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### Editorial: Food Legume Diversity and Legume Research Policies

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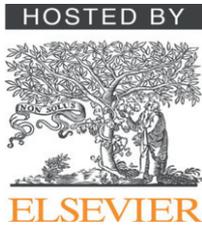
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## Editorial: Food Legume Diversity and Legume Research Policies



This special issue is focused on grain legumes, which belong to the Fabaceae family. Legumes are the second largest family of plants in the world after the grasses and are key components of manmade and natural ecosystems [1–3]. They provide the environmental service of nitrogen fixation, so essential to soil construction and fertility maintenance, and are thus essential to agricultural systems [4,5]. Different species of legumes range from huge trees to shrubs and herbaceous plants [6]. Their roles in human livelihood are as diverse as their architecture [7]. Legumes provide everything from fine timber to medicines, forages, and of course food. Many legumes are sources of grains used for human consumption. These grain legumes are known as pulses, and are being honored by the Food and Agriculture Organization in the year 2016 (International Year of the Pulses, FAO, 2016). Grain legumes are also produced for protein concentrates used in animal feeds, and as oil crops for cooking, biofuel, and industrial purposes [8]. Legumes are thus of both historical and modern-day importance and are especially pertinent for consideration in the present world of changing climate and human population growth [9]. In this editorial we concentrate on grain legumes used for food, including the beans and peas used in the diets of many cultures across the world as major sources of protein, vitamins, and minerals as well as food calories [10–13]. In many countries, the pulses are second in

importance only to cereals and animal sources of calories and protein, respectively [13,14].

Another focus of this special issue is the great diversity of food legumes. Diversity is key to progress in breeding in legume species, and several papers in this special issue evaluate aspects of phenotypic and genotypic diversity. The use of multiple legume species in rotations or mixtures is often critical to improving cropping systems [15,16]. Insect pests and some diseases, especially those found in the soil, are reduced by inclusion of a wider range of legumes in a rotation or a mixed cropping system [17,18]. China uses a greater amount of legume diversity in its cropping systems than most other countries (Table 1), and in many areas of the country, two or more major pulses are grown in alternating fields or different seasons. In several papers of this special issue we highlight the role of pulses in China's sustainable agricultural systems. For example, winter peas and faba beans often follow cropping systems incorporating common beans, cowpeas, mung beans, or yard-long beans. It is obvious from travel to any part of China and interviews with Chinese scientists, extension workers, or farmers, that the so-called “farmers of forty centuries” have vast experience with legume and pulse rotations.

The diverse use of intercropping with legumes in China is described in a chapter of a recent book on sustainable

**Table 1 – Legume yield and production area in four temperate nations or nation blocks of the world in 2014.**

Legume species	China		USA		Canada		Europe	
	Yield (t)	Area (ha)	Yield (t)	Area (ha)	Yield (t)	Area (ha)	Yield (t)	Area (ha)
Adzuki/rice bean	242,000	151,700	NA	NA	NA	NA	NA	NA
Chickpea	10,500	3,000	127,369	85,834	123,000	66,000	174,644	143,657
Common bean	1,046,000	936,000	1,324,760	674,090	273,200	119,700	703,090	306,371
Cowpea	13,500	13,000	19,641	11,655	NA	NA	23,950	6,840
Fababean	1,595,000	925,000	NA	NA	N/A	NA	673,343	226,091
Lentil	22,500	153,000	14,571	152,720	16,326	1,987,000	11,693	94,466
Mungbean	689,000	540,100	NA	NA	NA	NA	NA	NA
Pea	1,575,000	907,000	778,140	359,970	3,444,800	1,467,000	3,370,416	1,621,016
Peanut	15,782,813	4,521,644	2,363,260	536,210	NA	NA	11,330	10,810
Soybean	12,201,173	6,730,668	108,013,660	33,613,960	6,048,600	2,235,100	9,001,953	4,495,806

Data were collected from FAOSTAT (<http://faostat.fao.org/>) and 2014 China Agricultural Statistical Report (Ministry of Agriculture of P.R. China ed., Beijing: China Agriculture Press, 2015). t, metric ton; ha: hectare; NA, data not available.

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agriculture [3]. Production statistics show that most provinces of China produce at least two grain legumes plus soybean. For example, Liaoning province produces mung bean and cowpea together with soybean. Shandong province produces common bean, mung bean, rice bean, and winter pulses. In Yunnan province, crops of common bean are grown in spring and fall, with winter pulses grown in the dry seasons. Across southern China there are variations on pulse-dependent legume rotations, depending on microclimate, altitude, soil, and market preferences. In contrast, North American farmers in Canada and the USA use a much smaller palette of legume species and tend not to rotate pulse crops in consistent sequences [19]. US production is very dependent on soybean, to the exclusion of most pulses (Table 1). North American agriculture tends to regionalize production of each legume rather than using two or more types and mixtures of legumes. This practice is evident in dry bean production, which is concentrated in the states of North Dakota, Michigan, and Minnesota [20,21] or lentil and pea production, which is concentrated in Montana and Washington. Production of common bean was important in New York, but only for black beans, and declined with the American embargo on exports to Cuba, the state's major market.

Lack of diversity in legume rotations can have dire consequences [19]. This is seen in modern American agriculture more acutely than in most countries. For example, the availability of genetically modified, herbicide-resistant soybean has led to a vast monoculture of a single legume throughout the mid western and southern USA [22]. The sustainability of soybean as the only legume rotation for corn is beginning to fail in many parts of the US, owing to Roundup herbicide-resistant weeds and the buildup of soil borne pests that are very virulent to soybeans, such as soybean cyst nematode [23,24]. Some nematodes are also spreading to common bean in North Dakota where acreages of soybean and dry beans overlap [25]. Central-pivot irrigation production of soybean is only increasing the risk of soil pest buildup and is spreading as the main production technique in the South. Meanwhile, the concentrated production of common beans in Michigan has led to disease susceptibility, with extreme root rot pressure in the sandy soils of the western part of the state where kidney beans are grown. Fluctuation of black bean production in the state's Saginaw area occurs in response to market forces. The result is that production is losing ground in the upper midwest and moving to North Dakota and Canada [21]. In Canada, common bean is specialized into white beans for Ontario and pinto beans for Saskatchewan, where production has taken advantage of increasing global temperatures to move the agricultural frontier for row crop legumes and pulses northward [26,27]. In terms of diversity of grain legumes, at least the western provinces Alberta, Manitoba, and Saskatchewan in Canada also produce lentils and peas in year-to-year summer rotations with cereals or common bean [26]. Similar systems are in place for the northwestern states of the USA.

Greater diversity of pulse legumes is generally found in the developing world than in the above countries [28]. With the exception in Argentina and Brazil of soybean, which is grown in monoculture on large acreages, most of the tropics and subtropics including other countries of Latin America, South

and Southeast Asia, and most regions of sub-Saharan Africa grow a range of legumes in mixed cropping systems, often with corn or root crops such as cassava [29]. Many countries of Africa use multi cropping in a single field and have a wide variety of legumes to grow, although more pulses could be beneficial if introduced or improved. This is especially true for native grain legumes such as Bambara groundnuts or dual-purpose grain and forage cowpeas [30]. Tropical Asian legumes of South and Southeast Asia are diverse and include moth bean, mung bean, pigeon pea, rice bean, urd bean, and other grams [31]. The wider use of these legumes in eastern and southern Africa would reduce dependence on common bean, which is the least heat-tolerant legume used on the continent in highland environments and is very likely to suffer from climate change [29]. A change to other tropically adapted species would avoid losses to heat, drought, and excessive rainfall but would require changes in consumer preferences. Another advantage to Africa for growing Asian legumes is that they could be readily exported to the large Indian pulse market and thus fulfills the breadbasket potential of the large amount of arable and well-watered lands of countries like Angola, D. R. Congo, Mozambique, Zambia, and Zimbabwe.

Pulse exports are on the move and increasing in importance and economic significance. The market in south Asia for grain legumes is driving an expansion in pulse production in some countries of eastern Africa such as Ethiopia and Kenya that are physically close to the subcontinent, and also in Canada where warmer summers are allowing the expansion of common bean, lentil, and pea production. Argentina has a history of exporting black-seeded common beans to Brazil, and this practice has spilled over to Bolivia and diversified into production of carioca cream mottled beans as well. Argentina and Bolivia also produce different classes of beans for markets in Europe, the Middle East and northern South America (Colombia and Venezuela) in countries that are not self-sufficient in their favorite grain legume. Michigan produces most of its black beans for markets in Mexico and Central America and for re-export to Cuba. Production of lentils and peas is expanding in Washington and Montana, where they can be exported to South America and south Asia and compete well with wheat in the region. In China, the major common bean production area is in northern Heilongjiang province, which produces and exports high-quality common beans including white, red mottled, cream mottled and black beans at competitive prices.

Given the interconnectedness of grain legume production and consumption across import and export markets around the world, climate change presents a unique challenge to legume availability. The need to maintain and increase legume productivity at current or higher levels in a hotter and drier world is of paramount importance [32]. All legumes are  $C_3$  plants and therefore very susceptible to the effect of heat stress and less drought-adapted than  $C_4$  plants [33]. Their shallow roots compared to those of cereals make them inherently more susceptible to either too little or too much water [34]. A wetter climate in some regions such as in the inter tropical convergence zone in the tropics will reduce the productivity of many legumes, owing to root rots and water logging or flooding damage [35]. Increased research

investment in grain legumes and resourceful agronomic research and plant breeding will be necessary to ensure a steady or increasing supply of grain legumes for the world market. Breeding must take into account the best seasonal planting dates, growth habits, and patterns of legume development as well as the capacity of legumes to fit into intercropping or crop rotations, something that is rarely considered in breeding for mono crops.

As part of this editorial we discuss the policies and strategies used by different countries to promote pulse research and production and the baseline for their use in agricultural rotations and systems. The Chinese government, unlike most other countries except for India, invests directly in research on a large diversity of food legumes, separating that program from research on soybeans and peanuts. This policy leads to a more balanced research portfolio in China than in other major pulse-producing regions listed in Table 1.

China's support for pulse research and production is diversified and forward-thinking. For example, investments are made by the Ministry of Agriculture and the Ministry of Finance within a coordinated governmental program across provinces, agencies and universities. The China Agriculture Research System for food legumes is one of over a dozen programs to improve the efficiency of scientific research in agriculture and the management of research in agriculture. European research has had some coordinated programs for the pulses, but these tend not to be long-term. The United States Department of Agriculture (USDA) invests heavily in soybean, but not in other legumes except in the context of regional programs or international aid from the US Agency for International Development. The result of the USDA approach is that entire regions of the US have no viable food legume program. Underserved regions that could benefit from pulse production research in the USA include the southeast, northeast, and parts of the Midwest. Grain legume research is heavily centered on a few land-grant universities in California, Michigan, North Dakota, and Washington, while research at non-land grant or minority-serving institutions is rarely supported or included in an overall grain legume strategy for the United States.

Argentina and Brazil provide some support for national dry bean research but do not have high-level diversification programs. Canada supports lentil/pea/chickpea research in the west and dry bean research in Ontario [36,37]; while the private sectors in South and North America invest almost exclusively in soybeans. India does make large investments in legumes [38]; however, much of this investment is through the national program in Kanpur and through ICRISAT, an international center whose goals are more project-driven. Decentralization of grain legume programs and direct involvement of university research in breeding would be valuable in India, although the private sector is advanced in investing in food legumes. Access to germplasm collections and support to breeding programs that do more than just research without relying so heavily on dominant programs in Hyderabad and Kanpur are issues to address with an emphasis on diverse environments such as hillside regions, and better rotations with rice would be valuable. Currently, India is a big importer of its food legumes from Canada and Australia [39].

With this perspective, some of the articles in this special issue show how China is maintaining and increasing the food legume diversity used in the country and how this can inspire other countries to do the same. Selected research from Africa, North America, and south Asia is highlighted to show where diverse legumes are being considered and to describe traits such as disease and insect resistance or abiotic stress tolerance that are of primary importance. This special issue compiles recent research in important areas of legume research, highlighting the most important challenges to legume productivity and genetic/agronomic and nutritional strategies for improvement.

As an aid to the reader, we have organized the articles into sections based on major research objectives in improvement of pulse production. The first section is on resistance to biotic stresses and includes recent research by 1) Zhu and colleagues on a major disease of dry bean called common bacterial blight. The authors have identified candidate genes and diagnostic markers for selection of various epistatic loci for high-level resistance in a Chinese variety, with results applicable both in northern China and around the world, 2) Sun and colleagues, who present a second disease resistance paper on powdery mildew disease and the combination of resistance alleles in peas useful for controlling this less well-studied pathogen, and 3) Wang and colleagues, who present an integrated map for bruchid resistance in mung bean. Bruchids are a major insect pest in most pulse crops and mung bean itself could be a crop of great importance worldwide, given its diversity and productivity in Asia.

A second section of this special issue describes the evaluation of abiotic resistance traits, with research papers from 4) Darkwa and colleagues on evaluating drought tolerance in common bean in Ethiopia using the most up-to-date techniques for phenotypic characterization including the use of root pulling force as a tool for selection, 5) Zhang and colleagues, who describe the large-scale evaluation of a pea diversity collection for cold tolerance, which is of high importance for fall, winter and spring production of this crop, and 6) Chen and colleagues, who discuss the cloning of a proline transporter from common bean that is shown to be involved in various abiotic stress tolerances including to drought and salinity, stresses of increasing risk to pulse production.

The third section tackles a growing area of research in pulses, namely their nutritional components, with articles from 7) Nassourou Maina and colleagues on the genetics of antioxidants and flavonoids in cowpea from Cameroon, 8) Shi and colleagues on the nutrients and antioxidants found in mung beans in China, and 9) Dixit and colleagues on the potential of grass pea as a food legume in India.

The final section includes examples of diversity analysis and genetic tools for pulse breeding. The first of these papers, on agro morphological traits including seed size, is from 10) Archak and colleagues, who evaluated the chickpea core collection of the National Bureau of Plant Genetic Resources of India, comparing this to the ICRISAT core collection and determining relationships among Desi-type genotypes. The last paper in the special issue is from 11) Gupta and colleagues and describes the development of microsatellite markers from expressed sequence tag sequences in lentil. It is our

expectation that the wide variety of papers in this grain legumes special issue will inspire further research on pulses that will be pertinent for many years to come.

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