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Food legume production in China

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ABSTRACT

Food legumes comprise all legumes grown for human food in China as either dry grains or vegetables, except for soybean and groundnut. China has a vast territory with complex ecological conditions. Rotation, intercropping, and mixed cropping involving pulses are normal cropping systems in China. Whether indigenous or introduced crops, pulses have played an important role in Chinese cropping systems and made an important contribution to food resources for humans since ancient times. The six major food legume species (pea, faba bean, common bean, mung bean, adzuki bean, and cowpea) are the most well-known pulses in China, as well as those with more local distributions; runner bean, lima bean, chickpea, lentil, grass pea, lupine, rice bean, black gram, hyacinth bean, pigeon pea, velvet bean, winged bean, guar bean, sword bean, and jack bean. China has remained the world's leading producer of peas, faba beans, mung beans, and adzuki beans in recent decades, as documented by FAO statistics and China Agriculture Statistical Reports. The demand for food legumes as a healthy food will markedly increase with the improvement of living standards in China. Since China officially joined the World Trade Organization (WTO) in 2001, imports of pea from Canada and Australia have rapidly increased, resulting in reduced prices for dry pea and other food legumes. With reduced profits for food legume crops, their sowing area and total production has decreased within China. At the same time, the rising consumer demand for vegetable food legumes as a healthy food has led to attractive market prices and sharp production increases in China. Vegetable food legumes have reduced growing duration and enable flexibility in cropping systems. In the future, production of dry food legumes will range from stable to slowly decreasing, while production of vegetable food legumes will continue to increase.

1. Introduction

Food legumes in China are defined as all legume crops used for human food either as dry grains [1–3] or as vegetables [3,4], except for soybean and groundnut [4]. China has a vast territory, complex ecosystems, and a great variety of pulse species [4–6]. Food legume crops can be divided into three groups according to their cropping seasons: cool-, temperate-,

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and warm-season food legumes [4,5]. Cool-season food legumes, composed of broad bean (*Vicia faba* L.), pea (*Pisum sativum* L.), chickpea (*Cicer arietinum* L.), lentil (*Lens culinaris* Medik), grass pea (*Lathyrus sativus* L.) and lupine (*Lupinus* L.), are sown in fall in south China and in early spring in north China [4,5]. Temperate-season food legumes include common bean (*Phaseolus vulgaris* L.), runner bean (*Phaseolus multiflorus* Willd), lima bean (*Phaseolus lunatus* L.), and hyacinth bean [*Lablab purpureus* (L.) Sweet], suited to sowing in late spring [4,5]. Warm-season food legumes include mung bean (*Vigna radiata* wilczek), adzuki bean [*Vigna angularis* (Willd) Ohwi & Ohashi], cowpea (*Vigna unguiculata* L. Walp.), rice bean [*Vigna umbellata* (Thumb.) Ohwi and Ohashi], black gram [*Vigna mungo* (L.) Hepper], pigeon pea [*Cajanus cajan* (L.) Millsp.], velvet bean [*Mucuna pruriens* (L.) DC.], winged bean [*Psophocarpus tetragonolobus* (L.) DC.], guar bean [*Cyamopsis tetragonoloba* (L.) taubert], sword bean [*Canavalia gladiata* (Jacq.) DC.], and jack bean [*Canavalia ensiformis* (L.) DC.], which are summer-sown in China [4,5]. Soybean [*Glycine max* (L.) Merr.] and groundnut (*Arachis hypogaea* L.) are not treated as food legumes in China, but defined as oil crops [4].

Mung bean and adzuki bean originated partially in China [7,8] and faba bean and pea have been cultivated in China for over 2000 years [9,10], while common bean, cowpea, chickpea and lentil have been cultivated in China for hundreds of years [11–14]. Other pulse species appear sporadically in Chinese cropping systems [15–20]. Food legumes have played an important role in Chinese cropping systems for traditional and sustainable agriculture since ancient times [4,5]. Food legumes are also key nutritional components for dietary protein, vitamin B, and diversified recipes in traditional food dishes, ensuring the basic health of Chinese people [5,21]. Although 20 species of cultivated pulse crops can be found in China, nine of them, including faba bean, pea, common bean, mung bean, adzuki bean, lentil, chickpea, runner bean, and cowpea, are those most commonly seen in cropping systems [4–6].

2. Area and production of food legumes in China

Mung bean and adzuki bean originated partially in China [22], and faba bean and pea have been cultivated for more than 2000 years [4,6]. Common bean, cowpea, chickpea and lentil have been cultivated for hundreds of years [4,6]. Food legumes play an important role in Chinese cropping systems for traditional and sustainable agriculture since ancient times [5]. Food legumes are also key components providing dietary protein, vitamin B, and diversified recipes in ordinary food dishes, whose traditional preparation has ensured the basic health of Chinese people [5].

2.1. Distribution of food legumes

Cropping of the major food legume crops can be found in all provinces, autonomous regions, and suburban areas of big cities in China [4,6], but most of these crops are distributed unevenly (Table 1). For faba bean, 85% is sown in the winter cropping areas of the semi-tropical climate zone of China [23–26]. For pea, most production is in the semi-tropical climate zone as an upland winter crop [25,26]. Common bean and runner bean are cultivated mainly in southwest and northwest China [4,6]. Mung bean and adzuki bean are cultivated mainly in the northeast provinces [4,22]. Cowpea is cultivated mainly in the northeast and east of China [4,6]. Lentil and chickpea are cultivated mainly as winter crops in the northwest and as spring crops in the north and southwest of China, on dry and degraded land [4,6].

2.2. Harvesting area of major food legumes

Food legumes are favored foods in the daily life of Chinese people and have been important historically [5]. Dry food legume production rapidly decreased from above 10 million to 3 million ha from 1961 to 1992, increased to 4 million ha after two years, then kept steady after 1995 at 4–5 million ha. The proportion of vegetable food legume production has increased sharply during the past 15 years (Fig. 1). Owing to their short cropping duration and high market value, pea and common bean have become dominant vegetable food legumes in China [26,27]. Vegetable faba bean is following the same trend as pea and common bean. According to statistical data from National Center for Extension of Agronomic Techniques, Ministry of Agriculture, China [26], vegetable faba bean were cropped on 0.4277 million ha (6.416 million mu) in China in 2014.

Table 1 – Distribution of major food legumes in China [†].

Food legume	Distribution region	Main producing province or autonomous region
Faba bean	Southwest, East, Southeast, North	Yunnan, Sichuan, Chongqing, Guizhou, Gansu, Qinghai, Jiangsu, Zhejiang, Hebei, Anhui, Hubei, Ningxia, Inner Mongolia, Xinjiang
Pea	Southwest, Northwest, East, North	Gansu, Ningxia, Qinghai, Sichuan, Yunnan, Guizhou, Chongqing, Jiangsu, Hubei, Shanxi, Hebei, Shandong, Inner Mongolia, Xinjiang, Liaoning, Guangdong
Common bean	Southwest, Northeast, North	Heilongjiang, Inner Mongolia, Yunnan, Guizhou, Xinjiang, Hebei, Chongqing, Gansu, Shaanxi, Jilin, Shanxi, Sichuan, Shandong, Liaoning
Mung bean	Northeast, Middle, East, Southwest	Inner Mongolia, Jilin, Liaoning, Shaanxi, Henan, Shanxi, Hebei, Anhui, Shandong, Hubei, Sichuan, Chongqing, Guangxi, Xinjiang
Adzuki bean	Northeast, East	Heilongjiang, Jilin, Liaoning, Hebei, Inner Mongolia, Shanxi, Shaanxi, Shandong, Beijing, Tianjin, Gansu, Hubei
Lentil	North, Middle, Southwest	Henan, Shanxi, Shaanxi, Gansu, Xinjiang, Inner Mongolia
Chickpea	Northwest, North, Southwest	Gansu, Xinjiang, Inner Mongolia, Yunnan
Cowpea	Northeast, East	Henan, Hebei, Shandong, Liaoning, Guangxi, Hubei
Runner bean	Southwest, Middle	Yunnan, Guizhou, Sichuan, Shaanxi, Gansu, Shanxi

[†] Cited from Ministry of Agriculture (MOA) reference (unpublished) with editing.

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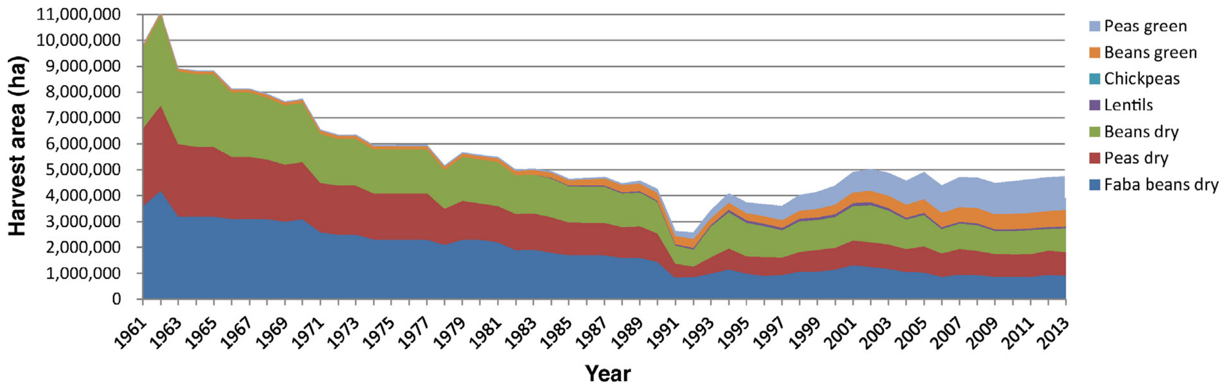

Fig. 1 – Harvest area of food legumes in China since 1961 [27].

Although there are no data in the FAO database, mung bean was sown on 0.5401 million ha and adzuki bean was 0.1517 million ha in 2014 according to Ministry of Agriculture, China [28].

2.3. Yield of major food legumes

In the past 60 years, China has released more than 380 pulse varieties [3,29]. Since 1949, large advances have also been achieved in the breeding of mung beans, broad beans, peas, common beans, and other food legumes [3]. Table 2 shows the names of elite varieties of major pulse crops in China. These contributed to the improvement of pulse yield in the past 60 years.

The trend of slowly increasing yield of food legumes since 1961, for common bean, runner bean, faba bean, pea and lentil (Fig. 2), yields differ a little from the world average; however, chickpea yield has increased sharply since 1993 (Fig. 2), well above the world average [27]. The mean dry grain yield of mung bean was 1276 kg ha^{-1} and that of adzuki bean was 1595 kg ha^{-1} in 2014 [28].

2.4. Production of major food legumes

Pulse production in China was quite stable from 1961 through 1991 [27], even with a decreasing sowing area (Fig. 3). Pulse grain production has been stable from 1992 until now, while pulse green vegetable production has sharply increased over this period (Fig. 3), with both area (Fig. 1) and yield (Fig. 2) sharply increasing.

The production of mung bean in China was 0.69 million tons and that of adzuki bean 0.24 million tons in 2014 [28].

Currently, China is one of the largest producers of food legumes in the world [27]. The positions of China in the world production of food legumes are presented in Table 3. Excluding chickpea, China is ranked in the top 10 producers for the other food legumes [27], including mung bean and adzuki bean [3].

3. Cropping systems involving major food legumes in China

Food legumes are widely grown throughout China, with a long cultivation history and in a diversity of cropping systems

Table 2 – A list of elite varieties of food legume crops in China †.

Food legume	Variety
Faba bean	Yundou 324, Yundou 147, Fengdou 6, Fengdou 10, Chenghu 14, Chenghu 15, Chenghu 16, Tongcan 5, Tongcan(xian) 6, Chonglicandou, Qinghai 9, Qinghai 10, Qinghai 12, Qinghai 13, Qinghai 14, Lincan 4, Lincan 5, Tongcanxan 6, Tongcanxuan 7
Pea	Zhongwan 4, Zhongwan 6, Airuan 1, Kewan 1, Kewan 2, Suwan 1, Caoyuan 276, Caoyuan 224, Qinxuan 1, Baofeng 3, Caoyuan 12, Yunwan 4, Yunwan 10, Chengwan 7, Chengwan 8, Shijiadacaiwan 1, Caoyuan 31, Taizhong 11, Tiancui 761
Common bean	Xiaobaiyundou, Zaolvdidou, Pinyun 2, Zihuayundou, Changnaihuayundou, Ziyuanyundou, Dahongyundou, Shenhongyundou, Xiaohongyundou, Zhunaihuayundou, Huangyundou, Honghuayundou, Longyundou 4, Longyundou 5, Naihuayundou, Ayun 1, Ayun 2, Suyundou 1
Mung bean	Zhonglv 1, Zhonglv 2, Zhonglv 4, Jilv 2, Jilv 9239, Jilv 7, Jilv 9, Baolv 942, Nenlv 1, Lvfeng 5, Bailv 5, Bailv 6, Dayinggelv 935, Jilv 2, Weilv 1, Weilv 4, Elv 2, Yulv 2
Adzuki bean	Jihongxiaodou 2, Jihongxiaodou 4, Jihong 9218, Jibaohongxiaodou 2, Bao 876–16, Zhonghong 2, Baohong 947, Baihong 2, Baihong 3, Jihong 6, Jingnong 5, Jingnong 8, Liaoxiaodou 1, Jinlinghongdou, Ehongxiaodou 1
Lentil	Dingxuan 1, Ningbian 1, Qindou 9, Xiangfenxiaobiandou, Binxianbiandou, Qingyangbiandou, Lijiangbiandou, Tongxinbiandou, Dingbianbiandou
Chickpea	Muying 1, Keying 1, A-1, 88-1
Cowpea	Zhongjiang 1, Zhongjiang 2, Yujiang 1, Lijiangdou, Zaozhuangjiangdou, Tai'anbaijiangdou

† Cited from reference [3,29] and the list of newly registered food legume varieties.

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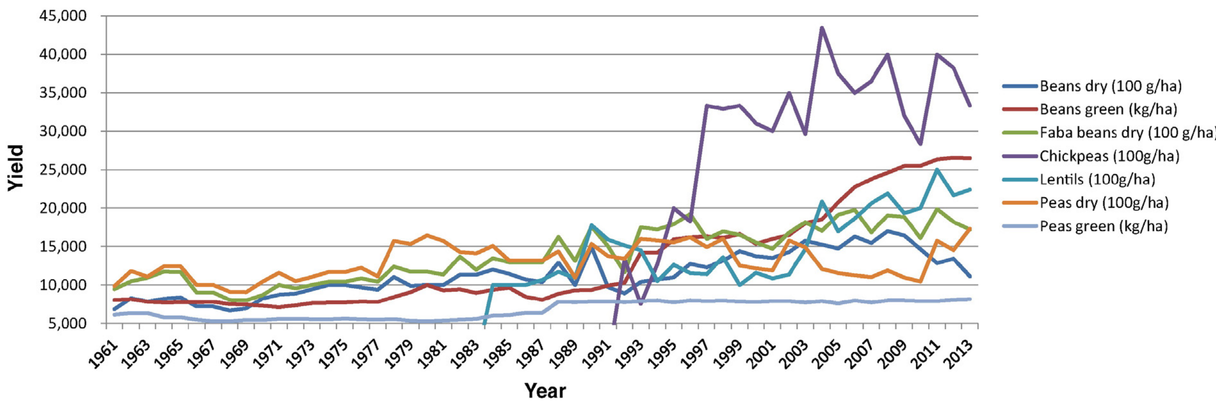

Fig. 2 – Yields of food legumes in China since 1961 [27].

[3–5]. With the advantages of short growing periods and biological nitrogen fixation (BNF), food legumes play an important role in cropping systems of China [5]. Food legumes can be integrated in rotations with cereals, tuber and vegetable crops. Such systems provide a quality food harvest after nonleguminous crops and improve soil fertility on farms [5]. To obtain full farm productivity in favorable environments, intercropping or relay intercropping of food legumes with other crops is another good choice [5]. As ideal intercrops, food legumes can increase crop yields and economic benefits of intercropping systems [31], and much more innovation will be needed in the future for adaptation to climate change and to increasing demand for food.

The main cropping systems involving major food legumes in China are summarized next.

3.1. *Faba bean*

3.1.1. *Southern cropping patterns*

In the Yangtze river region, including Shanghai, Zhejiang, Jiangsu, Jiangxi, Anhui, Hubei, and Hunan [24], winter faba bean is sown in late October to early November and harvested in the following spring. The main cropping patterns (with two to three crops per year) are as follows [22,24,30,32,33].

(1) Faba bean – rice – barley intercropping with green manure – cotton.
(2) Faba bean – transplanting cotton – faba bean intercropping with green manure – maize intercropping with soybean, sweet potatoes, or rice.
(3) Faba bean intercropping with green manure – cotton – faba bean or barley – transplanting cotton.
(4) Faba bean intercropping with green manure – maize intercropping with cotton – Faba bean intercropping with green manure – maize intercropping soybean or sweet potatoes.
(5) Faba bean intercropping with green manure – maize intercropping soybean – barley intercropping with green manure – cotton.
(6) Faba bean intercropping with green manure – corn multiple cropping with rice – barley – cotton.

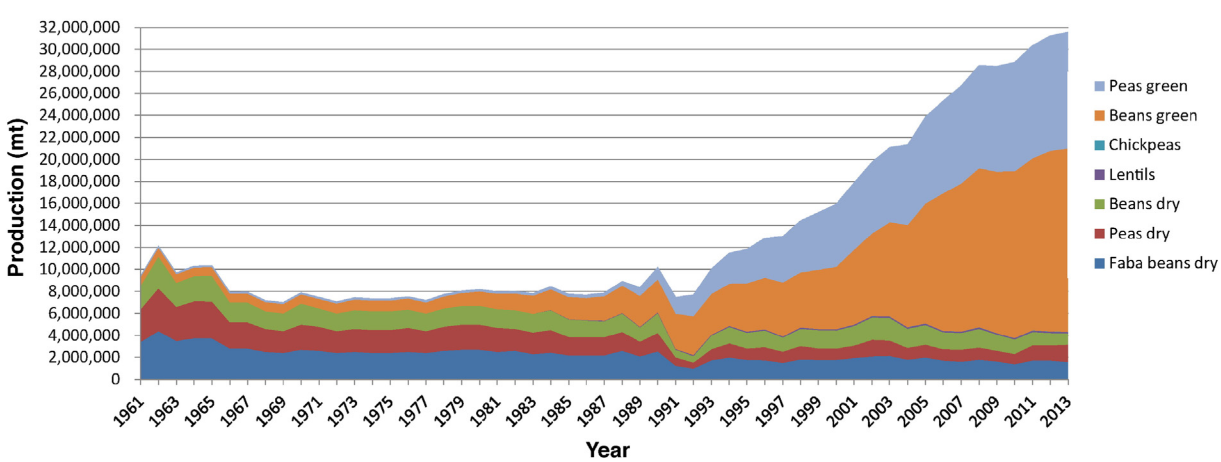

Fig. 3 – Production of food legumes in China since 1961 [27].

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Table 3 – World rank of China in the production of food legumes (2013) [†].

Food legume	% of the world total output	Rank	% of the world average yield
Broad bean (grain)	39.67	1	103.97
Pea (grain)	10.54	3	73.90
Pea (vegetable)	60.08	1	106.35
Chickpea (grain)	0.09	22	418.92
Lentil (grain)	3.47	7	208.03
Common bean (dry)	4.55	5	141.55
Common bean (vegetable)	75.10	1	192.24

[†] Calculated with data from the FAO database [27].

3.1.2. *Southwestern cropping patterns*

In the southwestern region, including Yunnan, Sichuan, Chongqing and Guizhou etc. [24], winter faba bean is sown at the beginning of October to early November and harvest in the next April and May. The main biennial cropping patterns, generally with two crops a year, are as follows [22,24,30,32,33].

(1) Faba bean – corn relay intercropping with sweet potatoes – wheat (canola) – peanut.
(2) Wheat – cotton – faba bean – corn relay intercropping with sweet potatoes.
(3) Wheat (barley) – corn relay intercropping with sweet potatoes – faba bean – peanut.
(4) Faba bean – early rice – late rice – canola – semi-late rice.
(5) Wheat – semi-late rice – faba bean – semi-late rice – barley.

3.2. *Pea*

3.2.1. *Southern cropping patterns*

Distributed in Sichuan, Hunan, Hubei, Zhejiang, Guangdong, Guangxi, Fujian, and Yunnan provinces, with warm seasons, natural water resources, and a high multi-crop index. Average winter temperature is 9–14 °C, which is ideal for pea, one of the main winter crops. The following is a common rotation system involving peas [22,30,32,33].

The first year: peas – early rice – late rice.
The second year: barley (wheat) – early rice – late rice.
The third year: canola – early rice – late – rice.

3.2.2. *Intercropping and relay intercropping*

A new cropping system of three-dimensional agriculture has been developed along the southeastern coast of China, such as in Jiangsu, Shanghai, Zhejiang, and cotton-producing areas of Anhui and Henan, which have a new comprehensive configuration cropping system of "early-late", tall–short" and "legume–nonleguminous crops", such as pea intercropping with vegetables, maize, wheat, or cotton [22,30, http://www.doc88.com/ p-310736851815.html].

3.2.3. *Northern cropping patterns*

These include the alpine regions of Qinghai, Xinjiang, Gansu, Ningxia, Inner Mongolia, Shanxi, Hebei, and the northern part of northeastern China, with summer cropping only. The following rotation cropping systems are dominant over successive years [22,30,32,33].

(1) Pea – maize – maize.
(2) Pea – canola – wheat.
(3) Pea – wheat – potato.
(4) Pea – barley – maize.

Moreover, to make full use of natural resources, intercropping system is very common in these areas. Pea may be intercropped with maize, potato, sunflower, wheat, and canola. (http://www.doc88.com/p-310736851815. html).

In the vegetable regions (with two crops per year) of the southern part of northeastern China (Jilin and Liaoning), pea is sown in late March and harvested in early June and immediately followed by maize. The pattern of dry pea or green pea (vegetable-type) multiple cropping with vegetable crops is also popular.

3.3. *Mung bean*

3.3.1. *Southern cropping patterns*

These include the middle and lower Yangtze River regions. Mung bean is summer-sown in early June and harvested in middle to late August. The main biennial cropping patterns (usually with two crops per year) are as follows [22,30,32,33].

(1) Wheat (canola) – mung bean – wheat – maize (millet).
(2) Wheat – mung bean – wheat – mung bean (sweet potato).
(3) Wheat – mung bean – cotton – wheat – mung bean (millet) (three crops in two years).
(4) Wheat – mung bean – sweet potato – maize – wheat – mung bean (five crops in three years) (http://wenwen.sogou.com/z/q163672879.htm).

3.3.2. *Spring-sown areas in northern China (one crop per year)*

These areas include Inner Mongolia, Hebei, Shanxi, Shaanxi, and Gansu, with sowing in late April to early May and harvesting in early September. The main rotation cropping system is mung bean–millet–sorghum (maize). Mung bean is also intercropped with millet, maize, or sorghum [22,30,32–33; http://wenwen.sogou.com/z/ q163672879.htm].

3.3.3. *Summer-sown areas in northern China (two crops a year)*

These areas are found in the winter wheat production areas and the north bank of the Huai river, with sowing in early June and harvesting in early September, of mung bean intercropped with wheat [22,30,32,33].

3.4. *Adzuki bean*

3.4.1. *Southern cropping patterns*

The lowland regions of southern provinces are not major production areas for adzuki bean, with complex terrain and various cropping system including intercropping, relay intercropping, and multiple cropping. Adzuki bean is sown from spring to autumn. There are rice + adzuki bean multiple cropping systems, and maize + adzuki bean relay intercropping systems [22,30,32,33].

3.4.2. *Northern cropping patterns for spring-sown areas*

These areas are distributed in Inner Mongolia and the north part of Hebei, Shanxi, and Shaanxi, with the main cropping patterns (one crop per year) as follows [22,30,32,33].

(1) Adzuki bean – maize (sorghum) – millet.
(2) Adzuki bean – maize – sorghum.
(3) Adzuki bean – spring wheat – maize (flax) – maize.
(4) Adzuki bean – wheat – wheat.
(5) Adzuki bean – millet – maize – wheat.

3.4.3. *Northern cropping patterns for summer-sown areas*

These areas are distributed in Shandong, Henan and south part of Hebei. The main cropping patterns (with two crops per year) are as follows [22,30,32,33].

(1) Winter wheat (barley) – adzuki bean – winter wheat (barley) – adzuki.
(2) Winter wheat (barley) – adzuki bean – cotton (maize, sorghum, or millet).
(3) Winter wheat (barley) – summer maize intercropping with adzuki bean – spring maize intercropped with soybean.
(4) Spring wheat – millet (broomcorn millet) – adzuki bean.
(5) Winter wheat (barley) – maize intercropped with adzuki bean – winter wheat (barley) - maize intercropped with adzuki.
(6) Winter wheat (barley) – sunflower intercropped with adzuki bean – winter wheat (barley) – sunflower intercropped with adzuki [22,30,32–33; http://www.doc88.com/p-2993088111690.html].

3.5. *Common bean*

Common bean is planted widely in China, mainly in the southeast and northeast of China and the Xinjiang autonomous region. These areas have complex terrain and various cropping systems, with little monocropping and more intercropping/relay intercropping systems, such as dwarf common bean intercropped with maize, sorghum, potato, sweet potato, or cotton, and sorghum relay intercropping into common bean in North China [22,30,32,33].

4. Soil fertilities in major food legumes production areas of China

In 2014, 150 soil samples from food legume production areas of 17 provinces and 2 municipalities in China were collected. Soil pH, soil organic matter (SOM), available nitrogen (AN), available phosphorus (AP), and available potassium (AK) of the samples were analyzed [34]. The results of pH tests indicated that the soils were neutral to slightly alkaline. The SOM and the AN contents were relatively low, while the AP and the AK contents ranged from moderate to high.

4.1. *Pea production areas*

Values were 6.1–8.3 for soil pH, 0.8–4.3% for the SOM, 21–253 mg kg^{-1} for the AN, 1.4–310.5 mg kg^{-1} for the AP, and 59.7–333.7 mg kg^{-1} for the AK in pea production areas (Table 4). The minimum coefficient of variation (CV) was 9.3% for pH in surface soil and the maximum CV was 137.3% for soil AP content, much higher than for other elements. The CVs of soil pH and available nutrients were in the order AP > AN > AK > SOM > soil pH.

4.2. *Faba bean production areas*

Values were 4.9–8.3 for soil pH, 0.6–6.1% for the SOM, 28–331 mg kg^{-1} for the AN, 3.3–113.5 mg kg^{-1} for the AP, and 38.5–301.1 mg kg^{-1} for the AK in faba bean production areas (Table 4). The minimum CV was 11% for pH in surface soil and the maximum CV was 75.7% for soil AP content, much higher than for other elements. The CVs of soil pH and available nutrients were in the order AP > AN > SOM > AK > soil pH.

4.3. *Common bean production areas*

Values were 4.9–8.4 for soil pH, 0.9–7.9% for the SOM, 37.5–254 mg kg^{-1} for available nitrogen (AN), 5.7–186.5 mg $kg^{-1}$for the AP, and 78.3–486.7 mg kg^{-1} for the AK in common bean production areas (Table 4). The minimum CV was 9.1% for pH in surface soil and the maximum CV was 109.7% for soil AP content, much higher than for other elements. The CVs of soil pH and available nutrients were in the order AP > SOM > AN > AK > soil pH.

4.4. *Mung bean production areas*

Values were 4.7–9.2 for soil pH, 0.7–7.8% for the SOM, 28–190 mg kg^{-1} for the AN, 4.7–229.1 mg kg^{-1} for the AP, and 57.4–294.9 mg $kg^{-1}$for the AK in common bean production areas (Table 4). The minimum CV was 15.5% for pH in surface soil and the maximum CV was 109.4% for soil AP content, much higher than for other elements. The CVs of soil pH and available nutrients were in the order AP > SOM > AK > AN > soil pH.

4.5. *Adzuki bean production areas*

Values were 6.0–8.5 for soil pH, 0.6–5.4% for the SOM, 47–215 mg kg^{-1} for available nitrogen (AN), 8.7–132.1 mg kg^{-1} for the AP, and 40.4–257 mg kg^{-1} for the AK in common bean production areas (Table 4). The minimum CV was 7.9% for pH in surface soil and the maximum CV was 91.7% for soil AP content, much higher than for other elements. The CVs of soil pH and available nutrients were in the order AP > SOM > AK > AN > soil pH.

5. Export and import of major food legumes in China

Historically, as a net exporter of food legume products, China provided common beans, faba beans, lentils, mung beans, and adzuki beans to the international markets for foreign currency or for exchange with cereal grains, with almost no import of food legumes up to 1995 [4]. However, increased consumption of pea, mung bean, and chickpea has changed the export and import situation of food legume products since 1995, and China has become a top importer of peas as well as an important importer of mung bean and chickpea [27].

Table 4 – Summary of analytical results of soil samples collected from farmland where major pulse crops are grown.

Measurement†	Mean	Median	Mode	Min	Max	SD	CV (%)
Pea							
pH	7.5	7.8	7.1	6.1	8.3	0.7	9.3
SOM (%)	1.9	1.7	1.6	0.8	4.3	0.8	42.1
AN (mg kg^{-1})	85.2	76.0	42.0	21.0	253.0	48.3	56.7
AP (mg kg^{-1})	58.1	28.0	12.2	1.4	310.5	79.8	137.3
AK (mg kg^{-1})	147.6	136.7	139.7	59.7	333.7	71.9	48.7
Faba bean							
pH	7.3	7.6	7.8	4.9	8.3	0.8	11.0
SOM (%)	2.3	1.9	1.4	0.6	6.1	1.3	56.5
AN (mg kg^{-1})	99.3	93.0	105.0	28.0	331.0	56.7	57.1
AP (mg kg^{-1})	51.0	41.5	–	3.3	113.5	38.6	75.7
AK (mg kg^{-1})	154.7	157.8	157.8	38.5	301.1	57.3	37.0
Common bean							
pH	7.7	7.8	7.9	4.9	8.4	0.7	9.1
SOM (%)	2.9	1.9	2.1	0.9	7.9	2.3	79.3
AN (mg kg^{-1})	101.7	85.3	71.7	37.5	254.0	60.2	59.2
AP (mg kg^{-1})	50.5	28.2	–	5.7	186.5	55.4	109.7
AK (mg kg^{-1})	212.3	160.2	124.1	78.3	486.7	123.0	57.9
Mung bean							
pH	7.1	7.2	7.5	4.7	9.2	1.1	15.5
SOM (%)	1.8	1.6	1.2	0.7	7.8	1.2	66.7
AN (mg kg^{-1})	81.7	80.2	112.7	28.0	190.0	32.6	40.0
AP (mg kg^{-1})	43.8	22.9	17.3	4.7	229.1	47.9	109.4
AK (mg kg^{-1})	144.0	139.0	139.8	57.4	294.9	60.3	41.9
Adzuki bean							
pH	7.6	7.6	7.6	6.0	8.5	0.6	7.9
SOM (%)	1.9	1.4	1.2	0.6	5.4	1.4	73.7
AN (mg kg^{-1})	84.3	75.0	74.1	47.0	215.0	39.4	46.7
AP (mg kg^{-1})	51.7	21.6	–	8.7	132.1	47.4	91.7
AK (mg kg^{-1})	141.2	116.0	–	40.4	257.0	79.6	56.4

† pH, soil pH; SOM, soil organic matter; AN, available nitrogen; AP, available phosphorus; AK, available potassium.

5.1. *Export of major food legumes*

Pulse exports were very limited, at less than 150,000 tons per year from 1961 through 1985 (Fig. 4). Since 1985, exports of beans (including common bean and runner bean) to Europe and other countries from Heilongjiang and Yunnan provinces have increased strongly (Fig. 4), becoming very important exports on international markets [27]. Faba bean, adzuki bean, and mung bean are in second place as exports, to Japan, Republic of Korea, and European countries, with limited amounts each year from targeted production areas such as Qinghai, Hebei and Heilongjiang provinces.

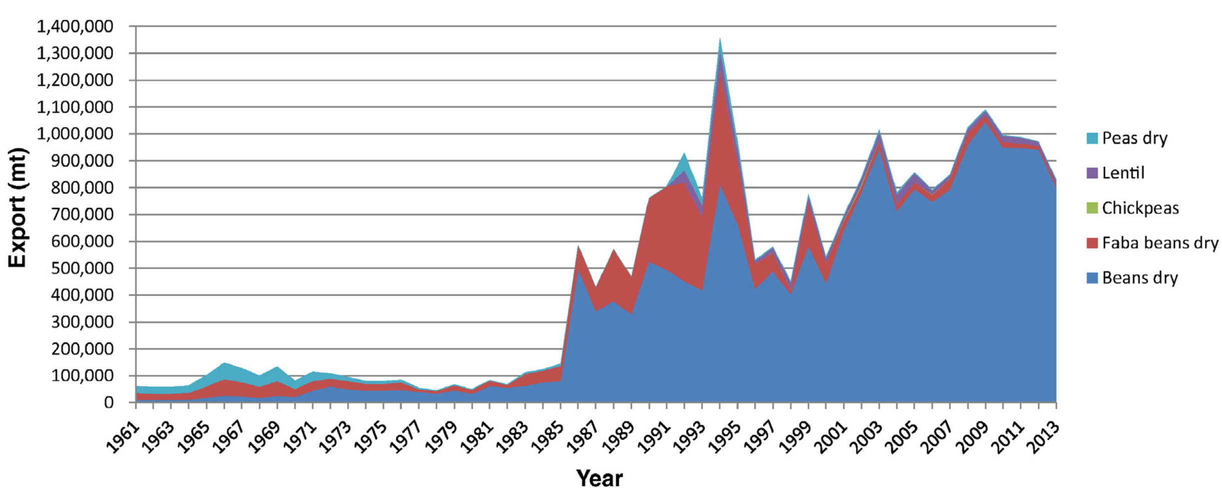

Fig. 4 – Dry grain export of food legumes [27].

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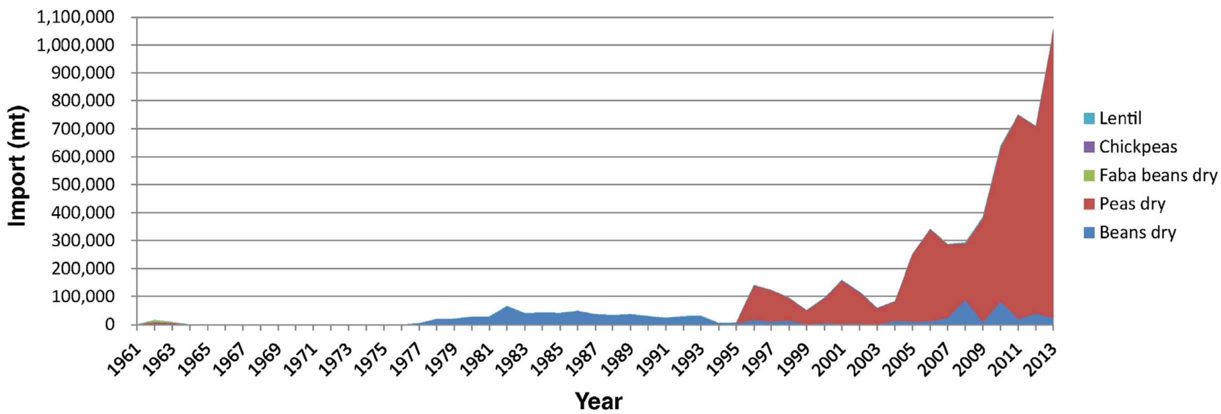

Fig. 5 – Dry grain import of food legumes [27].

5.2. *Import of major food legumes*

The import of dry grain legumes was very little, less than 50,000 tons per year, from 1961 through 1995 (Fig. 5). Since 1995, imports of dry peas for vermicelli production from the USA, Brazil, Argentina, and Canada have sharply increased yearly (Fig. 5), reaching more than 1 million tons in 2013 and reducing the price of dry peas in China. The dry grain import of other cool-season and temperate food legumes (beans) has remained below 100,000 tons per year since 1995 (Fig. 5), while the dry grain import of mung bean, 35,000–60,000 tons per year through 2009, declined to ~12,000 tons per year for 2010–2014.

The import of green vegetable food legumes began in 1992, but never exceeded 3500 tons per year. There is little need for import of green vegetable food legumes, but occasionally green pea and green beans have been imported [27].

5.3. *Comparison of export, import, and production of major food legumes*

China is a top world producer of food legumes and historically a large consumer of food legume products. In comparison with the total amount of dry grain from pulse production, the export and import amounts of food legume products are very limited [27], and more than 80% are consumed within China (Fig. 6). For green vegetable food legume products, China has very limited exports and imports, with almost all consumed within China (Fig. 7), contributing to improved food quality for ordinary Chinese people.

6. Conclusions and future perspectives

6.1. *Consumption requirements for food legume production*

Food legumes play a special role in the human diet, given that they contain nearly two or three times more protein than cereals, with low fat and high fiber. The nutritional value of food legumes is very high [5]. Food legumes have historically been an important part of the traditional diet and will be more important than before for improving human nutrition in the future. Consumption of food legumes in China declined from 1949 to the early 1990s and then rose after the early 1990s at an annual growth rate of 6.3% [35].

In the early years after the founding of the People's Republic of China, owing to the insufficient supply of staple foods and meat, food legume products were an important source of starch and protein supplements for ordinary people, and consumption of food legumes reached 10.36 million tons in 1962 [27]. With China's economic growth and the improvement of people's living standards, consumers were inclined to consume more animal products to meet their protein requirements and consumption of food legumes began to decline. By 1991, food legume consumption had dropped to 2.05 million tons. Since

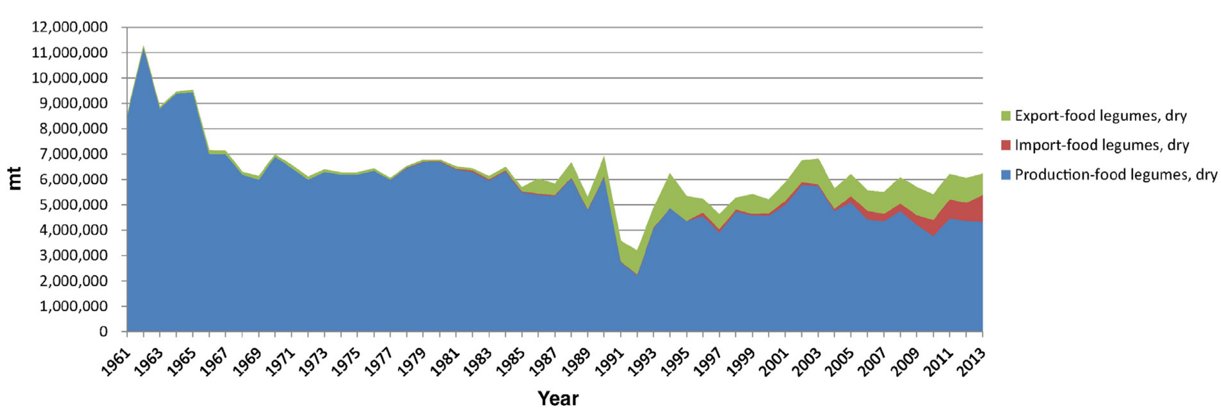

Fig. 6 – Comparison of dry grain export, import, and production of major food legumes [27].

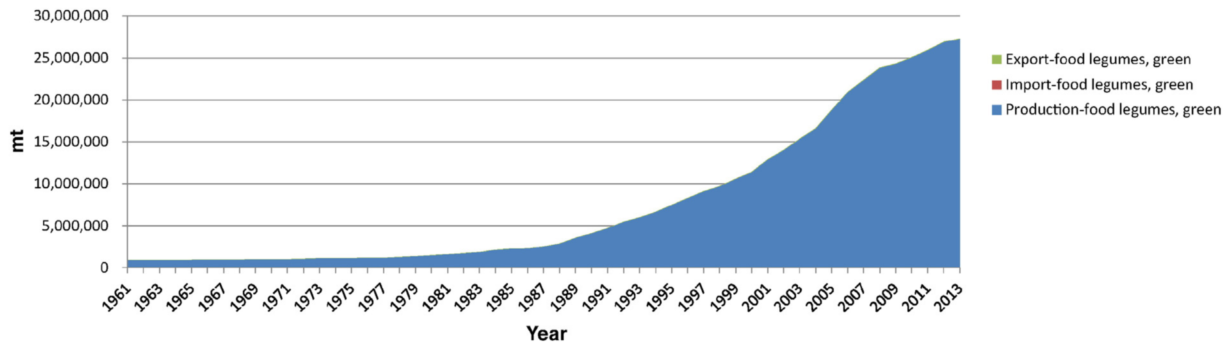

Fig. 7 – Comparison of green vegetable export, import, and production of major food legumes [27].

1994 [27], the demand for food legumes as nutritious healthy food and fiber is rising. The major reasons are consumer satisfaction with food and clothing, rising incomes, and improved living standards, as well as the establishment of a market system in China. As a result, nutritional and balanced food has been preferred by ordinary people and the consumer pays more attention to healthy and functional diets. At the same time, the demand for livestock products has led to the development of an animal feed industry and rising animal consumption of food legumes. With the expanded human consumption of food legumes, the demand of the food and feed industries for food legumes is increasing, resulting in a gradual increase in food legume production. However, pulse prices keep rising with costs of production, inhibiting to some extent the daily consumption of food legumes. Recently, according to our investigation, the prices of food legumes have gradually stabilized, though imports of food legumes have increased greatly. With government intervention in the market prices of food legumes and a continuous increase in consumer income, the requirements of food legumes has become stable. However, the consumption requirement of vegetable legumes, such as green peas, green faba beans, and green common beans as highly nutritional and delicious vegetables, is continually and rapidly increasing.

6.2. Needs from sustainable agriculture

Sustainable agriculture is defined as "an agriculture that can evolve indefinitely toward greater human utility, greater efficiency of resource use, and a balance with the environment that is favorable both to humans and to most other species" [36]. Modern agriculture is based on maximum output in the short term, with inadequate concern for input efficiency or stock maintenance [37]. Nitrogen fertilizer ranks first among the external inputs used to maximize output in agriculture. The efficient input of N fertilizer is one of the lowest among the plant nutrients, and in turn, contributes substantially to environmental pollution. Millions of tons of chemically synthesized nitrogen are applied annually in China, and the amount has been increasing since the 1940s. Although the primary feedstock and energy resource for the manufacture of nitrogen fertilizer is natural gas, petroleum and coal could also be used to supply the energy and hydrogen required to convert atmospheric nitrogen to ammonia. These fossil fuels are exhaustible resources [38]. The continued and unabated use of N fertilizers would further accelerate the depletion of stocks of nonrenewable energy resources used in fertilizer production. The removal of large quantities of crop produce from the land additionally depletes soil of recycled N reserves [36]. Another issue that needs urgent attention in China is the decline in crop yields under continuous use of N fertilizers [36]. For example, from 1997 to 2005, the productivity of applied N (PEP_N) of annual grain decreased from 55 to 20 kg kg^{-1} N, meaning that N use efficiency has decreased dramatically and the overuse of N has contributed to severe environmental degradation from drainage of excess fertilizer since the 1990s [39]. Thus, modern agricultural production systems are not sustainable. Advances in agricultural sustainability will require an increase in the use of BNF from food legumes as a major source of nitrogen for plants [40]. Clearly, it is not realistic to consider sustainable agriculture on a broad scale in the absence of BNF. The increased use of food legumes offers the potential to substitute nitrogen from BNF for fertilizer nitrogen and is thus a key component of sustainable agricultural systems.

Until the middle of the 20th century, Chinese agricultural production depended mainly on soil nitrogen that had accumulated over time or had been recently added by BNF and natural atmospheric deposition or animal manure rather than chemical fertilizer. Soil organic matter, manures, and unharvested crop residues, especially those of food legumes, can meet crop nitrogen needs in many circumstances. Because significant amounts of nitrogen reside in the unharvested portion of pulse crops, it is important for sustainability to return these byproducts to the soil. The need for chemical fertilizers can be reduced by nitrogen supplied by BNF in the field or by recycling through animals, including humans, back to the soil [38,41]. BNF, a microbiological process in the biosphere, converts atmospheric dinitrogen into a plant-usable form. BNF can help maintain soil N reserves as well as substitute for N fertilizer to achieve high crop yields [42]. As a society, we must find ways to reduce dependency on fossil fuels for economic, environmental, and geopolitical reasons. The development of sources of renewable energy will be particularly important for agriculture. BNF will be a major component in the improvement of agricultural sustainability in China. Food legumes with the ability to perform BNF are a key component of sustainable agricultural systems, and have broad prospects for development.

6.3. Production trends for environmental conservation

There are several significant environmental reasons to seek alternatives to chemical nitrogen fertilizer: it affects the balance of the global nitrogen cycle, pollutes groundwater, leads to extensive pollution and eutrophication of rivers and lakes by nitrogen in runoff and surface waters [36,38], and increases the risk of chemical spills. Gaseous oxides of nitrogen, derived from N fertilizers, increase atmospheric nitrous oxide (N_2O), which is highly reactive and poses a threat to the stability of the ozone layer [36,38].

Increasing and extending the role of BNF would reduce the need for fertilizer nitrogen and decrease adverse environmental effects [38]. The natural process of BNF has a critical role in the achievement of a sustainable farm environment. Increased use of BNF will mitigate the need for fertilizer nitrogen, with concomitant benefits accruing in terms of effects on the global nitrogen cycle, global warming, and ground- and surface-water contamination [38]. BNF benefits for pulse yields of dry grain and vegetable products have been demonstrated in Vietnam with rhizobial inoculation across a variety of legume crops [43]. Rotation benefits for subsequent wheat crops have been shown in Australia from BNF in chickpea and faba bean crops [43]. Increases of 10–40% in wheat grain yield were observed, with up to 40 kg ha^{-1} of additional nitrogen available from BNF.

6.4. *Conclusions and future perspectives*

Food legumes have long occupied an important position in cropping systems, food composition, and human life in China. Food legumes have an irreplaceable role in the management of cropping systems for human health and soil fertility, with the characteristics of short growth periods, wide adaptation, and drought and abiotic stress resistances. Food legumes can be planted as catch crops and are also suitable for poor production condition in cold regions and on mountain hillsides or arid and barren land. Food legumes offer a variety of planting patterns, such as intercropping, relay intercropping, and mixed cropping with major crops such as wheat, corn, and rice. These patterns can improve land utilization, optimize crop production systems, and promote sustainable agricultural development. Food legumes can also be integrated into existing single continuous cropping patterns in gramineous crops, with reductions in land tillage and increased soil organic matter content, and effectively reduce the spread of disease in cereal crops. Economic benefits accrue from crop rotation systems of gramineous crops and food legumes in southern China. The need for fertilizers can be reduced for rotation crops sown into stubble by BNF supplying nitrogen and helping to maintain soil N reserves and soil nitrogen balance on farms [41].

Food legumes are key components providing dietary protein, vitamin B, and diverse recipes in ordinary food dishes whose traditional preparation has ensured the basic health of Chinese people. The consumption for food legumes in China will further steadily rise, along with the continuous improvement of people's living standard and the pursuit of more healthy diet. At present, per capita consumption of edible beans in China is low. In 2011, domestic Chinese consumption of edible beans was about 4.4 million tons, nearly 3.27 kg per capita; however, Japan consumed 9.9 kg per capita [35]. At present, dry grain pulse production in China is only 4–5 million tons, which cannot meet the needs of growth in food demand, but vegetable legumes are increasing in production area. China must take effective measures to accelerate the development of the food legume industry, improve production capacity and extend the sowing area of food legumes, so as to meet the growing demand, promote the sustainable development of agriculture, and protect the ecological environment.

In exploring approaches to expanding food legume production, the main thrust is to address the present low levels of yield and to reduce the cost of production through research. In conclusion, some issues related to research should be taken into consideration.

(1) The need to raise yields of food legumes to narrow the gap with those now being attained by top producing countries, and to decide whether the goal should be to raise yield or to improve yield stability.
(2) The need to expand use of BNF in new farming systems. A keystone technique in making agriculture more sustainable will be the expanded use of BNF in new farming systems. This will require site- and situation- specific research on crops, rhizobia, and good management practices. Present knowledge is inadequate to provide economically competitive alternatives to fertilizer nitrogen in many situations. Research on BNF should be strengthened, so as to increase the use of BNF in developing sustainable agriculture by commercializing the production and distribution of rhizobium inoculum.
(3) The need to strengthen research on mechanized technology in food legume production. In comparison with staple crops such as rice, maize and wheat, mechanized production technology research on food legumes has lagged far behind, because of small production areas and multiple food legume species. At present, food legume production in China is still a labor-intensive industry. The increase in labor costs and other production costs is reducing farmers' enthusiasm for growing food legumes and hindering the development of food legume industry.
(4) The need to strengthen research on social sciences and to link technical and social science efforts more closely so as to accelerate adoption of new technology.
(5) The need to make most effective use of the relatively limited global research resources likely to be available for research on food and feed legumes.
(6) The need to emphasize research on N fixation and on expanding use of BNF in new farming systems. In China, soil quality, fertility and the quantity of arable soil have declined significantly, in part due to long-term use of chemical fertilizers affecting pH (acidic soils are hostile to the majority of legumes) and cation exchange profiles, plus pesticide-related declines in soil-renewing earthworms [44]. It is time to change the situation of overdependence on chemical fertilizer and cereal monocropping in China. Food legumes will become more important for their BNF nitrogen contribution to intercropping and rotation with cereals and other crops in the future in China [45].

To make BNF more useful, progress must be made to meet numerous scientific challenges. A keystone technique in making agriculture more sustainable will be the expanded use of BNF in new farming systems. This will require site- and situation- specific research on crops and microorganisms and on good management practices. It will also require the extension of existing low-cost technologies of rhizobial inoculation to the small farmer [46]. Present knowledge is inadequate to provide economically competitive alternatives to fertilizer nitrogen in many situations. Clearly, there are many challenges to be met in maximizing the use of BNF for the common good. An expanding knowledge base and the powerful tools of biotechnology should be helpful.

Moreover, it is important to emphasize that the constraints to fuller adoption of BNF technologies are not solely scientific but include cultural, educational, economic, and political factors [35]. A successful BNF-based program, therefore, must involve, in addition to scientific research, efforts in training, education, outreach, and technical assistance. Evaluations of socioeconomic constraints are needed to publicize the benefits of BNF technology and provide advanced warnings about potential difficulties, facilitating their removal or circumvention.

Research opportunities abound to use food legumes to improve crop production in environmentally friendly ways, to conserve energy resources, and to improve and maintain sustainability in agriculture worldwide [47]. Providing financial and human resources for these tasks in China must also be required.

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REFERENCES

[1] R.J. Summerfield, E.H. Roberts, Grain Legume Crops, Sheridan House Inc., London, 1985.
[2] B. Balder, S. Ramanujam, H.K. Jain, Pulse Crops, Oxford&IBH Publishing Co. Pyt., New Delhi, 1988.
[3] X.Z. Cheng, S.M. Wang, Records of Chinese Food Legumes Cultivars, China Agricultural Science and Technology Press, Beijing, 2009 1–16 (in Chinese).
[4] Z.J. Zheng, S.M. Wang, X.X. Zong, Monograph on Food Legumes in China, China Agriculture Press, Beijing, 1997 3–24 (53–365, in Chinese).
[5] X.X. Zong, High-yield Cultivation and Processing of Food Legumes, China Agricultural Science and Technology Press, Beijing, 2002 2–10 (in Chinese).
[6] J.Y. Long, L.F. Lin, X.S. Hou, X.N. Duan, H.Y. Duan, Food Legume Crops, Science Press, Beijing, 1989 1–15 (83–315 ,in Chinese).
[7] X.Z. Cheng, S.H. Wang, L.X. Wang, Descriptors and Data Standard for Mung Bean [*Vigna radiate* (L.) Wilezek], China Agriculture Press, Beijing, 2006 1–4 (in Chinese).
[8] X.Z. Cheng, S.H. Wang, L.X. Wang, Descriptors and Data Standard for Adzuki Bean [*Vigna angularis* (Willd) Ohwi & Ohashi], China Agriculture Press, Beijing, 2006 1–3 (in Chinese).
[9] X.X. Zong, S.Y. Bao, J.P. Guan, Descriptors and Data Standard for Faba Bean (*Vicia faba* L.), China Agriculture Press, Beijing, 2006 1–3 (in Chinese).
[10] X.X. Zong, Z.G. Wang, J.P. Guan, Descriptors and Data Standard for Pea (*Pisum sativum* L.), China Agriculture Press, Beijing, 2005 1–2 (in Chinese).
[11] S.M. Wang, Y.Z. hang, S.H. Wei, Descriptors and Data Standard for Common Bean (*Phaseolus vulgaris* L.), China Agriculture Press, Beijing, 2005 1–3 (in Chinese).
[12] P.Z. Wang, X.X. Li, Descriptors and Data Standard for Cowpea [*Vigna unguiculata* (L.) Walp.], China Agriculture Press, Beijing, 2005 1–3 (in Chinese).
[13] X.X. Zong, J.P. Guan, L. Li, Descriptors and Data Standard for Chickpea (*Cicer* spp.), China Agriculture Press, Beijing, 2012 1–3 (in Chinese).
[14] X.X. Zong, J.P. Guan, X.M. Wang, Descriptors and Data Standard for Lentil (*Lens* spp.), China Agriculture Press, Beijing, 2012 1–3 (in Chinese).
[15] X.Z. Cheng, S.H. Wang, L.X. Wang, Descriptors and Data Standard for Rice Bean (*Vigna umbellata* (Thunb.) Ohwi & Ohashi), China Agriculture Press, Beijing, 2006 1–3 (in Chinese).
[16] X.Z. Cheng, S.H. Wang, L.X. Wang, Descriptors and Data Standard for Black Gram (*Vigna mungo* (L.) Hepper), China Agriculture Press, Beijing, 2012 1–3 (in Chinese).
[17] X.X. Zong, J.P. Guan, J.W. Chang, Descriptors and Data Standard for Grass Pea (*Lathyrus* spp), China Agriculture Press, Beijing, 2012 1–3 (in Chinese).
[18] X.X. Zong, J.P. Guan, X.M. Wang, Descriptors and Data Standard for Lupin (*Lupinus* Spp.), China Agriculture Press, Beijing, 2012 1–4 (in Chinese).
[19] X.X. Zong, J.P. Guan, Z.H. Li, Descriptors and Data Standard for Pigeonpea (*Cajanus* Spp.), China Agriculture Press, Beijing, 2006 1–3 (in Chinese).
[20] X.X. Zong, Pigeonpea, Dalian Publishing House, Dalian, 2003 4–6 (in Chinese).
[21] W.L. Jin, X.X. Zong, High-yield and Super-quality Cultivation Techniques for Food Legumes, China Braille Publishing House, Beijing, 2000 1–18 (in Chinese).
[22] J.Y. Long, Z.Q. Wang, Cultivation Techniques for Food Legumes, Jindun Publishing House, Beijing, 2002 (in Chinese).
[23] Q.F. Liu, Faba Bean Cultivation, Yunnan People's Publishing House, Kunming, 1984 1–3 (in Chinese).
[24] Y. Ye, Monograph on Faba Bean in China, China Agriculture Press, Beijing, 2003 5–6 (301–321, in Chinese).
[25] X. Hu, G.Q. Guo, High-yield Cultivation of Faba Bean and Pea, Jindun Publishing House, Beijing, 1994 1–7 (75–79, in Chinese).
[26] National Center for Extension of Agronomic Techniques, Ministry of Agriculture of China, National-wide Information on Extension of Agronomic Techniques of Grain and Oil Crops (2008–2014), Ministry of Agriculture of China, Beijing, 2015 (pp. 108, 132, 160, in Chinese).
[27] FAOSTAT, http://faostat3.fao.org/download/Q/QC/E 2015.
[28] Ministry of Agriculture of China, China Agricultural Statistical Report, China Agriculture Press, Beijing, 2015 35 (in Chinese).
[29] Y. Chai, B.L. Feng, S.X. Sun, Varieties of Minor Grain Crops in China, China Agricultural Science and Technology Press, Beijing, 2007 1–2 (in Chinese).
[30] X.X. Zong, Integrated Cultivation of Food Legumes, China Agriculture Press, Beijing, 2010 1–153 (in Chinese).
[31] M.M. Mucheru, P. Pypers, D. Muendi, J. Mugwe, R. Merckx, B. Vanlauwe, A staggered maize-legume intercrop arrangement robustly increases crop yields and economic returns in the highlands of central Kenya, Field Crop Res. 115 (2010) 132–139.
[32] D.S. Zheng, J.H. Fang, High-quality Varieties and Their Cultivation of Minor Legumes and Cereals, China Agriculture Press, Beijing, 2009 169–315 (in Chinese).
[33] R.F. Lin, Y. Chai, Q. Liao, S.X. Sun, Minor Grain Crops in China, China Agricultural Science and Technology Press, Beijing, 2002 192–333 (in Chinese).
[34] L. Li, T. Yang, R. Redden, W.F. He, X.X. Zong, Soil fertility map for food legumes production areas in China, Sci. Rep. 6 (2016) 26102.
[35] Y.T. Guo, Study on the consumption trend, feature and demand of food legumes in China, Food Nutr. China 20 (2014) 50–53 (in Chinese with English abstract).

[36] B.B. Bohlool, J.K. Ladha, D.P. Garrity, T. George, Biological nitrogen fixation for sustainable agriculture: a perspective, Plant Soil 141 (1992) 1–11.
[37] E.P. Odum, Input management of production systems, Science 243 (1989) 177–182.
[38] Board on Science and Technology for International Development National Research Council, Biological Nitrogen Fixation, National Academy Press, Washington D.C., 1994
[39] X.T. Ju, G.X. Xing, X.P. Chen, S.L. Zhang, L.J. Zhang, X.J. Liu, Z.L. Cui, B. Yin, P. Christie, Z.L. Zhu, F.S. Zhang, Reducing environmental risk by improving N management in intensive Chinese agricultural systems, Proc. Natl. Acad. Sci. U. S. A. 106 (2009) 3041–3046.
[40] J.K. Ladha, T. George, B.B. Bphlool, Biological Nitrogen Fixation for Sustainable Agriculture, Kluwer Academic Publishers, Boston, 1992.
[41] N. Dilip, Organic Farming for Sustainable Agriculture, Springer International Publishing AG, Switzerland, 2016.
[42] M.B. Peoples, E.T. Crasswell, Biological nitrogen fixation: investment, expectations and actual contributions to agriculture, Plant Soil 141 (1992) 13–39.
[43] D. Herridge, Inoculants and nitrogen fixation of legumes in Vietnam, ACIAR proceedings no. 109e, www.aciar.gov.au/publications 2002.
[44] J. Liu, J. Diamond, China's environment in a globalizing world, Nature 435 (2005) 1179–1186.
[45] E.S. Jensen, H. Hauggaard-Nielsen, How can increased use of biological N-2 fixation in agriculture benefit the environment? Plant Soil 252 (2003) 177–186.
[46] H.G. Peter, P.V. Carroll, Legumes: importance and constraints to greater use, Plant Physiol. 131 (2003) 872–877.
[47] S. Dasgupta, I. Roy, Proceedings of the Regional Consultation on the Promotion of Pulses in Asia for Multiple Health Benefits, Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok, 2016.