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A comprehensive overview

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Front cover:
Faba bean field at Nantong, Jiangsu Province, China.
Photo courtesy Xuejun Wang.

EDITORIAL

As the world's most populous country, China has placed high priority on the development of agriculture. The outstanding achievements in crop production in China during the past decades have exemplified how traditional and modern biotechnology can help to feed the billions. Here, we are pleased to introduce and disseminate this Chinese Legumes-themed special issue of Legume Perspectives, the official journal of the International Legume Society (ILS). It aims to provide timely and useful knowledge to both Chinese and overseas legume researchers and producers, to share the successful Chinese experiences to the world, and to provide a forum for the global legume colleagues.

The writing style of the articles in this special issue is concise, in line with the tradition of Legume Perspective. The contents are comprehensive, ranging from history, biodiversity, genetics, breeding to cultivation, animal and human nutrition, ecology, and economy. These review articles are assigned to specific themes and devoted to different legume crops, covering the current nine major Chinese food (predominantly vegetable) legumes viz. Common Bean, Cowpea, Mungbean, Adzuki Bean, Vegetable Soybean, Garden Pea, Faba Bean, Lablab Bean, as well as Grain Soybean. The reviews are written by invited seminal experts from the fields, reviewed and revised by the guest editors, and supervised by the Editorial Board. We heartfeltly appreciate all who participated in making this special issue.

The issue is expected to publish in celebration of the 2021 annual conference of the Vegetable Legumes Section, Chinese Society for Horticulture, which was founded in 2020 (Figure 1). We warmly welcome and look forward to meeting colleagues from all fields of legume research and industry to share their knowledge and enthusiasm.

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Figure 1. The Vegetable Legumes Section, Chinese Society for Horticulture.

Carte blanche to…

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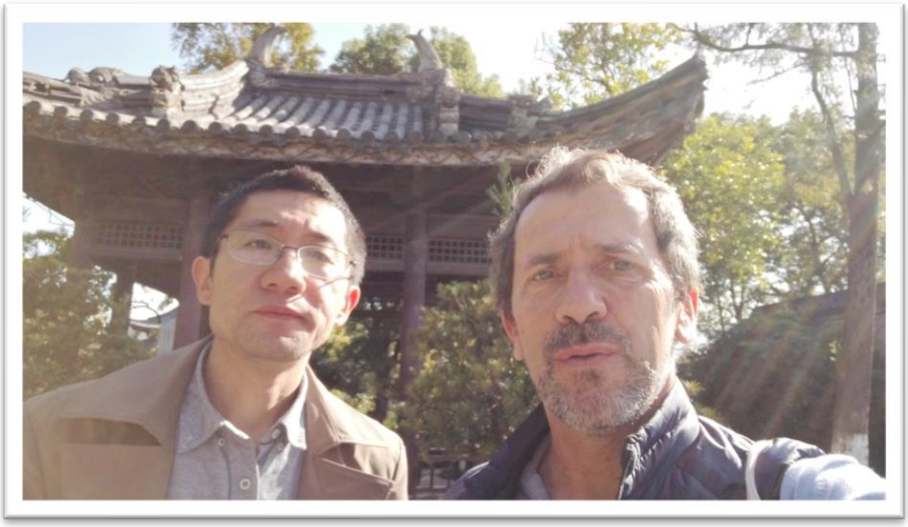
As the world's most populated country, China has placed high priority on the development of agriculture. The outstanding achievements in crop production in China during the past decades have exemplified how traditional and modern biotechnology can help feed the billions. Food legumes play a major role in Chinese agriculture, being well introduced in Chinese diet. This is shown by the large food legume production of the Chinese leading green bean, green pea, green soybean and broad bean, with circa 21, 13, 3.5, and 1.8 million tons (Mton), respectively in 2018. To this, dry soybean adds with 16 Mton, and dry pea and dry beans with 1.5 and 1.3 Mton, respectively. Still, China suffers from an external dependence on protein feedstuff, with over 55 Mton of soybean imported in 2011, which almost doubled to 91 Mton in 2019, representing 60% of the world soybean imports. Although at much lower levels, this external dependence relates also to dry pea, with 2 Mton imported in 2019, representing 31% of dry pea world imports. These amounts compare to the "only" 20 Mton of soybean and 1.2 Mton of dry pea imported by the whole European continent, for instance.

As Chinese population and people's living standard keep rising, the legume demand will keep increasing. Great efforts are paid to increase legume production to satisfy domestic demand. This is achieved by adjusting cropping practices and by developing better cultivars. China is one of the eight Vavilov Centers for cultivated crops (i.e. soybean) and is the second largest holder of PGR accessions in the world. This great legume genetic diversity available in China and the fast adoption of late state-of-the-art biotech technologies will speed up cultivar development.



Left to right: Pei Xu and Diego Rubiales.

Brief history and germplasm diversity of common bean (*Phaseolus vulgaris* L.) in China

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Abstract: The common bean is one of the most important food legumes in the world. It is a highly variable species with a long history. It was introduced from the Americas to China over 400 years ago and presently constitutes an important export crop in many areas of the country. The main categories of common beans, based on use, are dry beans, snap beans, and shell beans. These types also differ between populations from different ethnic cultural backgrounds and have been selected and domesticated according to the specific production and life activities of people, resulting in the formation of a unique distribution of germplasm resources in China. Evaluation of the genetic diversity present in Chinese accessions of common beans is essential for the conservation, management, and utilization of these genetic resources.

Key words: common bean, domestication, germplasm, genetic resources

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Introduction

Common bean (*Phaseolus vulgaris* L.) is one of the most important legumes and is high in protein, low in fat, and rich in vitamins and dietary fiber. The regular consumption of common beans can reduce coronary heart disease, type II diabetes, and cancer (1). Common bean is grown and produced all over the world. More than 120 countries or regions grow common bean, encompassing a total area of 28.78 million ha (2). China is a major producer of common beans (fifth worldwide in dry beans and first in snap beans) with a production distributed by many agricultural areas of the country, including primary bean growing areas in the provinces of Heilongjiang, Inner Mongolia, Yunnan, Guizhou, and Xinjiang (3). The total production in China is 21 million tons and the cultivation area is 749,860 ha dispersed across southern, central, and northern regions (2). China, Myanmar, and the United States are the main exporters, with India and the European Union being the largest importers (2). Owing to their short cropping duration and high market value, the common bean has become the dominant vegetable food legume in China (4).

Common bean was introduced into Europe in the early 16th century, spreading rapidly from Europe to the Middle East, West Asia, and other regions during the 16th and 17th centuries (5). Ultimately, secondary centers of origin were formed in Europe, Brazil, South Africa, and China (6). Common bean was introduced in China more than 400 years ago (5), and long periods of domestication and artificial selection have led to an increase in its genetic diversity. Given this history, the common bean is considered a traditional crop in China. Common beans in China are mainly produced under rain-fed conditions in traditional farming systems that often include rotation with vegetables or intercropping with maize (5). According to statistical data from the National Center for Extension of Agronomic Techniques (Ministry of Agriculture, China) common beans are cultivated in the Southwest, Northeast, and North regions of China. The common beans are mainly grown in Heilongjiang, Inner

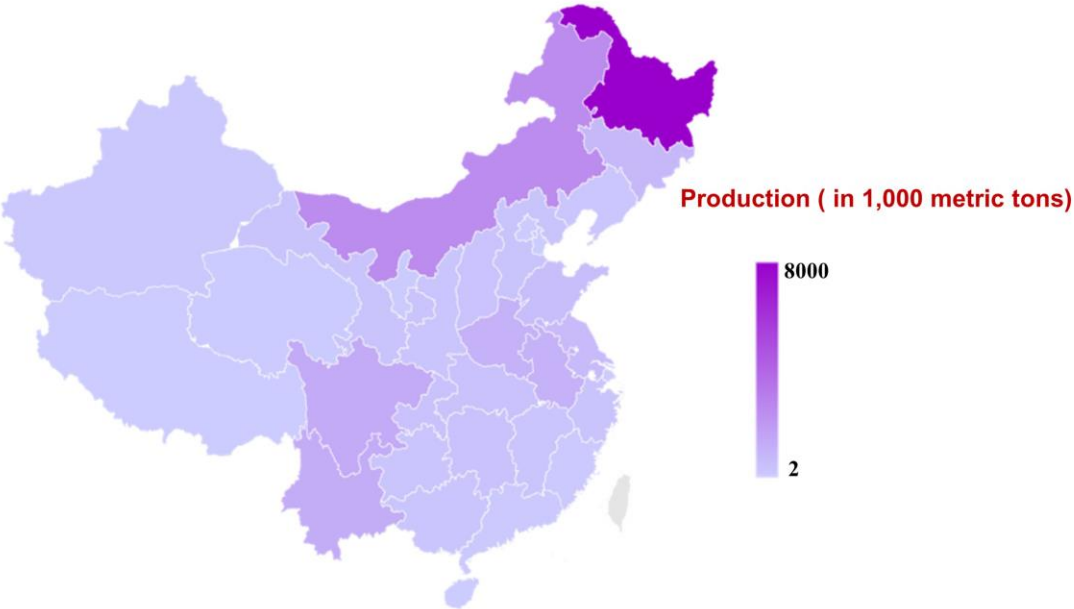

Figure 1. Common bean production in China in 2019, by region (in 1,000 metric tons). (Statista, 2021 https://www.statista.com/statistics/242639/bean-production-in-china-by-province/)

Mongolia, Yunnan, Guizhou, Xinjiang, Hebei, Chongqing, Gansu, Shaanxi, Jilin, Shanxi, Sichuan, Shandong, and Liaoning province or autonomous region of China (Figure 1).

Since 1949, large advances have also been achieved in the breeding of common beans, and other food legumes. The following listed common bean elite cultivars, Xiaobaiyundou, Zaolvdidou, Pinyun 2, Zihuayundou, Changnaihuayundou, Ziyuanyundou, Dahongyundou, Shenhongyundou, Xiaohongyundou, Zhunaihuayundou, Huangyundou, Honghuayundou, Longyundou 4, Longyundou 5, Naihuayundou, Ayun 1, Ayun 2, Suyundou 1 are the ones mainly grown in the various provinces of China. These elite cultivars contributed to the improvement of common bean yield in the past 60 years (5).

Morphological characteristics and genomic resources of Chinese common bean

Common bean germplasm resources have been selected and domesticated according to the specific production and life activities of people, resulting in the formation of a unique distribution structure of common bean germplasm (Figure 2). The distribution of common bean germplasm resources depends on the unique agricultural production preferences of farmers, and it has been suggested that seed selection is closely related to seed size and color. Chinese grain types are characterized by being mainly small to medium seeded, some large, with the predominance of white, cream, red, and brown or black seed colors although cream mottled, or red mottled seeds and some striped or bicolor patterns are also observed (7). Among the growth habits found in Chinese landraces, type IV climbing beans are the most common but type I, II, and III are also represented.

Cultivated common beans can be divided by gene pools and races depending on their Andean and Mesoamerican centers of origin in the New World. The two gene pools have been divided into seven races. The Mesoamerican gene pool contains four races: Durango (D), Jalisco (J), Central America (M), and Guatemala (G), and the Andean gene pool contains three races: Chile (C), New Granada (N), and Peru (P) (8). China, being outside Andean and Mesoamerican centers, is among the countries that could benefit from the use of imported germplasm and landraces from different gene banks (6). During common bean global domestication, several changes in its morphological characteristics occurred, including seed and leaf enlargement, alterations in growth habits and photoperiodic response, and changes in seed color and seed coat markings. The level of diversity for Chinese landraces of Andean origin was higher than for the Chinese landraces of Mesoamerican origin due to the presence of more infrequent alleles in this first group (5).

More than 4,900 accessions of common bean are conserved in the National Gene Bank of China located in the Chinese Academy of Agricultural Sciences in Beijing (6). More recently, from 2015 to 2017, 115 common bean germplasm resources were collected from different natural ecological regions of Chongqing (9). Chongqing is located in the middle and upper reaches of the Yangtze River in southwest China and the eastern edge of the Szechwan Basin. Morphological characteristics, disease resistance, and quality traits of some of these common bean accessions have been cataloged, but little information is available regarding the genetic relationship of Chinese common bean landraces to each other and international germplasm both within and between gene pools. Landraces are thought to have valuable traits in terms of agro-ecological adaptation, cooking quality or consumer preference, and resistance to diseases or abiotic stresses (10). It is also noteworthy that only a few accessions of Chinese beans are represented in international collections. Examples are the 186 Chinese common bean accessions in the International Center for Tropical Agriculture or the 131 in the United States Department of Agriculture plant genetic resource units. Chinese germplasm is presumed to include genotypes from the two centers of origin given the range in seed size, but this has not been studied with molecular markers before. Marker-based studies are also needed to validate the designation of China as a secondary center of diversity for the crop.

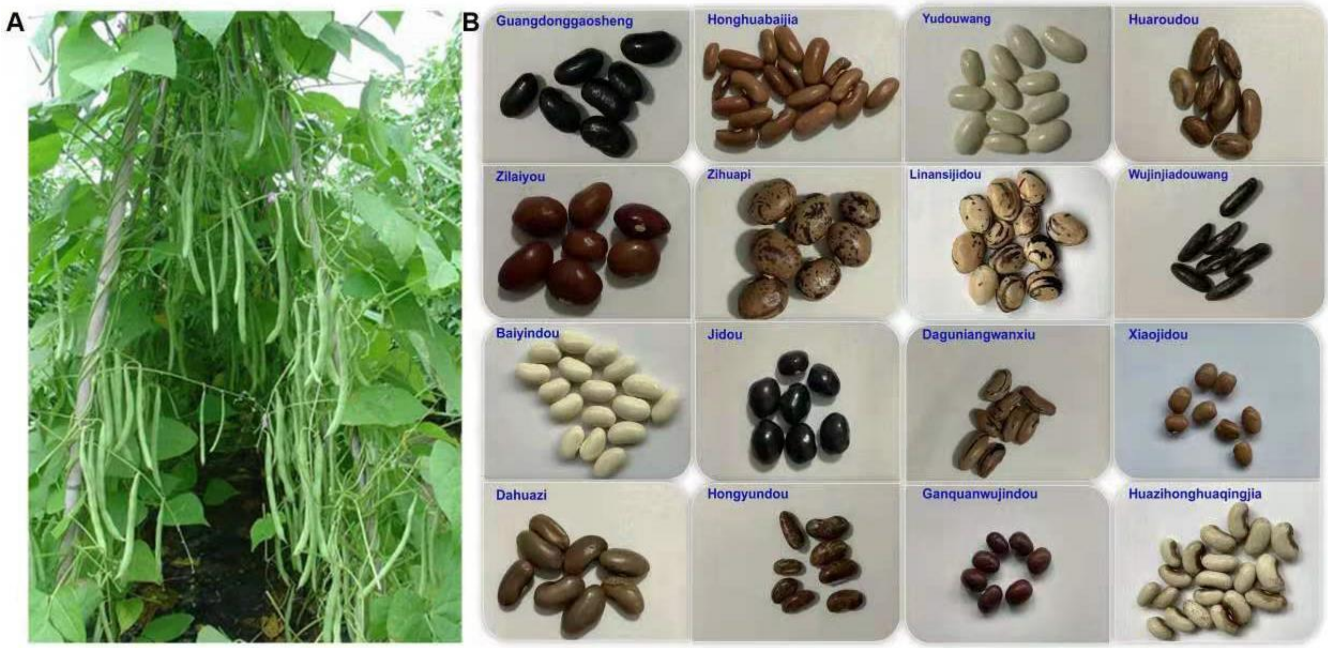

Figure 2. The morphology of a typical common bean cultivar (Zheyun 3) in Southern China (A) and the common bean seed morphology polymorphism (B).

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Cowpea in China

Huixia Zhao[1], Rui Guo[1], Chanyou Chen[1], Lei Pan[1*]

Abstract: Cowpea is an annual warm-season legume with heat tolerance and drought tolerance. It is planted for tender-crisp pods as well as seeds across China. In this article we provide a brief review of cowpea in China, including its agricultural importance, germplasm resources, cultivation management and breeding perspectives.

Key words: cowpea, breeding, germplasm, production

Introduction

Cowpea [*Vigna unguiculata* (L.) Walp] is an annual legume with tolerance to high temperature and drought. This species is planted for its pods and seeds that are rich in protein and dietary fiber needed by the human body. In addition to being eaten fresh, the edible pods and mature seeds are often processed to form dried or pickled traditional foods. Cowpea can also be used as forage, hay, and silage.

Currently, two cultivated forms of cowpea are popular in China, the subspecies *V. unguiculata* ssp. *unguiculata* (blackeyed pea) and *V. unguiculata* ssp. *sesquipedalis* (yard-long bean). Ssp. *unguiculata* is different from ssp. *sesquipedalis* with respect to the shape and length of the pod and seed characteristics (1). These characteristics are variable and are not so easy to be distinguished between the two subspecies. Generally, both have pencil-size pods, but show different pod length. Blackeyed pea, usually less than 30 cm in pod length, is mainly consumed for its seeds due to its hard and fiber pods. In contrast, yard-long bean pods may grow to 30-90 cm long, and are tender, sweeter and more succulent than the black-eyed pea pods.

Origin and global spread of cowpea is an issue of concern. *Vigna unguiculata* originated as an inconspicuous little creeper among the rocks of the dusty southern Sahel and the bone-dry upper rim of central Africa (2). It was originally domesticated in sub-Saharan Africa thousands of years ago. The yard-long bean originated in southern Asia and is now grown extensively in Asia, Europe, Oceania, and North America. The arrival of cowpea in China is much less well-documented, but trade routes, such as the Silk Road, have played a role in its distribution around the world (3). The earliest known reference to cowpea in China is from the 3rd century CE, when it was included in the "Guan Ya", compiled by Zhang Ji.

In China, cowpea (mainly blackeyed pea and yard-long bean) is grown extensively across the whole country. It is now found year-round in China markets. Its major production regions cover central, southern, and northeast China. As for output of cowpea dry beans in China, the average planting area is about 13,035 ha/year, with an average production of dried seeds of about 13,726 tonnes/year, and an average yield of 1,054.6 hg/ha between 2012-2018 (FAO, www.faostat.fao.org) (Table 1). The overall planting area and total production of cowpea fresh pods (mainly pods of yard-long bean) are unpublished in the official data of FAO (www.faostat.fao.org). Based on the data (www.agdata.cn) between 2010-2016, the average planting area in China is about 48.62×10^4 ha/year (Table 2), and the total annual production of tender pods is about $1,274.59 \times 10^4$ tonnes/year (Table 3). Also, top ten provinces of cultivated area and production for cowpea fresh pod in China are listed in Tables 2 and 3.

Table 1. Cowpea cultivated area, production, and yield of dry beans from 2012 to 2018 in China. (Source: FAO, www.faostat.fao.org)

Year	Area (ha)	Yield (kg / ha)	Production (tonnes)
2012	12,000	1,083.3	13,000
2013	12,500	1,216.0	15,200
2014	13,000	1,038.5	13,500
2015	12,000	1,083.3	13,000
2016	13,082	772.6	10,107
2017	13,556	1,152.7	15,626
2018	15,108	1,036.0	15,652
Average	13,035	1,054.6	13,726

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Germplasm resources

Collection and preservation of cowpea germplasm resources have attracted world-wide concern during the past decades. The IITA (International Institute for Tropical Agriculture, http://old.iita.org) conserves the world's largest collection of cowpea accessions in its gene bank with 15,122 unique samples of cowpeas from 88 countries. The United States Department of Agriculture (USDA, http://www.ars-grin.gov) holds 6,845 cowpea accessions from all over the world. The Chinese Academy of Agricultural Sciences (CAAS, http://icgr.caas.net.cn/) collected 3,306 cowpea accessions from all over the world (4). Cowpea varieties in China exhibit a wide range of growth habits. They may be short and bushy, prostrate, or tall and vine-like depending on the cultivar. Usually they bloom in mid-summer with large white or purple flowers. Their pod colors include white, light green, dark green, red, purple, and stripe and dots pattern. The beans are mainly kidney-shaped, ripening to brown, black, white or mosaic colors (Figure 1).

Cultivation management

Cowpea can endure acid soils but prefers the soil pH range of 5.5-7.5. Its lateral roots generally distribute in a depth of 15-18 cm in soils, while the main root is deeper. To enhance soil fertility, it is useful to mix in compost or composted manure in Spring.

Figure 1. Seeds and pods of cowpea. (Source: Hubei Province Engineering Research Center of Legume Plants).

Table 2. Top ten provinces of cultivated area for cowpea fresh pod in China (in 10,000 metric ha). (Source: China Agriculture Data, www.agdata.cn)

Year	Henan	Guangxi	Hunan	Hubei	Sichuan	Jiangsu	Guizhou	Anhui	Hainan	Chongqing	Total area in China
2010	7.96	2.43	1.97	3.72	3.90	2.46	1.73	1.92	1.19	1.37	39.95
2011	7.87	4.40	1.93	4.16	4.00	2.64	2.12	2.16	1.34	1.44	44.47
2012	7.48	4.59	1.90	3.90	4.07	2.69	2.18	2.44	1.44	1.62	45.06
2013	7.54	4.81	3.32	4.01	4.21	2.75	2.09	2.20	1.74	1.71	47.59
2014	8.04	5.20	4.43	4.32	4.35	2.81	2.36	2.42	1.97	1.73	52.32
2015	10.19	4.99	4.30	4.36	4.40	3.10	2.56	2.64	2.16	1.65	55.14
2016	10.42	5.22	4.54	4.43	4.39	3.22	2.76	2.60	2.00	1.82	55.83
Average	8.50	4.52	3.20	4.13	4.19	2.81	2.25	2.34	1.69	1.62	48.62

For sowing, it is better to select a place in full sun with loosen soils. In China, cowpea can be planted from April to July in the middle and lower reaches of the Yangtze River. Cowpea flourishes in hot seasons, and give rise to pods very quickly. The present major cultivars can produce harvestable pods as soon as two months after planting, and continue providing fresh pods for months. The best time to harvest cowpea dry beans is when the seed pods have fully ripened.

Different pests could be encountered in different regions. Cowpea may be affected by cowpea aphid born mosaic virus (CAMV), anthracnose (*Colletotrichum truncatum*), root rot disease (*Fusarium solani*), rust (*Uromyces vignae*), cercospora leaf spot, and powdery mildew. Insect damage may be caused by common cutworm (*Prodenia litura*), bean pod borer (*Maruca testulalis*), cowpea aphid (*Aphis craccivora*), vegetable leafminer (*Liriomyza sativae*), pea weevil (*Bruchus pisorum*), thrips, and mites.

Breeding perspectives

Most cowpea bean breeding programs in China have employed conventional breeding of hybridization and progeny selection to develop improved lines. Target traits of cowpea breeding are focused on high yield, high quality and disease and insect pest resistance. Recently, cowpea breeding programs have been paying attention to cultivars suitable for facility agriculture cultivation and post-harvest processing. Additional essential points attracting the particular interest of breeders and researchers are: to improve the photosynthetic efficiency of cowpea plants; to find out the balance point between vegetative growth and reproductive growth; and to solve the problem of shedding of flowers and pods at mature stage.

Molecular breeding programs have also been launched in cowpea. Some cowpea genomic resources are available nowadays (5), providing new opportunities for germplasm enhancement (6,7). Genetic diversity studies have used various types of markers in cowpea, including amplified fragment length polymorphism (AFLP), simple sequence repeat (SSR), single nucleotide polymorphism (SNP). Several linkage maps have been used to identify QTLs for desirable traits in yard-long bean in China. While gene editing technology has become a hotspot area in crop breeding using clustered regularly interspaced short palindromic repeats (CRISPR) / CRISPR-associated (Cas) 9 (CRISPR / Cas9), an *Agrobacterium*-mediated transgenic system was successfully applied to create a nodule-free mutant using CRISPR / Cas9 gene editing in cowpea (8). In a recent report, a detached leaf assay for testing transient gene expression and gene editing in cowpea was described (9).

Conclusions

Cowpea is an annual warm-season legume crop widely planted in China for food, animal feeding and soil fertility improvement. The edible parts include fresh green leaves, dry leaves, green pods, green beans, or dry grain, which are rich in protein. Cowpea is one of the most widely grown vegetable legume in China, with over 3,000 accessions preserved in the national crop germplasm bank, which plays an important role in the maintenance of genetic variations for *V. unguiculata* improvement. Most varieties are derived from conventional hybrid breeding strategies, while more researchers and breeders are becoming interested in marker assisted breeding. The lack of well-spread efficient transgenic- and gene editing methodologies in cowpea remains a bottleneck for generating transgenic plants to withstand multiple pests, viruses, abiotic stresses and with an improved nutritional quality.

Table 3. Top ten provinces of production for cowpea fresh pod in China (in 10,000 metric tonnes). (Source: China Agriculture Data, www.agdata.cn)

Year	Henan	Hubei	Sichuan	Hunan	Jiangsu	Guangxi	Shandong	Anhui	Hebei	Hainan	Total production
2010	304.7	117	90.4	36	59.5	37.7	27.2	36.9	29.2	21.9	1019
2011	315.06	113.59	94.54	36.1	67.72	77.79	31.61	43.52	37.88	29.42	1147.38
2012	289.46	106.62	97.12	34.66	71.59	81.3	36.92	49.69	45.99	37.71	1152.49
2013	299.33	122.16	100.7	59.31	74.32	86.04	34.63	48.09	46.53	44.84	1268.84
2014	313.6	132.96	106.1	97.01	79.99	92.81	52.37	52.7	55.16	50.05	1405.1
2015	370.71	123.44	109.3	90.27	89.21	91.76	53.04	58.24	56.83	49.82	1455.21
2016	381.39	128.85	116	103.63	91.1	69.33	58.94	55.78	52.96	48.24	1474.12
Average	324.89	120.66	102	65.28	76.2	76.68	42.1	49.27	46.36	40.28	1274.59

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Mungbean production in China

Ranran Wu[1], Xin Chen[1], Chenchen Xue[1], Jingbin Chen[1], Qiang Yan[1], Yun Lin[1], Xingxing Yuan[1*]

Abstract: Mungbean is an important grain legume crop, widely grown in South, East, and Southeast Asia. With a long history of mungbean cultivation, China is presently the second largest producer of mungbean next to India. Recently, a series of new agricultural policies brought new opportunities for the boost of mungbean industry in China. However, there are still several constraints affecting the rapid and sustainable development of mungbean industry in China, such as relative low yields, cultivar degeneration, unstable quality and price, incomplete processing techniques and consumption network. Given that the demand of mungbean will keep growing in the future, it calls for a joint effort of the government, agricultural scientists, local farmers, and agricultural products processing enterprises to develop the mungbean industry in China.

Key words: mungbean, production, constraints, China

General situation of mungbean in China

Mungbean [*Vigna radiata* (L.) Wilczek], belonging to the family Leguminosae, subfamily Papilionaceae and genus *Vigna*, is a warm-season grain legume rich in dietary protein and micronutrients, adapted to tropical and subtropical regions (Figure 1) (1). In China, it has been cultivated for more than 2,000 years (2). In the early 1950s, mungbean sown areas in China ranked first in the world. Whereas it started to decline during the late 1950s, and there was only some scattered planting until the mid-1970s (3). Since 1978, germplasm resources of food legumes such as mungbean have been officially listed into the national key research projects (4). Therefore, the Chinese mungbean industry had a boom along with the extension and application of improved cultivars in the late 1980s (3). Both the sown area and the production of mungbean declined almost a half from 2002 to 2018, with nearly 970,000 ha resulting in 1,190 kilotonnes in 2002, to 485,000 ha resulting in 681 kilotonnes in 2018, with only a slight increase in average yield (Figure 2). With the implementation of relevant favorable policies, such as listing food legumes as one of fifty agricultural products' Modern Agricultural Industry Technology System (2009), the production of mungbean is recovering stably in the last five years. In 2020, the planting area of mungbean reached 600,000 ha, and the production was estimated to be 750 kilotonnes in China.

With the adjustment of Chinese industrial structure, the mungbean production regional layout altered slightly. Currently, the major producing provinces of mungbean in China are Inner Mongolia, Jilin, Shanxi, Henan, Heilongjiang, and Anhui (Figure 3). In 2018,

Figure 1. Mungbean in mature period.

the mungbean sown area in these six provinces was 376,900 ha, accounting for 77.7% of Chinese mungbean total planting area. Compared with 2013, the mungbean planting areas in Inner Mongolia and Heilongjiang provinces increased 21.29% and 65.84%, respectively. While, the mungbean planting areas in Jilin and Anhui provinces declined sharply to hardly a half. In Shanxi and Henan provinces, the sown areas also showed a downward trend (Figure 3A). Speaking of production, Inner Mongolia is unquestionably the largest mungbean producer in China. In 2018, the mungbean production was 212 kilotonnes in Inner Mongolia, accounting for 1/3 of the

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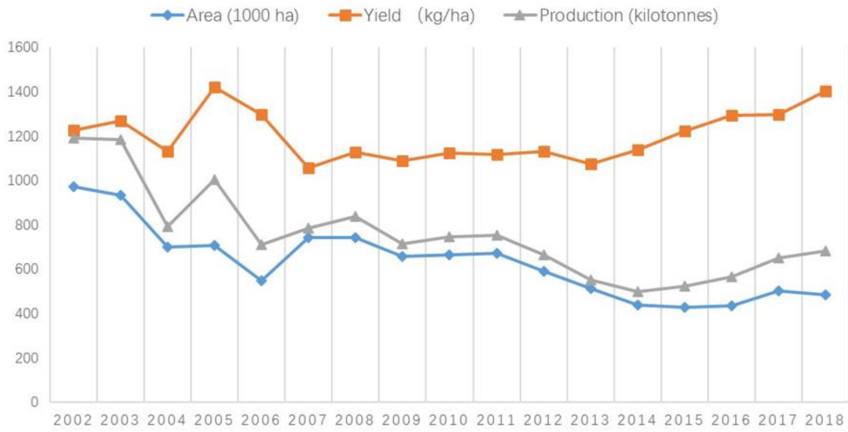

Figure 2. Mungbean cultivated area, production and yield from 2002 to 2018 in China. (Source: National Bureau of Statistics of China, https://data.stats.gov.cn)

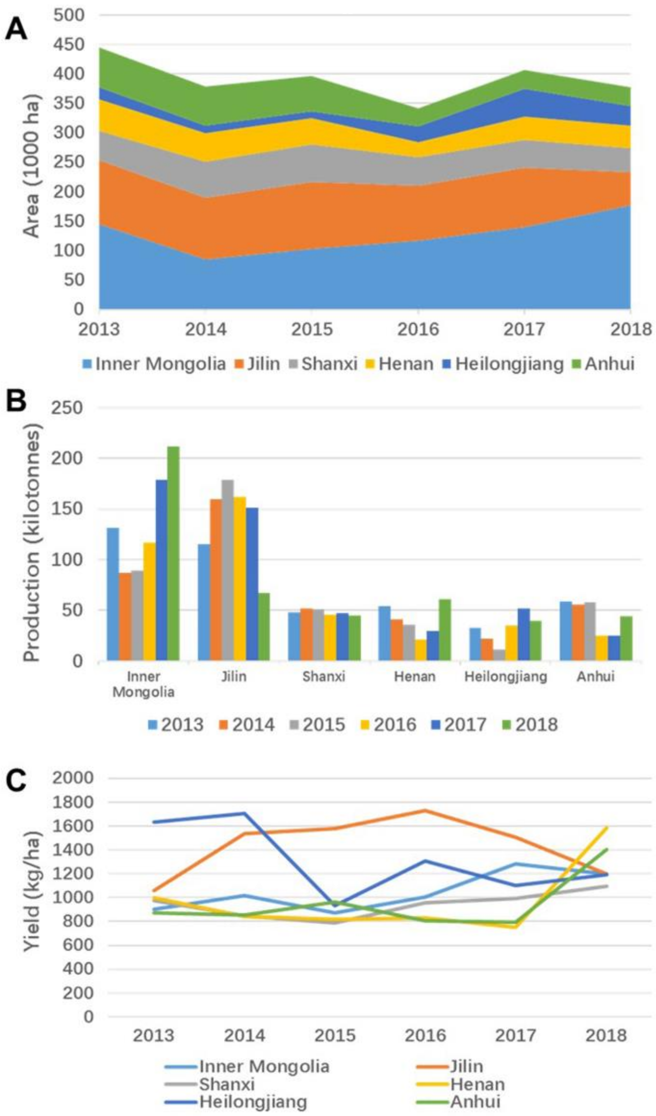

Figure 3. Mungbean cultivated area (A), production (B) and yield (C) in the major production areas in China from 2013-2018. (Source: Ministry of Agriculture and Rural Affairs of the people's Republic of China, http://zdscxx.moa.gov.cn:8080/nyb/pc/index.jsp)

country's ultimate production. The proportion of the six major regions' total production was 68.87% in 2018 (Figure 3B). However, an industrial problem, unstable fluctuating yield, was prominent in some regions, such as in the Heilongjiang and Jilin provinces (Figure 3C).

As one of the main legume crops in China, mungbean also plays a critical role in export markets (5). Although the major exporters of mungbean are Japan, Vietnam and USA, and the main importers are Australia, Myanmar and Indonesia (6), China has been a net exporter of mungbean for a long time, with a vital share in the international markets (3). The import and export markets of mungbean in China are relatively concentrated. The export quantity of mungbean fluctuated sharply from 1992 to 2009. After 2010, it tended to be gentle and increased a bit (Figure 4). Relatively speaking, the import quantity of mungbean was stable from 1992 to 2007. After 2007, it increased as a whole, with large fluctuation. In 2019, there was a minimal net export quantity of only 12.78 kilotonnes and the import quantity was more than 113 kilotonnes, which suggested the domestic demand for mungbean accelerated sharply.

Collection and research of germplasm resources are the foundation of the breeding work. The three largest mungbean germplasm collections are held at the University of the Philippines, the World Vegetable Center (AVRDC, Taiwan), and the Chinese Academy of Agricultural Sciences (CAAS) (7). AVRDC has established the mungbean core collection with 1,481 accessions and mini-core collection of 296 accessions (7, 8). In China, the collection of mungbean germplasm could go back to 1980's, and during that decade over 3,000 accessions of mungbean germplasm were conserved in the national gene bank of China (9). Currently, more than 6,000 accessions were collected from China and abroad, and some of them were evaluated with main nutritional quality analysis, biotic and abiotic resistance. A Resource Assessment Database was established based on these data (10, 11).

Cultivation constrains

Mungbean cultivation is restricted by several constraints limiting the production in China which will be discussed in the following paragraphs.

The yield is relatively low

Mungbean is mainly cultivated in the northeast, northwest and north China regions, where the environment is harsh, and the climate is mostly arid and semi-arid. Furthermore, in these regions, the mechanization of planting mungbean is not popularized and the field management is rough, which will result in plant diseases and insect pest epidemics. Consequently, the yield of mungbean is generally low (3, 12). Plus, the government subsidies for growing mungbean are insufficient. Therefore, the enthusiasm of farmers planting mungbeans is not high.

The mungbean cultivar degeneration is serious

In China, mungbean production mainly depends on household planting, which is small-scaled and decentralized. In a long period, they tend to use the traditional local cultivars. Due to the long-term repeated use, with little investment in selecting, purifying and strengthening, some characters end up seriously degenerated (6). On the other hand, the breeding research on mungbean is really behind that on crops such as rice, wheat, corn or soybean, with insufficient scientific and technological support. Therefore, improved, special and high-tech content cultivars are rare (3).

The quality and price fluctuate greatly

In China, the production of mungbean is mainly based on traditional natural cultivation, and standardized cultivation management techniques are hardly applied. Also, the ability to cope with climate and natural disasters is weak. Thus, the quality of mungbean is not very stable. Together with the International market impact, mismatched market information and hyping by fraudulent sellers, the price of mungbean frequently fluctuates. These also affect the confidence and initiative of the farmers to produce mungbean (6, 12).

The processing techniques and consumption networks are incomplete

In China, mungbean processing industry is mainly in the form of rough processing, and deep processing products with high added value are scarce. In addition, mungbean deep processing technique reverts without mature and systematic industry chains. In addition, mungbean processing enterprises are often small and producing regions are relatively scattered, lacking a leading enterprise that has profound influence around the whole country and forms a national famous brand. Besides, the consumption network is still a traditional one in which the supply and demand information is not timely acquired (3,12).

Future perspectives

With the improvement of citizens' living standards and the adjustment of dietary structure, the market demand for mungbean will keep increasing in the future in China. Recently, a series of preferential agriculture policies in China will benefit the development of the mungbean industry. Initially, as genetic diversity is the ultimate basis for genetic improvement, particular emphasis will be placed on the collection, creation, and protection of mungbean germplasm. Then, mungbean breeding research will attract more attention from the concerning agricultural scientists. So, the improvement of mungbean's yield and quality, or maybe one mungbean "Green Revolution" is expected to happen. Lastly, with the consumers' demand for mungbean products will come the rapid development of the processing industry.

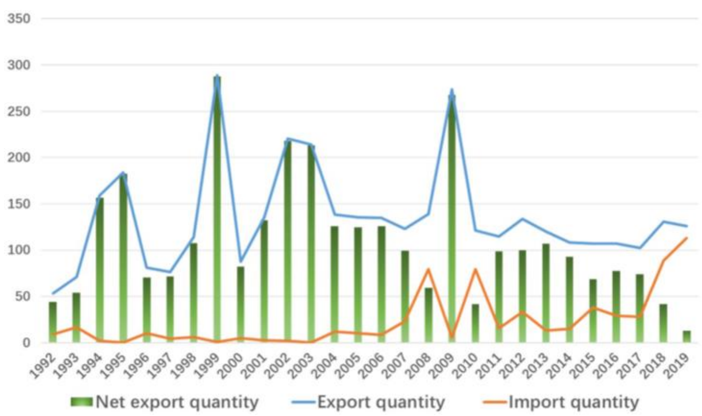

Figure 4. The quantity of mungbean trade in China from 1992 to 2019. (Source: UN COMTRADE Database, https://comtrade.un.org/data, mungbean (HS071331))

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Adzuki bean (*Vigna angularis*): Research progress and comprehensive utilization in China

Xiaoyan Zhang[1], Xin Chen[1], Chenchen Xue[1], Lu Huang[1], Xingxing Yuan[1*]

Abstract: China is the world's largest adzuki bean producer, where this legume crop is a traditional export commodity. The seeds of adzuki bean, which are rich in starch and low in fat, are popular foods for Chinese people. However, compared with staple crops, progresses on molecular genetics and genomics of adzuki beans are lagging, and the exploration and utilization of adzuki bean germplasm resources are insufficient. Thus far, genetic improvement of azuki bean has still largely relied on traditional pedigree selection. This review provides a summary of the collection and utilization of adzuki bean germplasm resources in China, the current status of adzuki bean breeding, as well as discussions on the research advances of classical and modern molecular genetics, which will serve as an engine for further research of adzuki bean in China.

Key words: Adzuki bean, germplasm resources, breeding and genetic studies, further development

Introduction

Adzuki bean (*Vigna angularis* (Willd) Ohwi & Ohashi) is a cultivated species of the *Vigna* genus in the Leguminosae family, which may constitute an essential part of the human diet as they are excellent sources of protein, carbohydrates, vitamins, minerals and bioactive compounds (Figure 1). Adzuki bean originated in China with a cultivation history of nearly 2000 years and is consumed by most households in Asia (1). In China, adzuki bean is not only an important crop for the adjustment of the modern agricultural planting structure, but also a cash crop for poverty alleviation in underdeveloped areas. With the increasing attention to health, research on health/ medical compounds of adzuki bean and related product development continue to increase. Therefore, the demand for adzuki bean breeding and its diversified processed products have gradually increased. This review aims to summarize the current research progress and analyze the existing problems of adzuki bean industry, which will form a cornerstone of future adzuki bean research.

The biology research and planting areas of adzuki beans in China

Adzuki bean is a short-day crop that is sensitive to photoperiod, and it is a thermophile crop with no strict requirements on soil fertility, possessing good waterlogging resistance (1). In China, the main planting area of adzuki bean are North China, Northeast China and Yangtze-huaihe river basin, whose planting area and yield account for about 70 % of the country's adzuki bean production (2). China is the world's largest adzuki bean producer, leading the world in both adzuki bean's output and exports. The planting area of adzuki bean in China is nearly 20,000 ha, which ranks first in the world. According to the National Bureau of Statistics of China, the planting area of adzuki bean decreased from 272,330 ha in 2002 to 122,940 ha in 2015, with a decrease of 54.86 %. The consequences were the decrease of the annual yield, which change from 383,600 tons in 2002 to 175,700 tons in 2015, decreasing by 25.20%. Nevertheless, since 2015, adzuki bean planting area has been increasing gradually. In 2018, the planting area of adzuki beans recovered to 182,440 ha, and the yield also increased to 277,900 tons. Although the output per unit area of adzuki beans fluctuates from year to year, the overall trend is increasing (Figure 2). The planting area and production of adzuki bean changed greatly among provinces and regions in China, among which the adzuki bean was mainly planted in Heilongjiang, Jilin, Inner Mongolia, Shanxi and Shaanxi. The planting area of adzuki beans in those regions accounted for about 70% of the country's total planting area, and the production accounted for about 60% of the country's total production (Figure 3) (http://www.moa.gov.cn/).

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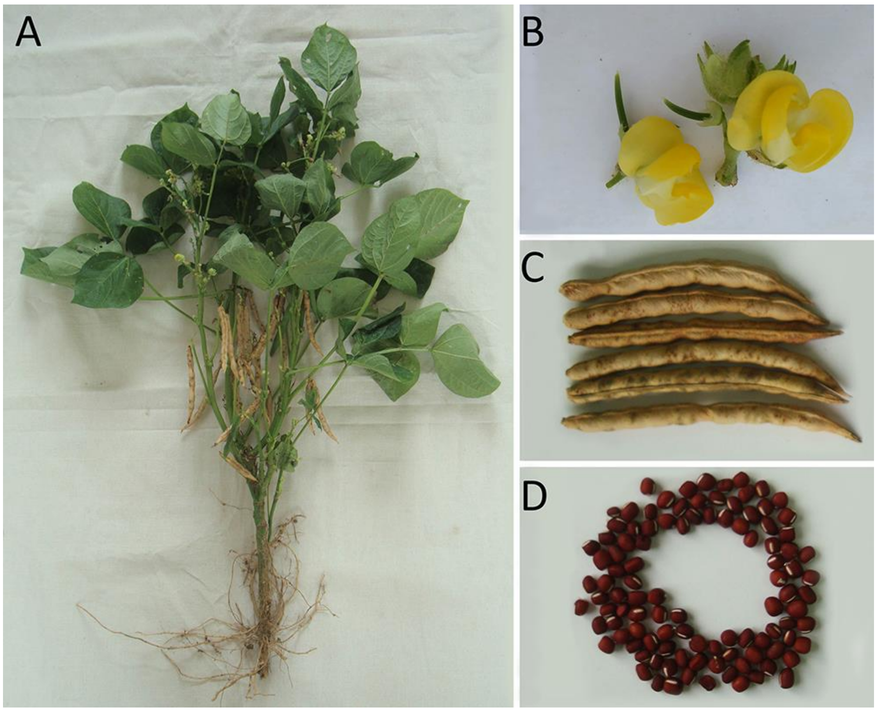

Figure 1. The local adzuki bean cultivar from Jiangsu Province, China. A) adzuki bean seedling; B) adzuki bean flowers; C) adzuki bean pods; D) adzuki bean seeds.

Table 1. The number and proportion of adzuki bean accessions collected from each province and and conserved at the national seed bank.

Type	Source	Number of accessions	Proportion (%)
Spring	Jilin	260	6.32
	Heilongjiang	258	5.27
	Liaoning	150	3.65
	Inner Mongolia	85	2.07
	Gansu	62	1.51
	Ningxia	17	0.41
Spring, Summer	Shanxi	600	14.59
	Hubei	426	10.36
	Hebei	390	9.48
	Shaanxi	322	7.83
	Beijing	258	6.27
	Guizhou	136	3.31
	Yunnan	109	2.65
	Jiangsu	86	2.09
	Sichuan	22	0.54
Summer	Henan	371	9.02
	Shandong	235	5.71
	Anhui	207	5.03
	Tianjin	39	0.95
Spring, Summer, Autumn	Hunan	56	1.36
	Guangxi	8	0.19
	Hainan	1	0.02
Autumn	Taiwan	3	0.07
NA	Imported resources	11	0.27
Total		4112	

Study and utilization on adzuki bean germplasm resources

At present, more than 10,000 adzuki bean accessions have been collected and preserved in the world. As the country of origin of adzuki bean, China has carried out the collection, preservation, identification and evaluation of adzuki bean germplasm resources since 1978. To date, more than 5,000 adzuki bean accessions have been collected in China and abroad, of which 4,856 have been characterized for their agronomic traits and listed in China Edible Legume Cultivar Resources Catalogue, and 4,227 have been submitted to the national seed bank for long-term preservation (Table 1).

Adzuki bean is distinct in its high starch and low fat accumulation. The protein content of adzuki beans is between 16.9% - 28.6%, whereas the total starch content is between 1.8% - 59.9%. The content of eight essential amino acids in adzuki bean is 2 -3 times than that of cereals. In addition, adzuki bean is rich in B vitamins and minerals such as calcium, phosphorus, iron, and others (1). Appropriate intake of adzuki bean seeds in the diet can purify the blood and relieve heart fatigue. Given these characteristics, adzuki bean is known as the 'red pearl' in food, and it is cooked with rice, millet, sorghum rice, etc., and mixed with wheat noodles, corn noodles, rice noodles and millet noodles in China. Furthermore, adzuki bean is a traditional Chinese medicine for diuretic and antidote, and to alleviate symptoms of dropsy and beriberi in China (3).

The selection and breeding of new adzuki bean cultivars mainly adopts conventional methods such as systematic breeding, artificial hybridization and variety's introduction. In the 1980s, China began to adopt hybrid technology for adzuki bean cultivar improvement. However, the breeding progress was slow and few cultivars were promoted and used in a large area. Adzuki bean is a self-pollinated crop, and specific genotypes can be obtained through mutation breeding. Nowadays, the mutagenesis techniques used in adzuki bean breeding include space radiation breeding, radiation mutagenesis and chemical mutagenesis. In previous studies, elite individuals with significantly better yield and grain size traits than the male parent were obtained through space radiation breeding and gamma-ray radiation mutagenesis (4). At present, the research on adzuki bean mainly focus on the genetic effects and heritability analysis of agronomic traits, including yield-related traits, stem color, seed coat color, biotic and abiotic stress resistance traits, 100-seed weight and grain quality. Compared with molecular genetics research of staple crops, research on adzuki bean is at the stage of initial utilization of molecular markers, which is lag far behind.

The molecular markers used in adzuki beans mainly focused on the study of genetic diversity and included randomly amplified polymorphic DNA (RAPD), amplified fragment length polymorphism (AFLP), restriction fragment length polymorphism (RFLP), and simple sequence repeats (SRR) (5-8). Genome duplication analysis revealed that the adzuki bean genome, unlike soybean, lacked the event of the recent whole-genome duplication. The genome sequence of adzuki bean will facilitate the identification of genes of agronomical importance and accelerate the improvement of adzuki bean (3).

Limitations of current knowledge and future perspectives

The fundamental research on adzuki bean has lagged far behind the staple crops in China. In recent years, adzuki bean was included in the national agricultural industry developed special funds and modern agriculture industry technology system, bringing opportunities to the fundamental research. Given this, it is necessary to strengthen the adzuki bean germplasm resources collection and preservation and to use plant genomics-based new gene discovery strategies and methods to discover new genetic resources to support adzuki bean breeding. In addition, the molecular marker-assisted selection breeding should be used to improve the efficiency of selection. The subsequent adzuki bean breeding work should also be based on the actual production, focus on solving the key issues in production (such as disease resistance, insect resistance, drought resistance, salt and alkali resistance), improve the market competitiveness, and promote the healthy and sustainable development of adzuki bean industry in China.

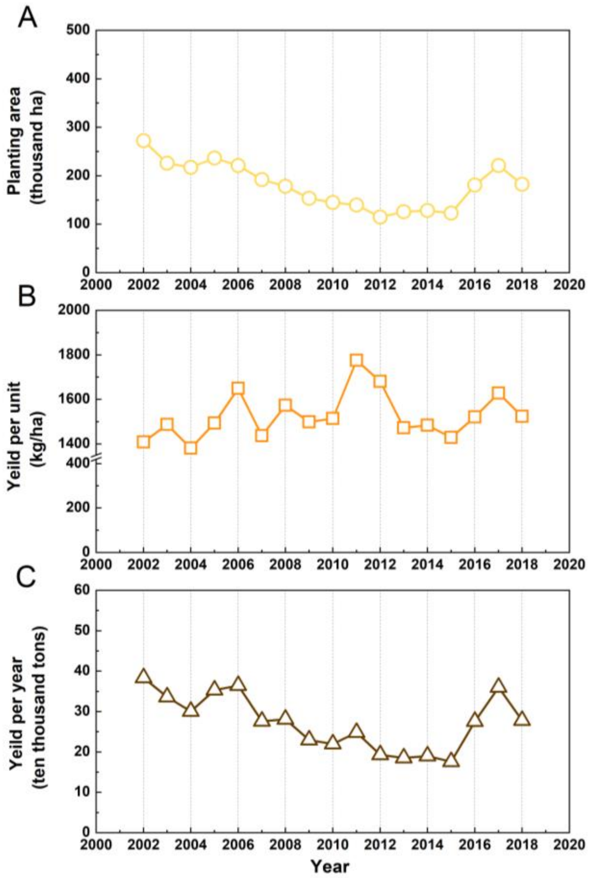

Figure 2. Summary of planting area and yields of adzuki beans in China (2002-2018).

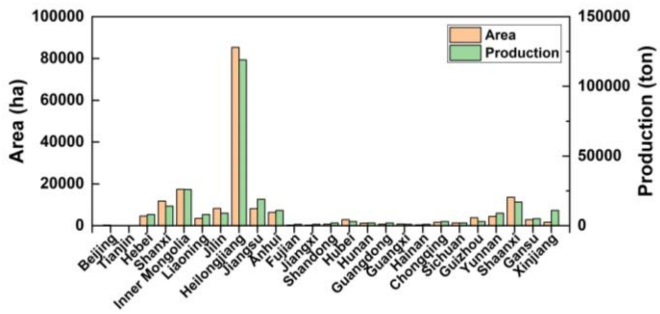

Figure 3. Area harvested and production of adzuki bean in China in 2018, by region.

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Soybeans in China: with focus on grain and oil uses

Yuqiu Li[1], Hua Tan[1], Zhengjun Xia[2*]

Abstract: Soybean is an important source of high-quality protein for human and animal feed. With the improvement of people's living standards, China's demand for soybeans continues to rise. Since China could only produce 17% of total demands, China's soybean industry mainly relies on imports. With the unpredictable uncertainty in international trade in recent years, China's soybean industry has faced unprecedented challenges and opportunities.

Key words: Soybean, mature seed, oil, protein

Cultivated soybeans were domesticated from wild soybeans. In China, soybean is one of the earliest domesticated crops. According to the "Book of Songs", it has a 4,000-years history of cultivation. Archaeological investigations have unearthed soybean remaining at the primitive society site in Wula Street, Yongji County, Jilin Province, China. ^{14}C determination has proven that these remaining are the earliest unearthed soybeans having around 3,000 years (1). Regarding the origin of soybeans in China, there are several controversial hypotheses. The popular one is that domestication took place at the Northeast area, i.e. Northeast Origin Theory (2); also, there are several other theories, i.e. the Southern Origin Theory (3), and the Yellow River Basin Origin Theory (4) or the Multi-origin Theory (5). The different hypotheses have their own supporting evidence to certain extent. No solid unanimously conclusion has been made. Further studies are needed to make a solid declaration.

China has rich soybean genetic resources. At present, more than 43,000 cultivated soybean resources have been deposited in the "National Crop Germplasm Bank". Taking advantage of the abundant soybean resources, breeders have bred soybean cultivars suitable from Mohe County (Heilongjiang Province), the most northern part of China, to Sanya (Hainan Province), the most Southern part of China. Currently, breeders are using conventional breeding strategies e.g. traditional hybridization, single seed transmission, and pedigree breeding methods towards various breeding targets e.g. higher protein contents and higher oil contents. Three national regulations, such as the "Seed Law of the People's Republic of China", "Methods for the Approval of Major Crop Varieties", and the "Main Crop Variety Approval Standard (National)", should be strictly followed in soybean breeding. A total of 248 soybean cultivars were bred from 2008 to 2019 nationwide (Figure 1), with more than 35% of the cultivars bred in Heilongjiang Province. According to statistical data from the National Center for Extension of Agronomic Techniques, Ministry of Agriculture, China, soybean is mainly produced in Heilongjiang and Inner Mongolia, followed by Henan, Anhui, Sichuan Provinces (Figure 2).

In recent years, new special soybean cultivars of high-quality have emerged (Table 1), e.g., small-grain soybean cultivars suitable to produce bean sprouts and natto, and high isoflavone soybean cultivars for processing food good for people’s health. Furthermore, the non-odor soybean cultivars are devoid of lypoxygenases and high-protein soybean cultivars are especial for food production. The vegetable soybean cultivars are consumed as fresh food.

According to China Agriculture Statistical Report, China's soybean production showed a slow but steady increase from 1978 to 2019 (Figure 3). During the 1990s, soybean yield increased significantly from 1,455 kg/ha to 1,789 kg/ha, and then increased with small fluctuation to 1,938.49 kg/ha in 2019. Although yield in China has increased year by year, there is still a big gap when compared to the world's soybean yield. This

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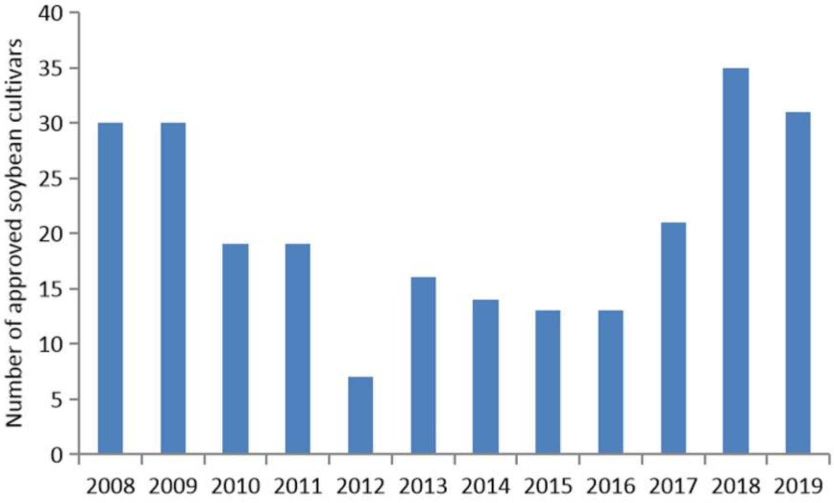

Figure 1. Soybean cultivars that have been issued with the national crop certification from 2008 to 2019.

Table 1. Special soybean cultivars per soybean type.

Type	Cultivars	Origin
Natto, Sprout beans	Jilin Xiaoli 1-15	Jilin AAS
	Henong92	Heilongjiang AAS
High isoflavones	Jiyu 94	Jilin AAS
	Zhongdou 27	Chinese AAS
	Zhongdou45	Chinese AAS
	Zhonghuang 68	Chinese AAS
	Dongnong 53	Northeast Agricultural University
Odorless soybean	Wuxing 1-2	Hebei Academy Agric. and Forestry Sciences Heilongjiang AAS
	Sui Wuxingdou1-3	Hebei Academy Agric. and Forestry Sciences Heilongjiang AAS
Vegetable soybean	Tiexian8	Tieling AAS
	Tiexian10	Tieling AAS
	Liaoxian16	Liaoning AAS
	Liaoxian20	Liaoning AAS
	Liaoxian21	Liaoning AAS
	Zhexian12	Zhejiang AAS
	Zhexian85	Zhejiang AAS
	Sudou16	Jiangsu AAS

is also an important factor restricting the development of China's soybean industry.

The utilization of heterosis is also one of the most effective ways to increase soybean yield. Soybean breeding towards heterosis utilization was first carried out in China and is more widely used in the northern China today. Similar heterosis utilization at large scale has not been reported in any other country. In 1995, the world's first hybrid soybean 'Hybrid Bean No.1' was bred ascribed to successful development of hybrid seeds by three-line method. Up to now, more than 400 cytoplasmic male sterile lines, their corresponding maintainer soybean varieties and more than 400 restorer soybean cultivars have been bred. A total of 32 soybean hybrids have been approved and cultivated, with an average yield increase of over 15%, up to 61% of total protein and oil content, and with strong stability and disease resistance (6). In 2020, hybrid soybeans achieved its highest record in seed production. The large-scale promotion of hybrid soybeans is just around the corner.

With the rapid development of biological sciences, molecular breeding has gradually been applied to crop breeding, which is bound to promote the development of soybean industry. In terms of molecular marker-assisted selection, biological companies have developed gene chips to meet various breeding needs, focusing on traits such as growth period (7), oil (8), SMV resistance (9), and cyst nematode resistance (10). In terms of transgenic breeding, in recent years, Chinese scholars have been greatly dedicated to improve soybean traits by genetic modifications technique in oil content, insect resistance, disease resistance, and stress tolerance. Additionally, many important genes have been cloned and issued independent intellectual property rights. Until now, strict regulations in China do not allow to grow GM soybeans in the field except for research purpose. Compared with conventional cultivars, genetically modified crops have the undeniable advantages of better quality and resistance. With the increasing popularity of sequencing technology and the integration of big data resources, molecular design breeding with clear breeding goals, precise improvements, and targeted selection will become the mainstream for future agricultural development.

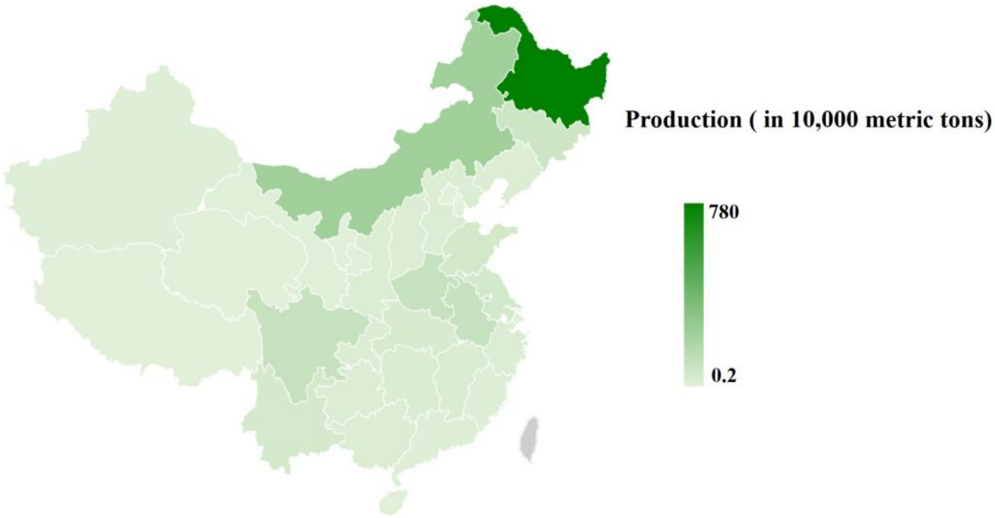

Figure 2. Soybean production in China in 2019 (in 10,000 metric tons).

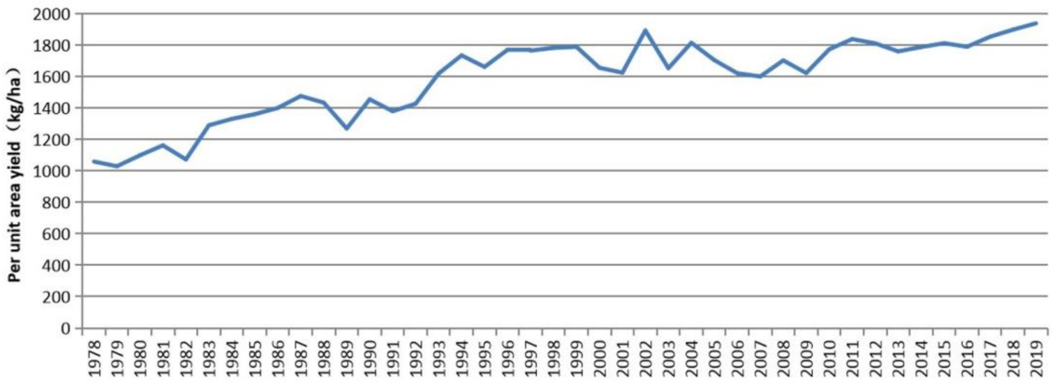

Figure 3. The slow increase in soybean yield from 1978 to 2019 in China (kg/ha).

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A brief overview of pea production in China

Rujia Jiang[1], Shuting Chen[1], Pei Xu[1*]

Abstract: Pea is an important vegetable and grain legume globally. It is also one of the most widely cultivated legume crops in China. In this review, we briefly summarize the origin, characteristics and classification of pea, its history in China, and the current status of pea research and cultivar development in China. We also briefly retrospect the recently progresses in pea research by Chinese scholars based on molecular genetic tools, including DNA marker development, genetic mapping, and dissection of QTLs governing important traits.

Key words: Pea, classification, production, breeding research

The origin of the pea

Pea (*Pisum sativum* L.) is an annual climbing herb belonging to the leguminous family. Indigenous to Central Asia and Eurasia (1), pea is considered one of the earliest domesticated crops in the world. The oldest archaeology evidence of domesticated pea dates back to 9000 BC, mainly from Syria and Israel (2). Due to its strong environmental adaptability, pea has been successfully distributed to many parts of the world. Over 2,000 years ago, the emperor of Han dynasty sent his envoy Zhang Qian to the western regions, bringing back many novel crops including pea, which since then has become popular in China.

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Figure 1. Field photographs showing a) the planting method and b) the plant morphology during the podding stage of pea in China.

Basic characteristics and classification of peas

Basic characteristics

Pea is a self-pollinating cool-season legume, ranking the second largest legume crop in the world and being grown in more than 85 countries. Pea plants are tolerant to cold, drought and barren soil but are susceptible to hot temperature. Mature pea pods are typically swollen and oblong, and the seed morphology is often spherical but also with alterative types such as elliptical, oblate or wrinkled. The calyx is bell-shaped, five-lobed, and the color of the corolla varies by genotype. In its entire growth season, especially during flowering stage, pea plants need plenty of irradiation, of which the lack would cause withering of flowers (3) (Figure 1).

Classifications

1) Flower color: white flower and purple flower;

2) Seed shape: round seeds and wrinkled seeds;

3) Seed size: large-, medium- and small-seeded varieties;

4) Cultivated forms: dry pea, green pea and forage pea. Dry peas (field peas) are harvested after seeds maturation, and the whole seeds are used for animal feed or in the dehulled form for human foods. Green peas (vegetable peas) are harvested as immature seeds, edible pods, or leaves for food. Forage peas are harvested for silage or grazing.

5) Leaf size: ordinary leaf, small leaf, semi-leafless and leafless types. The semi-leafless pea was suggested to be the most lodging-resistant type. The first semi-leafless pea germplasm was introduced into China in 1996 (4).

Nutritional value of peas

Pea is considered a nutritious food due to high contents of quality starch, protein, and fiber. Pea seeds and pods are also rich in minerals such as K, Mg and Ca, as well as nitrosamine decomposition enzyme and carotene. The functional components of pea can promote active bile secretion and reduce cholesterol level in the liver. Long-term consumption may help strengthen the intelligence and bone development of children and can enhance the physical strength of the elderly.

The yield, production, import and export of peas in China

The planting areas of peas in China are scattered and there is no solid source of statistical data on production by province. According to the FAO statistics (Table 1), the total output of peas has been slowly increasing. However, most of the domestic demand for peas are imported (Figure 2), and Canada is currently the largest source of imports.

Table 1. 2016-2019 yield and production of dry peas and green peas in China. (Statista, FAOSTAT, http://www.fao.org/faostat/en/#data/QC).

Item	Year	Area harvested (ha)	Yield (kg/ha)	Production (in metric tons)
Peas, dry	2016	926,642	1483.8	1,374,928
	2017	960,214	1586.1	1,522,950
	2018	980,240	1556.2	1,525,476
	2019	978,320	1491.2	1,458,858
Peas, green	2016	1,526,009	8006.4	12,217,839
	2017	1,573,667	8014.2	12,611,620
	2018	1,621,288	8021.8	13,005,571
	2019	1,668,876	8029.3	13,399,958

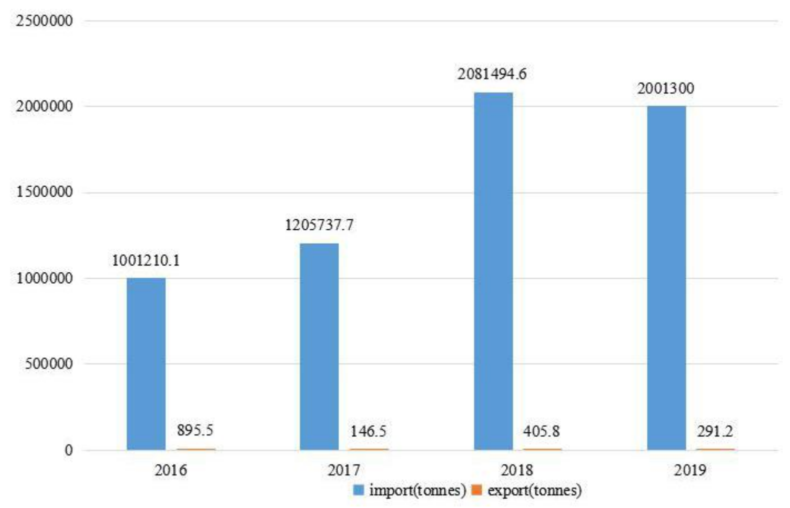

Figure 2. 2016-2019 dry peas import and export in China. (Statista, China General Administration of Customs)

Status of pea breeding in China

Traditional hybrid breeding

Traditional hybrid breeding remains to be the main form of pea improvement in China. Since pea is a strictly self-pollinated crop whose anthers crack before florets opening, emasculation is one of the key steps for making hybrids. Su *et al.* (5) and Du *et al.* (6) published two modified methods of making pea hybrids, which increased the success rate of hybridization compared with the traditional methods (Figure 3).

Some historical and current mainstream cultivars

The 'Zhongwan' series of hard-podded pea cultivars, released by the Chinese Academy of Agricultural Sciences (CAAS), are historically or presently the dominant commercial cultivars in China. The optimal planting season for 'Zhongwan 5' and 'Zhongwan 6' is spring in the north and winter or autumn in the south. The plant heights are typically 40-50 cm, bearing white flowers and hard pods. Each plant bears 7-10 pods that are 7-9 cm in length, about 1.2 cm in width and 1 cm thick. There are 6-7 seeds in a single pod. The mature dry seeds and fresh seeds of 'Zhongwan 5' and 'Zhongwan 6' are dark-green and light-green, respectively (7). Besides the 'Zhongwan' series, the Taiwan-sourced cultivar 'Changshouren' and the newly released 'Zhewan' series of cvs. from Zhejiang are also popular or gaining popularity in the Chinese market.

Molecular breeding

Thus far, no pea cultivars have been released in China as being bred through molecular breeding. Yet, rapid advances in both basic and applied genomics research were made in recent years, which have the potential to promote molecular breeding of pea in the near future. Liu *et al.* (8) performed SSR-based marker-trait association analysis of frost tolerance by using diverse pea accessions at three locations in Northern China in three growing seasons from 2013-2016. The functional marker EST1109 was identified to co-localize with a gene involved in the metabolism of glycoproteins in response to chilling stress (8). Ma *et al.* (9) constructed a linkage map using 1609 high-quality SNPs developed through GBS, based on which 89 QTLs for mineral concentration, content and seed weight were identified. Zheng *et al.* (10) conducted QTL (quantitative trait locus) mapping using the SLAF-BSA technology, identifying a set of SNP markers linked to leaf shape (10). The recently available reference genome of pea will provide a new engine for the boost of marker-assisted breeding.

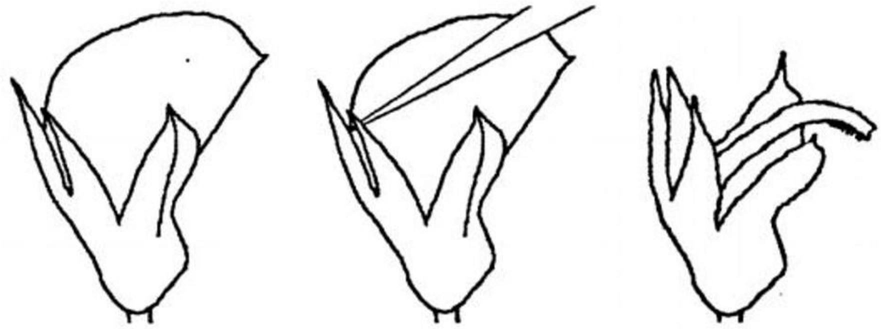

Figure 3. New method of making hybrid pea. (Adapted from Du *et al.* (6)).

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Advances in faba bean production in China

Na Zhao[1], Yamei Miao[1], Kaihua Wang[1], Dong Xue[1], Xuejun Wang[1*]

Abstract: Faba bean is an important cool-season legume that is used as a grain, vegetable and green manure. Here, faba bean's origin, production, and utility value, as well as its planting and breeding status in China are reviewed. Additionally, breeding targets and the future development of Chinese faba bean are discussed.
Key words: Faba bean, nutrition, planting distribution, breeding, utility value

Introduction

Faba bean (*Vicia faba* L.), also called broad or horse bean, is a member of the Fabaceae family (legume). It is a diploid plant with 2n = 12 chromosomes (1) and is an important grain legume in China. Faba bean has high protein (up to 35%) and starch contents, making it an important source of plant protein for humans and animal fodder. Faba bean seeds also contain many mineral nutrients, such as K, Ca, Mg, Fe, and Zn, and several other bioactive compounds, such as polyphenols and carotenoids (2). In addition, faba bean straw provides feed for animals. Faba bean replaces the available nitrogen in the soil when used in crop rotations with cereals and oilseeds, and it is expected to be used as a nitrogen source in future cropping systems (3). Faba bean is also used as green manure that fertilizes soil.

Faba bean germplasm resources are abundant, which show various agronomic characteristics. Multiple seed coat colors exist, including white, green, purple, red, and yellow. Faba bean flowers are also varied and colorful but are mainly white and purple. The diverse seed sizes are classified as major (large), equine (mid-sized), and minor (small), which have 100-seed weights of >110, 60.1-110, and <60 g, respectively (4). The fresh and dry seeds of faba bean are used as a vegetable and grain, respectively. In China, the minor type of dry faba bean is used for feed and export, whereas the other two types are used for human food. The vegetable faba beans are usually major to equine sized while the pods are green.

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Faba bean origins and production in China

The faba bean originated from the Near or Middle East and was domesticated during the early stages of agricultural development (5). The exact timing of its spread to China is unclear. However, grain fossils found in Wuxing, Zhejiang Province indicate that faba bean was first cultivated in China 4,000-5,000 years ago. Ancient references to the introduction of faba bean 2,100 years ago from the Middle East along the Silk Road have been found in northern China. China appears to be a secondary center of faba bean genetic diversity (4, 6).

China is the largest faba bean producer (approximately 40% of world output) with an average planting area of 1.1 million ha, which includes approximately 900,000 ha of dry and 200,000 ha of vegetable faba bean. The yield of dry minor seeds is 2,400-5,250 kg/ha, and that of equine to major seeds is 2,400-3,750 kg/ha. Fresh pod yields range from 15,000-27,000 kg/ha, producing 5,000-9,000 kg of fresh seeds.

Faba bean planting and breeding distribution characteristics in China

Faba bean is a cool-season annual legume that is usually planted in winter and spring agroclimatic zones. In China, faba bean is planted in at least 21 provinces, mostly in Southern China, including Jiangsu, Zhejiang, Shanghai, Fujian, Yunnan, Sichuan, Hubei, Hunan, Guizhou, Guangdong, Jiangxi, Anhui, Sha'anxi, and Guangxi. Winter faba bean covers 85.5% of the total planting area and accounts for 78.2% of the total production in China (4). Winter faba bean is usually sown in October and November and harvested in March to May. In cooler agroclimatic zones, including Gansu, Qinghai, Hebei, Neimenggu, and Ningxia provinces, sowing is postponed until Spring, from March to April, and harvested between June and September (6) (Table 1).

Although there is a long cultivation history and large planting area of faba bean in China, cultivar improvements were rare until the 1970s. Chinese scientists have bred several series of faba bean cultivars using traditional breeding methods, whereas the molecular breeding of faba bean is in the initial stage (7).

The Yunnan Academy of Agricultural Sciences bred the 'Yundou' series of faba bean cultivars. 'Yundoulvxin No.1-4', which have green seed coats and green cotyledons when the seeds mature. They successfully solved a series of major technical problems in the production of edible beans. Other researchers in Yunnan Province bred a series of new 'Fengdou' cultivars suitable for local ecological conditions. Beginning in 1983, the Sichuan Academy of Agricultural Sciences has been selecting new cultivars from the 'Chenghu' series that are suited to Sichuan ecological conditions. In Jiangsu Province, researchers bred cultivars 'Qidou No.2' and 'Haimendaqingpi' in the 1970s. The Jiangsu Yanjiang Institute of Agricultural Sciences introduced an extra-large-seeded faba bean from Japan in the 1990s. Then, using this cultivar as a parent, they successfully bred some extra-large-seeded high-quality cultivars of 'Tongcanxian' that have 180-220 g dry-seed weights, strong disease resistance, and wide ecological adaptability. Fresh pod and seed yields of the 'Tongcanxian' varieties are approximately 20,000 kg/ha and 6,600 kg/ha, respectively (Figure 1).

To further increase the benefits of planting faba bean and to produce earlier harvests, greenhouse fresh faba bean planting and vernalization-related technologies have been implemented since the end of the 20th century. Greenhouse faba bean was first planted in Fuzhou City, Fujian Province, and then, it developed rapidly, becoming a greenhouse vegetable in Zhejiang, Jiangsu, and Shanghai. A patent for cultivation and vernalization-related technology of faba bean was filed in 2013. The output value of early greenhouse vernalized faba bean in Fujian Province has reached € 19,200 per ha (Figure 2).

Spring faba bean is mainly planted in Qinghai and Gansu provinces. Faba bean cultivars of the 'Qinghai' series have been selected by the Qinghai Academy of Agricultural and Forestry Sciences since the 1970s. The Linxia Institute of Agricultural Sciences bred 'Lincan' cultivars using conventional selection.

Table 1. Faba bean production in China in 2019, by top nine provinces in cultivation area.

Region	Cultivation area (in 1,000 ha)	Production (in 1,000 metric tons)
Yunnan	267	600
Sichuan	134	200
Hubei	120	180
Jiangsu	87	195
Chongqing	53	120
Zhejiang	33	75
Fujian	20	45
Qinghai	20	54
Gansu	20	45
China (Total)	913.1	1916.4

Figure 1. Fresh pods and seeds of cv. Tongcanxian No.7.

Utility value of faba bean

Dry faba bean seeds may be ground into flour to make noodles and vermicelli, and they can also be consumed as bean sprouts, bean paste, and fried snacks. Mature faba bean is a dietary staple in many Chinese provinces, whereas green faba bean is a favorite vegetable in southern China. Fresh faba beans may be paired with other vegetables to make a variety of delicious dishes, and green seeds may be quick-frozen. The stem, leaf, flower, shell, and seed coat of faba bean are used in traditional Chinese medicines. Faba bean is an environmentally friendly crop owing to the ability of its root nodules to fix nitrogen through symbiosis with *Rhizobium leguminosarum*; consequently, it is often rotated and intercropped with other crops.

Future perspectives

Although the Chinese Academy of Agricultural Sciences in China has collected more than 5,200 faba bean accessions, Chinese faba bean germplasms are still poorly represented in the collections of the International Center for Agricultural Research in the Dry Areas. The genetic composition of germplasm resources needs to be further studied. Future breeding should focus on resistance to diseases, insects, and environmental stresses. In addition, greater efforts are needed to implement molecular breeding of faba bean and breeding-related mechanization.

In recent years, the medicinal- and healthcare-related values of faba bean have become important. Consequently, the nutrient quality and components, such as flavonoid and levodopa levels, desires more attention. Both ornamental and medicinal types of faba bean cultivars are expected by the market.

Figure 2. Faba bean in the green house at Nantong, Jiangsu Province, China.

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Research progress on germplasm innovation and cultivation technology of lablab bean in China

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Abstract: In this paper, the current situation of scientific research and cultivation of lablab bean in China was summarized, and the germplasm innovation (including collection and evaluation of germplasm resources, genetic research and breeding practice, nutritional analysis and processing utilization) and cultivation technology research were reviewed in detail. The future prospects of lablab bean cultivation, processing and research were put forward, so as to provide reference for lablab bean as a dual-purpose medicine and food. It can provide a reference for the promotion of lablab industry and traditional Chinese medicine.

Key words: lablab bean, germplasm creation, genetic breeding, cultivation techniques

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In China, lablab bean (*Lablab purpureus* L.), also known as hyascinth bean, dolichos bean, chadou, miandou, meidou, yueliangcai, etc., belongs to the genus *Lablab* of the leguminous family and is an annual or short-lived perennial vine, twining vine. The flower colors are mainly red and white; the immature pod colors are cyan, white, light green, sand red, vermilion, purplish red, etc. The lablab bean's mature pods and beans are often used as food vegetables.

At present, China's vegetable lablab bean cultivation area is about 216,000 ha, and the average yield of fresh pods is about 22,500 Kg/ha. About 165,000 hectares are distributed in Jiangsu, Shanghai, Zhejiang, Hunan, Jiangxi, Guangdong, Guangxi, Hainan, Fujian province and other southern regions, and 91,000 hectares in other regions (Table 1). Most of the cultivation areas are normally scattered in front and back of living houses, at the corners of the planting field or in the gap regions near to fences, resulting in a low production rate as well as economic benefit. With the development of market economy, a large area of continuous cultivation regions for demonstration has been established in recent years. Among them, the planting area of lablab bean in Shanghai suburbs is relatively large, with an annual planting area of about 2,000 ha. In particular, Pudong Honggangqing Lablab Bean Cooperative that has engaged in the cultivation of lablab bean for nearly 30 years, had led more than 10,000 local farmers to plant lablab bean. It is the Chinese biggest large-scale production base of fresh lablab bean. In only 10 years, from 2010 to 2019, the total planting area has reached 1.24 million ha, with total output value reaching ￥2.893 billion yuan ($431 million).

In China, lablab bean is appreciated not only for its good edible value, but also for its medicinal use. However, due to people's eating preference variation, it is mainly distributed in the south of China, fewer in North China and Northeast China, and rarely seen in alpine areas. In these Alpine areas it sometimes blossoms, but it does not pod. Due to the small planting area and low popularity of the lablab bean, it is usually being overlooked with relative scientific research and technology promotions being lagging behind; for example, due to insufficient in-depth research in the importance of the agronomic traits of lablab bean, lablab bean are easy infected by *Sclerotinia sclerotiorum* and damage of lablab bean borer is serious, lacking antigens and critical approaches to control and prevent the harmfulness by relative diseases and insect pests. Therefore, authors have collected some research works and summarized them to provide some references for the development of the lablab bean industry.

Collection and evaluation of germplasm resources

Since 1982, there have been reports on the research of lablab bean resources in Northwest Yunnan, Sichuan part of Qinba mountainous area, Southwest Sichuan, Western Guangxi mountainous area, Southern Guizhou mountainous area, Shandong, Hunan, Jiangsu, etc., but these studies are still at the level of morphological and biological characteristics identification.

In 2007, Zhang (1) and her group used electron microscope scanning technology to scan the pollen of eight lablab bean varieties obtained in Jilin Province, and found that their appearance and ornamentation were different. The variations of microscopic morphology of pollen surface could be used to identify the germplasm resources origins of lablab beans. At present, with the promulgation of the new "seed law" and the third census of crop germplasm resources, the research of germplasm resources has received unprecedented attention. It is believed that a lot of lablab bean germplasm materials will be collected, so as to get reasonable development and utilization.

Genetic research and breeding practice

In terms of genetic diversity research, Tian *et al.* (2) carried out DNA research on lablab bean germplasm resources in Hunan Province for the first time using RAPD technology in 2004, and obtained 3 fingerprints, 33 bands, among which 16 were polymorphic (2). After analysis, there were certain differences among different varieties, but the difference was not big. Some varieties had the same genetic characteristics, which basically matched well with the traditional morphological classifications. Zhang *et al.* (3), Wang *et al.* (4), Yao *et al.* (5) and others utilized EST-SSRs markers, indel primers, SSR markers and phenotypic diversity to study the genetic diversity of lablab bean, and made some progresses.

Table 1. Estimate Vegetable lablab bean cultivation area and yield in China.

Province	Cultivation Area /ha	Yield/tons
Jiangsu	30,000	675,000
Shanghai	2,000	45,000
Zhejiang	22,000	495,000
Hunan	26,000	585,000
Jiangxi	22,000	495,000
Guangdong	29,000	652,500
Guangxi	14,000	315,000
Hainan	8,000	180,000
Fujian	12,000	270,000
Others	91,000	2,047,500
Total	216,000	4,860,000

In terms of genetic map construction, Xi and Tang (6) constructed a fingerprint map that can distinguish different sites on various materials in 2006. In 2009, Yuan *et al.* (7) selected "Meidou 2012" and "Nanhui 23" as parent samples, to obtain a F_2 population with 136 individuals. This F_2 population was used to develop a linkage map with a total length of 1,302 cM and an average marker distance of 9.9 cM where QTL mapping was performed for 9 lablab bean inflorescence traits. They confirmed that genes controlling inflorescence traits of lablab bean could also control many other characters, which laid a foundation for lablab bean breeding. Since then, Yao *et al.* (8) have also carried out relevant research and found that the LPMYB1-Like gene of lablab bean is associated with drought resistance, which laid a foundation for key traits gene discovery in lablab bean breeding. Although molecular marker technology is developing rapidly, research progress on the application of such technology on lablab bean is still very slow.

With respective of breeding new varieties, scientific research by Shanghai Jiaotong University Agriculture and Biology College were carried out earlier. At the same time of conducting fundamental studies, they also bred new lablab bean varieties 'Jiaoda Hongbian No.2', 'Jiaoda Yanhongbian', 'Jiaoda Cuilvbian' and 'Jiaoda Qingbiandou No.1' (Figure 1). These cultivars have thicker meat, higher cyanidin content and stronger insect resistance. The yield can reach 30,000-40,000 Kg/ha, with a large promotion area in Shanghai and its neighboring regions.

Yangzhou Bangda Vegetable Research Institute and Jiangsu Academy of Agricultural Sciences selected 'HongYu', 'CuiYu', 'ZaoHongbian' and SuBian series, which have characteristics of early maturity and high yield and strong disease resistance. They can be planted in greenhouses in early spring or planted in open fields in autumn. The new varieties 'SuBian 1605' and 'SuBian 1607' (Figure 2) bred by Taixing Institute of Agricultural Sciences recently, were cultivated systematically from local widely-planted species. These two varieties are both medium long inflorescence and mid-late maturing, with higher yield, better quality, waxier grain and longer harvesting time, being good varieties for open field cultivation in autumn. According to the local consumption habits, some new varieties of lablab bean have been developed in other areas by adjusting measures to local conditions, which promoted the local agricultural development to a great extent.

Figure 1. Cultivar 'Jiaoda Qingbiandou No.1'.

Nutrition analysis and processing utilization

Nutritional value

Lablab bean is rich in nutrients, which can provide starch and protein for human beings with nutritional value higher than other leafy vegetables. In 1985, Muehlbauer *et al.* (9) compared the nutrient content of lablab bean with other beans (Table 2). It was found that the protein content of lablab bean was as high as 24%, without any harmful nutrients for human bodies. Even its stems and shells contained 50% carbohydrates, 21.4% cellulose, 4.4% protein, 1.8% fat, 12.2% ash and 10.2% water, as other superior fodders.

Edible value

Lablab bean is rich in protein (contains a variety of essential amino acids for human body such as Lys, Met, Thr, Leu, He, Val, Phe, etc.), fat, carbohydrate, phosphorus, calcium, iron, vitamins, cyanophoric glycoside, hemagglutinin, etc. Its immature pods, beans or seeds are all edible, not only eligible for cooking, stewing, frying, but also a good choice for making into porridge and summer cool drinks.

Medicinal value

Lablab bean, mainly white lablab bean seeds, are often used in traditional Chinese medicine. According to the Pharmacopoeia of the People's Republic of China (10), white lablab bean can strengthen the spleen, remove dampness, and relieve heat. It can be used for weakness of spleen and stomach, loss of appetite, inconvenience of loose diarrhea, chest tightness and abdominal distension. It can be used for diarrhea due to spleen deficiency and excessive leucorrhea.

According to the modern pharmacological research, lablab bean contains blood agglutinin, which can prevent tumor. However, the lablab bean should always be cooked thoroughly, otherwise, dizziness, nausea, vomiting, diarrhea, and other symptoms would appear after eating the badly cooked lablab bean. Also, the lablab bean should not be eaten too much at one time, otherwise it is easy to cause abdominal distension and discomfort.

Feeding value

Lablab bean are rich in protein and can be used as feed for grazing animals. It is reported that corn-lablab bean mixed feed can improve the apparent digestibility of nutrients, milk yield and milk protein of dairy cows. The highest digestibility of crude protein can reach 83.11%, which shows its high feeding value.

Table 2. Comparison of nutrient contents between lablab bean and other important legumes. (Source: Muehlbauer *et al.* (9))

Crop	Heat (J/Kg)	Moisture (%)	Protein (%)	Oil (%)	Cellulose (%)	Carbohydrate (%)	Ash (%)
Chickpea	14985.88	11	20.1	4.5	4.9	56.6	2.9
Soybean	14023.1	11	36.8	17.4	4.7	25.5	4.6
Pea	14483.56	11	22.5	1.8	5.5	53.7	5.5
Broad bean	14567.28	11	23.4	2	7.8	52.4	3.4
Cowpea	14316.12	11	23.4	1.8	4.3	56	3.5
Lablab bean	14483.56	11	24.2	1.8	1.8	59	2.2

Research on cultivation techniques

At present, the research in this field mainly focuses on the exploration of high-yield and high-efficiency cultivation technology and planting mode. The research of high-yield cultivation technology mainly includes variety selection, high density cultivation technology research, occurrence law and control technology of lablab bean pod borer, pathology characteristics of anthrax and integrated pest control technology. In terms of planting mode, by combining local characteristics and rotation arrangement, many efficient planting modes were explored according to local conditions, such as "harvest twice in one crop of lablab bean", "two seasons rotation of lablab bean and vegetables"; “tomato-lablab bean in the greenhouse”, etc. The exploration of new cultivars, new technologies and new models is very practical, which translated into a high-yield and high-efficiency planting experience of lablab bean, worthy of promotion and demonstration.

It is worth mentioning that in recent years, the Shanghai area has made continuous innovations and carried out a series of exploration and research. For example, in order to solve the labor shortage problem in production, reduce production costs and improve planting efficiency, dwarf-vertical cultivation approaches were introduced. In this approach, after the seedlings are fixed, the main vine is pinched in time to promote the growth of the seed vine and flower spike branch. When the seed vine grows up with two leaves and one heart, the heart will be pinched for better growth of the next-generation seed vine and flower spike branch; continuously pinching the heart of new-generation vines could cultivate crown-growth trend and generate more flow spike

Figure 2. Cultivar ‘SuBian1607’.

branches of the lablab bean. The average pruning time was 7-10 days, which promoted the transformation from vegetative growth to reproductive growth. The height of such plant was controlled at 40-50cm to maintain a fascicular condition (Figure 3). With this approach, the annual yield reached 60,000 Kg/ha, or 30,000 Kg/ha within 100 days of harvest. During the China World Expo in 2010, researchers in Shanghai also planted the potted green lablab bean as landscape crops in front of the Chinese Pavilion, thereby excavating the economic value of its seedlings. In terms of lablab bean deep processing, they developed white lablab bean spleen invigorating oil tea powder, lablab bean stripe-wise dried leisure food etc., which added value to lablab bean products, developed lablab bean’s value as a kind of both food and medicine crop, and effectively promoted the sustainable industry development of lablab bean.

Future Studies

In recent years, with the development of economy and the continuous improvement of people's living standards, the daily consumption demand of Chinese people has

Figure 3. Dwarf and erect cultivation of lablab bean.

gradually changed from quantitative consumption to qualitative consumption. Coarse grain food, fruit and vegetable food and special food with particular nutritional value and medicinal value become more and more favored by people. Therefore, it is a new mission for agricultural researchers to explore new types of cereals, fruits and vegetables, and special foods.

Lablab bean is a small crop, which has been planted sporadically in China. Its germplasm resources, genetic breeding, production and promotion, preservation and processing of products have not been systematically studied. Therefore, the authors think that we should start from the following aspects:

1) Speed up the collection, identification, classification and organization of lablab bean germplasm resources, expand and preserve excellent germplasm materials: on the one hand, it could help clarify the origin and evolution theories of lablab bean; on the other hand, the scope of genetic and breeding materials could be broaden, such as valuable resources with excellent characteristics on plant resistance to pod borer, low plant lectin, perennation and orthotropism etc., which would provide precious and extensive information for new varieties selections.

2) Vigorously develop new lablab bean selection and breeding. Apply modern biological technology and molecular technology to speed up the breeding process and promote new and high-quality lablab bean varieties with good yield, strong disease resistance, good marketability quality and high adaptability, to meet the continuous demand of the market.

3) Explore the cultivation technology and deep processing technology of lablab bean. Adjust measures to local conditions, choose proper technologies that match with local climate conditions, cultivation systems' intercropping, oil testing formula, plastic film covering, as well as the preservation and deep processing of lablab bean tender pods. Provide corresponding technical chain support for the promotion of new cultivars.

4) Further study on chemical composition and pharmacology of lablab bean, such as lectin, saponin, protein, and starch contents. Preferably apply its nutritional, edible and medicinal values to industry, medicine and other extensive fields, and let the lablab bean, once a humble obscure crop, make more contributions to human beings.

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Current status and prospect of vegetable soybean production in China

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Abstract: Vegetable soybean, a world-wide recognized healthy and nutritional food, plays a very important role in regulating food structure and improving nutritional status. This review introduces the historical origins and the current status of vegetable soybean breeding and production in China. It also emphasizes the seed composition traits related with nutritional quality and taste quality. Based on the above information, future development strategy and development directions of vegetable soybean in China are proposed.

Key words: Vegetable soybean, breeding, nutrition, taste quality

Soybean [*Glycine max* (L.) Merr.] is an important crop grown worldwide for the provision of vegetable oil for human consumption and protein meal for animal feeds. Vegetable soybean is of similar growth and development peculiarities as traditional soybean. Vegetable soybean also called 'maodou' in China, is a type of specialty soybean, harvested at the R6 growth stage, when the pods and seeds are still green (1). Fresh green soybeans have low oil and high protein content (9～15 g 100 g^{-1}). Vegetable soybean has been recognized as a safe and healthy food with high protein content and vitamins, and is widely planted in Asian countries, especially Japan and the southeast coastal areas of China.

Although there is a long history of vegetable soybean cultivation in China, which dates back to 1620 (2), its production was in a state of self-sufficiency before the 1970s with grain-type soybean varieties being used for vegetable soybean production and just a few improved vegetable soybean cultivars were available, such as 'Tai292', 'Tai75', and 'Aijiao' introduced from the Asian Vegetable Research Center or Japan. Since the 1980s, soybean researchers started to pay more attention to breeding vegetable soybean cultivars adapted to different ecological regions. Since then, a series of vegetable soybean cvs., such as 'Zhenong 6', 'Liaoxian 1', 'Suzao 1', 'Sudou 18' and 'Tongdou 6', have been released and widely grown in China. Among these soybean cultivars, 'Zhenong 6', 'Liaoxian 1', and 'Suzao 1' were used as spring-sowing soybeans (Figure 1), and 'Sudou 18' and 'Tongdou 6' as summer-sowing soybeans. Traditionally, vegetable soybeans were planted in the coastal regions of South China, including Zhejiang, Jiangsu, and Fujian Provinces. The recent average annual sowing acreage is about 150,000 ha, and the average fresh green pod yield is about 10～12 t ha^{-1} and 12～18 t ha^{-1} for spring-sowing and summer-sowing vegetable soybeans, respectively (Table 1). With the rapid increase of fresh green pod yield and sowing area, China has become the largest producer, consumer and exporter country of vegetable soybean in the world (3).

For vegetable soybean breeding, improvement of seed nutritional quality is one of the most important objectives (4-6).

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The protein content of vegetable soybean ranges from 33 to 43.2 %, while the oil content of fresh seed in vegetable soybean ranges from 13 to 20.6 % (3-7). Because of its low oil percentage and high protein content, vegetable soybean is popular among the people pursuing healthy diets (8).

Taste quality is another important trait of vegetable soybean, which involves sweetness, flavor, texture, and freshness. Breeders pay major attention to sweetness in soybean breeding in China, which is primarily determined by total soluble sugar. It was reported that 78.9 to 93.7% of the total soluble sugar in vegetable soybean was sucrose, which increases as the plant grows and peaks at or after around 35 days after flowering (9). The mean sucrose content of 54 vegetable soybean accessions at the R6 stage was 29.5 g / kg, with a range of 16.9-42.1 g / kg, lower than that in the mature seed of 60.2 ± 4.9 g / kg on average (6). Due to the negative correlation between sucrose and protein contents (10), we proposed that lower protein content could be an indirect index in selecting higher sucrose varieties. Besides sucrose content, flavor and taste are also determined by free amino acids and organic acids (9). The total amino acid content of vegetable soybeans was significantly higher than that of grain-type soybean. The organic acid content is also one of the most important factors affecting the quality of soybean cultivars concerning nutritional value and potential use.

As people's living standard rises and the diet structure changes in China, the demand of vegetable soybean will keep increasing. Vegetable soybean yield and quality can vary depending on genotype, weather conditions, and other environmental and agro-technological factors. In recent years, breeders have paid more attention to food quality and nutritional quality, such as soluble sugar and glucose content, and amino acids content. Besides, the breeding for disease and insect resistances, such as soybean virus disease and aphids, should be strengthened. Mechanized harvesting will be vigorously developed to replace the costly manual picking of vegetable soybeans. Post-harvest biotechnologies for vegetable soybean have been developing rapidly, which include the quick-frozen and storage technology, and different preservation methods. Cross-region cooperation will further increase the knowledge, personnel and germplasm exchange nationwide, facilitating the boost of the vegetable soybean industry in China.

Figure 1. The spring-type vegetable soybean cultivars at Nanjing, Jiangsu Province, China.

Table 1. Agronomic traits of spring-and summer-sowing vegetable soybeans

Traits		Spring sowing	Summer sowing
Fresh green pod yield (t·ha-1)		10~12	12~18
HFW (g)		65~93	70~95
GP (day)		75~93	75~100
Response to Anthracnose Disease		> S	> S
Response to SMV resistance	SC3	> MR	> MR
	SC7	> S	> S

HFW: hundred-seed fresh weight; GP: growth period from VE stage to R6 stage; S: susceptible; MR: moderately resistant; SMV: soybean mosaic virus; SC3: SMV strain 3 in China; SC7: SMV strain 7 in China.

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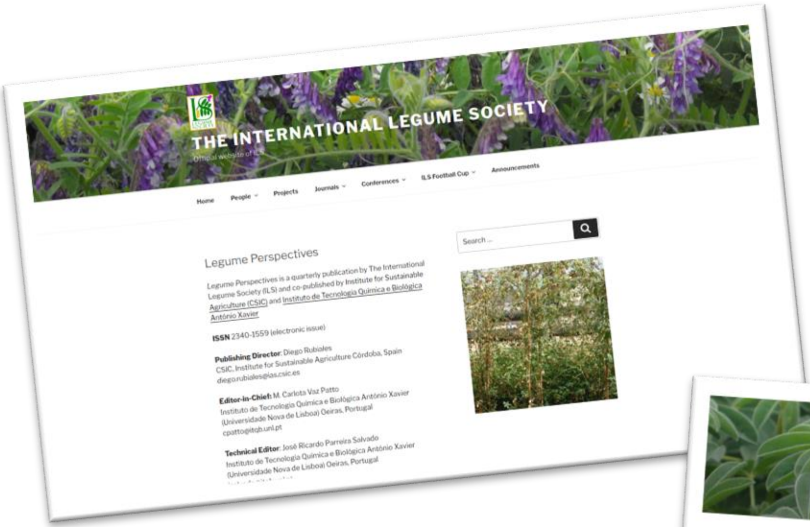

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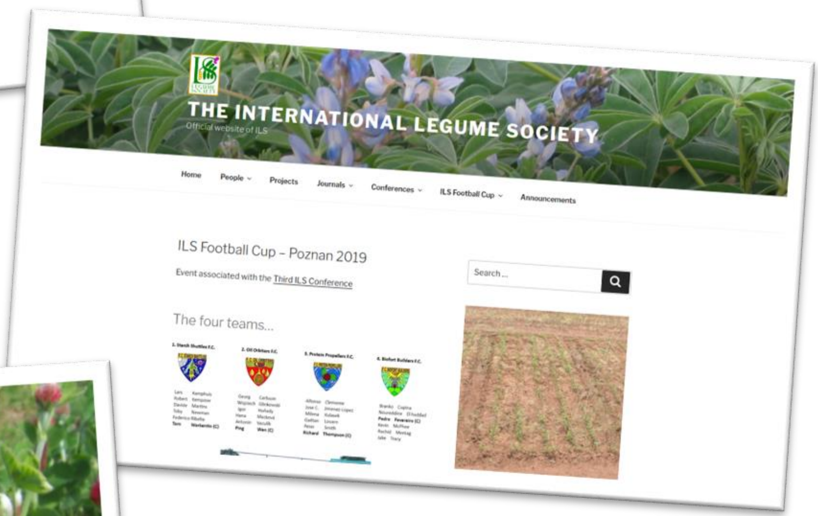

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