventions although high variability in location-specific climate change predictions makes it difficult for producers and scientists to adapt. Stress conditions do follow detectable patterns, which can inform development of new pulse varieties (e.g. drought tolerant cultivar for a location likely to experience dry conditions 80% of time). With increased understanding about highly diverse farming conditions, scientists can identify the best suited plants more quickly and easily using a model-informed approach.

In addition to long-term weather data, 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).[lxii] To increase the likelihood of farmer adoption and value chain development for improved varieties, more integrated research packages are needed that bring Geographic Information Systems (GIS), crop simulation models, and socio-economic expertise into breeding and agronomy programs and this should be complemented by assessment of production value to farmers.

Life Cycle Assessment

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. Life Cycle Assessment (LCA) is one approach that 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; energy use for cooking), food loss,[lxiii] processing efficiency, and affordability of food products re-formulated to include pulses (i.e. extent of advantage of pulses to deliver nutrition similar to meat, fruit, and vegetables at a cheaper price and lower environmental footprint). 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). Note that LCA may not be easily adapted to smallholder farms.

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; greenhouse gas 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.

Capacities and competencies

Modeling capacity

While relevant crop simulation modeling tools exist (e.g. Simple Simulation Modeling, SSS), their use in backstopping crop improvement remains marginal and further work is needed so that models are more routinely used for important pulse species and growing regions. Crop simulation brings a new paradigm of breeding for specific conditions, focused at smaller geographical scales, to deliver larger overall returns. To embed modeling analysis in breeding programs, models need to be calibrated and validated. 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, especially with a view to assessing nutrient productivity of a cropping or farming system. This requires better understanding of the effect of genetic changes on nutritional characteristics. More work is also needed to simulate the beneficial effects of pulse crops in farming systems such as the amount of residual nitrogen available to crops following pulses in a rotation and the nutritional (e.g. protein) benefits produced on a farm when pulses are grown.

The community of pulse crop modelers is still 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 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.

A recent effort by the CGIAR to determine priority regions for research and development in dryland cereal-legume farming systems illustrates how diverse geographic datasets for biophysical (e.g. soil fertility; drought probability) and socioeconomic (e.g. population) conditions can be combined for strategic targeting of programmatic investment.[lxiv] 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. In India, the ICAR-National Bureau of Plant Genetic Resources and Bioversity International have worked together to map hotspots for germplasm conservation and vulnerable areas for chickpea, pigeon pea, and other crops.

Data systems

Robust public sector agricultural data systems (especially weather and soils information) are an important foundation for investing strategically to maximize food security, community development, and natural resource integrity (i.e. as a basis for design of research strategies, programs, and activities). Higher temporal and spatial resolution data can improve spatially-resolved scenarios and predictions. Opportunities for data improvement may exist through recent advances in crowdsourcing information, big data, ICT, and 'pre-competitive' private-public partnerships.[lxv] Building constituencies for robust, open data and model infrastructure involves communicating benefits of spatially-explicit evaluation of investments.

RECOMMENDATIONS

A vision for research on pulse crops

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:

- **Sustainable food systems in the face of global challenges**, specifically, agricultural systems that can meet growing global protein and micronutrient needs and are resilient to weather extremes and increased pest and disease burdens.
- **Sustainable natural resource management** including soil fertility, water use efficiency, microbial diversity, and reduced greenhouse gas emissions and environmental impacts in cropping systems.
- **Diversification as a source of agricultural sustainability and human well-being** including increasing overall productivity of cereal-based systems by inclusion of pulse crops for dynamic markets and climatic conditions and dietary diversity to combat health problems associated with under- and over-nutrition.
- **Economic sustainability at the farm scale** including reduced risks and improved farm income, supported by accessible and affordable agronomic management tools and input supply systems.

Source: http://iyp2016.org/

- **Sustainable value chains** that better utilize whole grain pulses and pulse fractions (for food, animal feed, fiber, and fuel) 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 participatory research (especially women and youth) and pipelines for locally-adapted, end-user preferred varieties, technologies, and management practices.

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. Responding to this call will deliver knowledge systems that lower barriers to efficient, equitable pulse value chains by providing:

- Context-specific options for profitable, sustainable pulse production that will enable pulse producers to anticipate and respond to emerging risks and changing market expectations and to meet global needs for stable sourcing of high-quality pulse crops.

- Strong scientific basis for including pulses in national policies and dietary and medical guidelines, which will allow pulses to be more financially competitive with other crops and better represented in food products and global diets.

- Guidance for targeting public and private investment in pulse value chains, which can unlock financing for essential infrastructure and commercial ventures.

Investing in global and regional priorities

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

Global and cross-regional scale

To assess status, 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:

- Assessment of available genetic resources and analysis of gaps (e.g. wild relatives, structured populations, mutant pools, and other sources of novel alleles that confer resistance to emerging abiotic and biotic stresses);
- Data-driven determination of where greater integration of pulses into cropping systems is appropriate and remunerative (e.g. diversification; reduced dependence on inputs);
- Linking different disciplines and establishing platforms for collaboration among pulse scientists and researchers working in other crop types 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. Hence, 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;
- Location-specific agronomic practices and production technologies;
- New types of sustainable, diversified cropping systems optimized for specific regions;
- Socio-economic dimensions of production and consumption;
- Value chain / market conditions and consumer preferences;
- Locally and regionally relevant policies and enabling environments; and
- National level capacity to undertake research (e.g. through intra- and cross-regional partnerships).

The table below summarizes major research functions that require investment at **global** (or cross-regional) and **regional** (or local) scales. Many of these recommendations are specific to pulse crops. Others that are relevant to all crops will maximize and accelerate scientific advances for pulse crops.

Research priorities	Global and regional functions
Germplasm resources	Global. Acquisition, maintenance, and availability of germplasm and mutant collections.
	Global. Evaluation (genotyping; phenotyping) to understand potential sources of desired traits (e.g. stress resistance; nutrient bioavailability).
	Global / regional. *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; phenotyping; 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, agronomic, and policy interventions.
	Regional. Baseline data collection and *ex ante* or *ex post* impact assessment of agriculture and value chain interventions (e.g. yield gaps, farmers' risk perceptions; desired pulse traits; market expectations; potential for nutrition and health; supply chain needs) with emphasis on women (e.g. income, household nutrition) and youth (e.g. agri-enterprise).
Crop improvement (including climate resilience)	Regional. Breeding regionally-adapted varieties that are optimized for growing conditions and objectives including yield, multiple stress resistance, water / nutrient use efficiency, suitability within farming 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 across production pipelines and value chains (e.g. farmer levy supported projects; international development funded studies; company funded work in key sourcing regions; gender-sensitive research modes).
	Regional. Establish or improve production pipelines to deliver improved pulse varieties (i.e. pulse seed multiplication, distribution, and quality assurance systems) together with location-specific agronomic packages.
Integrated cropping systems for sustainable production	Regional. Maximize integrated management of crops, weeds, pests, and diseases including innovation in mechanization (e.g. multi-crop systems; sowing, harvesting, threshing equipment) and post-harvest technologies (e.g. hermetic 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 for inclusive growth	Regional. Establish or improve producer support programs including rural advisory services and ICT platforms (e.g. pest and disease early warning; weather and market information).
Value chains and poverty reduction	Regional. Maximize value addition through quality enhancement (e.g. targeted to specific end uses), reduced loss (pre- and post-harvest), aggregation (e.g. storage, transport), processing (e.g. cleaning, de-hulling, milling) facilities, and market development (e.g. manufactured products; novel uses).

Research priorities	Global and regional functions
	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.
Sustainable consumption for nutrition and health	Global. Solidify the evidence base for contribution of pulses to malnutrition and non-communicable diseases.
	Global. Improve understanding and capacity for enhancing micronutrient bioavailability including biofortification.
	Regional. Evaluate the potential for nutritional and 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; health) to support 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; incomes; climate adaptation and mitigation) that can feed into and policy guidelines (e.g. subsidies; minimum support prices; agriculture / rural development).
Scientific capacity and partnerships for development	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 cropping systems, 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. This requires investment in the regional and global pool of scientists capable of addressing critical needs in pulse breeding and genetics, agronomy, nutrition and health, socio-economic dimensions, and spatial analysis.

Collaboration anchored in global and regional networks of scientists, government partners, and industry players is necessary for improved productivity and sustainability of pulses. Dedicated support is needed for pulse scientists to establish and sustain collaboration with food scientists, cereal crop researchers, medical scientists, the food industry, and policy communities.

Call to action

These recommendations are directed at public and private sector stakeholders in government, agriculture, health, the food industry, consumer groups, foundations, funding agencies, and research institutions.

- **Industry groups**, such as the Global Pulse Confederation, are essential research partners in developing value addition pathways for pulse-based products by engaging local agri-enterprises, regional partners, and major food companies and promoting innovation and transparency in pulse value chains. Industry groups can serve as conduits for scientific knowledge to their members.
- **National governments** can utilize research findings to target public investments, policies, and enabling environments designed to 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 to combat malnutrition). National programs and regional intergovernmental initiatives are critical to guiding and funding priority research and establishing or modernizing pulse supply chain infrastructure and information systems (e.g. spatial planning; rural advisory services; agricultural statistics).
- **Research institutions** are the engines of knowledge and innovation that can serve as nodes for regional collaboration among public and private sector partners and lead development of appropriate pulse varieties, technologies, and practices that are resilience to climate and market conditions and reduce labor demand and risks. By quantifying the benefits of pulses for different social groups, researchers can support their integration into public and private initiatives targeting local and global sustainability challenges.
- The mandates of **global donors** and **international agencies** would benefit from greater integration of pulse crops into their programs. Agricultural development, humanitarian, and finance organizations in public and philanthropic sectors can use research findings to capitalize on the benefits of pulses for agricultural sustainability and human well-being.
- **Producer associations** are pivotal to designing and conducting research that is responsive to real-world agricultural constraints (e.g. biotic and abiotic stresses; market dynamics) and possibilities (e.g. increased yield; efficient resource use). When these groups can co-invest with government, they are well-positioned to serve as effective knowledge hubs for their members.
- **All stakeholders** can work to ensure that pulses are included in major policies and sustainability finance mechanisms (e.g. Green Climate Fund).

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.

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	X	X
2.	Noel Ellis	University of Auckland, School of Biological Sciences (*Lead Author*)	Author	X	X	X	
3.	Robin Buruchara	Pan Africa Bean Research Alliance, CGIAR CIAT (*Lead Author*)	Author	X		X	X
4.	Carol Henry	University of Saskatchewan (*Lead Author*)	Author	X		X	X
5.	Diego Rubiales	Spanish National Research Council (*Lead Author*)	Author	X	X	X	X
6.	Jeet Singh Sandhu	Indian Council of Agricultural Research (*Lead Author*)	Author	X		X	
7.	Christine Negra	Versant Vision LLC (*Coordinating Author*)	Author	X	X	X	X
8.	Steve Beebe	CGIAR CIAT	Committee	X		X	
9.	Jens Berger	CSIRO	Committee	X			
10.	Gerard Duc	INRA	Committee	X		X	
11.	Jeff Ehlers	Bill and Melinda Gates Foundation / University of California, Riverside	Committee	X			
12.	Todd Scholz	US Dry Pea & Lentil Council	Committee	X			
13.	BB Singh	Texas A&M University / G.B. Pant University	Committee	X			
14.	Denis Tremorin	Pulse Canada	Committee	X		X	
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16.	Tom Warkentin	University of Saskatchewan	Committee	X		X	
17.	Irv Widders	Michigan State University - Legume Innovation Lab	Committee	X		X	
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19.	Tomas Nemecek	Agroscope - Institute for Sustainability Sciences		X		X	
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23.	Glenn Hyman	CGIAR CIAT		X			
24.	Shiv Kumar Agrawal	CGIAR ICARDA		X		X	
25.	Seid Ahmed Kemal	CGIAR ICARDA			X	X	
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	Name	Affiliation	Advisory committee	Interview / early input	Write-shop	Bilateral input / review	Verification meeting
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39.	Thiago de Souza	EMBRAPA - Arroz e Feijao		X			X
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52.	Abderrahim Bentaibi	INRA - Morroco		X			
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55.	Claire Domoney	John Innes Centre		X	X	X	X
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58.	Barry Pittendrigh	Michigan State University				X	X
59.	Jim Kelly	Michigan State University				X	
60.	Phil McClean	North Dakota State University				X	
61.	Christine Watson	Scotland's Rural Use College			X	X	
62.	Marta Santalla	Spanish National Research Council			X	X	
63.	Erik Steen Jensen	Swedish University of Agricultural Sciences		X	X	X	
64.	Frederic Muel	Terres Inovia		X	X	X	
65.	Pete Iannetta	The James Hutton Institute		X		X	
66.	Ruth Charrondiere	UN Food & Agriculture Organization				X	X
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APPENDIX 2 MAJOR PROGRAMS AND STAKEHOLDER INSTITUTIONS

Major pulse research programs and funding sources[lxvi]

Funders / programs / projects	Pulse types	Focus areas
CGIAR Research Program Grain Legumes	chickpea, dry bean, cowpea, faba bean, lentil and pigeon pea	Developing countries
World Vegetable Centre (AVRDC)	mungbean	South & Central Asia
Bill & Melinda Gates Foundation: Tropical Legumes III, CGIAR, N2Africa	chickpea, dry bean, cowpea, pigeon pea	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, faba bean	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), UK Pulse Crop Genetic Improvement Network (Defra), UK Research Council (BBSRC), other programs…	pea, lentil, chickpea, faba bean, dry bean, grasspea	Europe; developing countries
India: Indian Agriculture Research Institute (IARI), Indian Institute for Pulse Research (IIPR)	pea, lentil, chickpea, pigeon pea, dry bean, cowpea, mungbean, urdbean, '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, faba bean	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; African Orphan Crops Consortium (NEPAD-led public-private partnership).
Regional consortia	Pan Africa Bean Research Alliance (PABRA); Association for the Advancement of Agricultural Sciences in Africa; Inter-American Institution for Cooperation in Agriculture; European System of Cooperative Research Networks in Agriculture (ESCORENA).
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	Agriculture and Agri-Food Canada; 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; Bean Improvement Cooperative; 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; BEPA-UK; Ugandan Farmers Federation; Terres Inovia (formerly UNIP)-France, UFOP (Germany), PGRO (UK)
Industry	Global Pulse Confederation; India Pulses and Grains Association; BASF; DowDupont; Syngenta; Bayer; Novozymes; Panner; Advanced Seed

APPENDIX 3 EXAMPLES OF PULSE RESEARCH CAPACITY AND ISSUES

Major centers for pulse genetic resources[lxvii]

- Global Gateway to Genetic Resources (GENESYS)
- World Vegetable Center (AVRDC) (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)
- Institut National de la Recherche Agronomique (France, https://urgi.versailles.inra.fr/siregal/siregal/grc.do)
- 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)
- Plant Gene Resources of Canada (http://pgrc3.agr.gc.ca/index_e.html)
- Ustymivka Experimental Station of Plant Production (Ukraine; https://www.genesys-pgr.org/wiews/UKR008)

Major pulse pests affecting different regions[lxviii]

- 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
- Europe: Ascochyta blights; Rusts; Aphanomyces; Chocolate spot; Botrytis gray mold; Wilt / root rots; Parasitic weeds; Bruchids; Aphids; Sitona weevils; Nematodes; Pod borers; Viruses; Powdery mildew
- Sub-Saharan Africa: Ascochyta blights; Rusts; Chocolate spot; Wilt / root rots; Pod borers; Aphids; Powdery mildew; Bruchids; Viruses; Faba bean gall; parasitic weeds (Striga and Alectra)
- 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

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[xvi] 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.

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