Chapter 7
Faba Bean (*Vicia faba* L.) Breeding

Xuxiao Zong, Tao Yang, and Rong Liu

Abstract Faba bean (*Vicia faba* L.) is an important cool season legume grown widely in the world due to its palatability as well as its ecological and environmental value in sustainable agriculture and cropping system. As its protein content is higher than other common food legumes, it is mainly harvested in the form of dry seeds for human food and for animal feed worldwide, but its fresh seeds or pods are often used as vegetables in China, India and other countries with rapidly expanding areas. The dry grain, fresh seeds and sprouts of faba bean are a highly nutritional food source for the human diet. Fresh faba bean seeds are used for a variety of savory dishes, and dry grain are used for paste and snacks, while sprouts for traditional food. The dried fresh stems and leaves of faba beans are good fodder for cattle, sheep and pigs. Faba bean flowers contain a large amount of L-DOPA and can be used to make flower tea. Various faba bean cultivation practices like intercropping and rotation are described. Germplasm diversity and conservation studies on faba bean genetic resources, in vitro regeneration and genetic transformation studies of faba bean, are summarized. Simple sequence repeats (SSRs) and single nucleotide polymorphisms (SNPs) have been developed for faba bean genetic linkage map construction and quantitative trait loci (QTLs) analysis of important genes, are discussed. Achievements of breeding and the future breeding objectives like winter hardy, heat tolerance, herbicide resistance, double-zero, machine sowing and harvesting, biological nitrogen fixation efficiency, photosynthetic efficiency, flavor and palatability, dual usage and market price are reviewed. Current research initiatives and recommendations for future research, like gene editing, are also illustrated.

Keywords Breeding · Dry grain · Faba bean · Quality · Resistance · Vegetable

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7.1 Introduction

Faba bean (*Vicia faba* L.) is a grain legume crop of the Fabaceae family with a long history of cultivation in temperate regions of the northern hemisphere (Duc et al. 2015). Faba bean is a rich source of protein, fiber, and other non-nutrient bioactive compounds (L-DOPA, favin, saponins, tannins) considered beneficial for health (Multari et al. 2015). Its protein content is higher than other common food legumes (Burstin et al. 2011; Griffiths and Lawes 1978). Sometimes called fava, broad bean or horse bean, faba beans are mainly harvested as dry seeds for human food or animal feed globally, but their fresh seeds or fresh pods are often used as vegetables in China, India and other countries. Faba bean is one of the most widely grown cool season legume after pea (*Pisum sativum* L.), chickpea (*Cicer arietinum* L.) and lentil (*Lens culinaris* Medk.) globally (FAOSTAT 2018). Faba beans provide valuable ecological and environmental services for sustainable agriculture, a variety of delicious and nutritional food, a diversity of planting systems and many related organisms, including pollinators (Duc et al. 2015; Zong et al. 2019). Faba bean has advantages over other legumes such as soybean in cool season environments being adapted to grow under low temperatures (Fouad et al. 2018). As such, it is well suited to sustainable farming practices in temperate to cool environments (Temesgen et al. 2015). Like other legumes, faba beans play a critical role in cereal-based farming systems, for improving soil fertility (Jensen et al. 2010). The symbiosis of the species with specific rhizobium bacteria leads to biological nitrogen fixation, which effectively reduces fertilizer input to the arable land (Duc et al. 2015). Faba bean has an intrinsic ability to adapt to diverse climates; however, its yield is unstable due to biotic and abiotic stresses, as is the case with many other major legumes (Cernay et al. 2015). In addition, the total grain yield of faba bean was positively correlated with the protein content of the dry grain (El-Sherbeeny and Robertson 1992).

The cultivation of faba bean can be traced back to the origin of agriculture (Cubero 1973), and it is still an important crop today due to its high-yield potential, nutrient-intensive grain (Fouad et al. 2018) as dry seeds and a fresh vegetable, as well as its role as forage and cover crop. The global faba bean harvested area was 2.4 million ha in 2016, and the total production in 2016 was 4.46 million mt of dry grain (FAOSTAT 2018), covering wide range of latitude from about 40°S to 50°N and from sea level to an altitude of 3000 m (Gnanasambandam et al. 2012). Over the past few decades, the global productivity of dry faba bean remains relatively stable (Fig. 7.1), as well as that in China (Fig. 7.2). However, the global area of dry faba bean cultivation has been declining, especially in China (Fig. 7.2) and countries in North Africa and West Asia (FAOSTAT 2018; Fouad et al. 2018). This reflects a general trend observed since the 1960s that farmers are increasingly relying on nitrogen fertilizer as a source of nitrogen inputs (Crews and Peoples 2004), and due to the achievements in faba bean breeding globally.

The major producing countries of dry faba bean in harvesting area are China, Ethiopia, Australia, Morocco, France, UK, Sudan, Tunisia, Peru and Italy; in year 2016, covered 33.57, 17.79, 14.58, 3.44, 3.24, 3.13, 2.95, 2.39, 2.24 and 2.09% of

Fig. 7.1 The harvesting area and productivity of dry faba bean production in the world. (Source: FAOSTAT 2018)

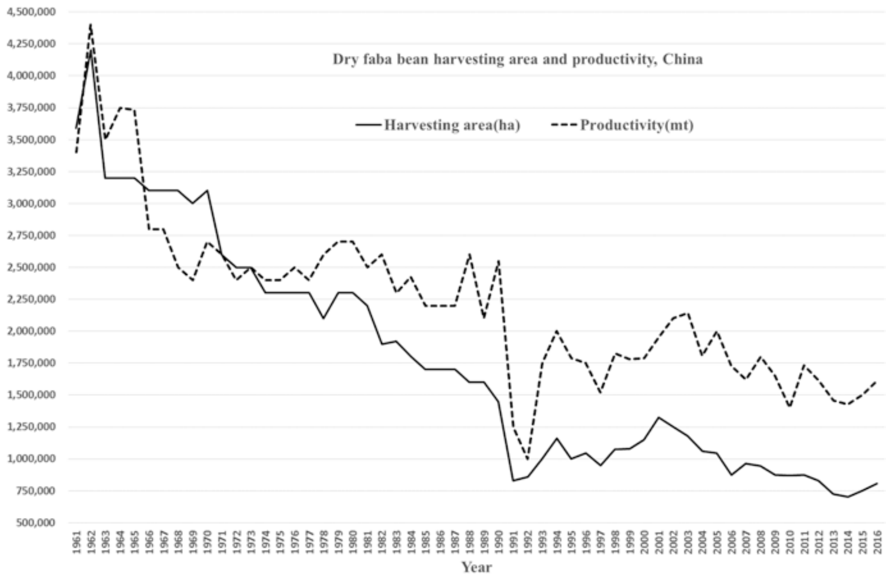

Fig. 7.2 The harvesting area and productivity of dry faba bean production in China. (Source: FAOSTAT 2018)

world share, respectively, covered 85.43% of the global production in total (Fig. 7.3). While, the major countries for dry faba bean productivity in the world are China, Ethiopia, Australia, United Kingdom, France, Germany, Sudan, Egypt, Italy and Peru; in year 2016, covered 36.08, 19.69, 9.50, 6.48, 4.45, 3.45, 2.72, 2.67, 2.24 and 1.61% of total global productivity, respectively, with a total coverage of 88.88% (Fig. 7.4) (FAOSTAT 2018).

In China, vegetable faba bean was cropped on 0.4277 million ha (6.416 million mu) in 2014 (Li et al. 2017); there are no accurate statistics on the production of fresh seeds as vegetables because other producers of faba beans are mainly small scale producers (Duc et al. 2015), except in China.

The seed production system of faba bean is weak; biological stress (leaf diseases and broomrape *Orobanche* spp.) and abiotic stress (heat, cold, drought, acidic soil, waterlogging) limit the development of faba bean production; moreover, lack of effective herbicides and poor adaptability to agricultural mechanization make weed control very difficult (Fouad et al. 2018). However, despite the problems affecting the production of faba beans, the average global yield has increased from 0.9 mt/ha in 1961–1964 to 1.86 mt/ha in 2016 (FAOSTAT 2018). Researchers around the world have made major achievements in genetic improvement of faba beans.

This chapter reviews and highlights the progress and achievements made in understanding the origin of the cultivated faba bean, the achievements in its genomics, breeding and genetic diversity, the advances in molecular genetics and breeding methodologies on breeding for resistance (tolerance) to major biotic and abiotic stresses as well as for yield and market value. Together, these will help to speed up the breeding efforts to improve targeted traits of faba bean.

7.1.1 Origin and Distribution

Faba bean (*Vicia faba* L.) (2n = 2x = 12), with a genome size of approximately 13,000 Mb (Johnston et al. 1999), is a close relative of *Narbonensis* (2n = 14) within subgenus *Vicia*, although they have different chromosome numbers and nuclear DNA content (Kew 2017). Faba bean became a model species for plant cytogenetics in the 1970s and 1980s because it has a small number of chromosomes (6) and are so large that they are easy to observe (O'Sullivan and Angra 2016). Useful agronomical characters such as winter hardiness, resistance to black bean aphid (*Aphis fabae* Scop.) and chocolate spot disease caused by the fungus *Botrytis fabae* Sard. are found among *Narbonensis* species (Birch et al. 1985). Unlike the case in other legume crops, there is no successful record of interspecific crosses between *V. faba* and other *Vicia* species (Caracuta et al. 2016). Faba bean has a long history of cultivation and is widely distributed in different environments. Faba bean is often cross-pollinated; crossing and the response to human selection have given it wide-ranging variation in seed shape, size and color; leaf size and shape and plant architecture (Fouad et al. 2013). Seed size of *Vicia faba* has a range of more than one order of

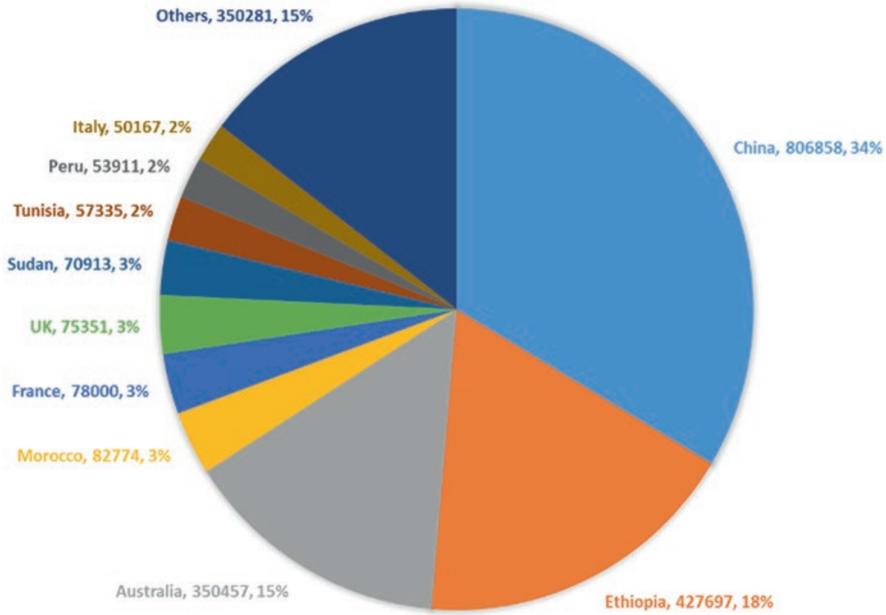

Fig. 7.3 The harvesting area (ha) of top ten producers in the world for dry faba bean production in 2016

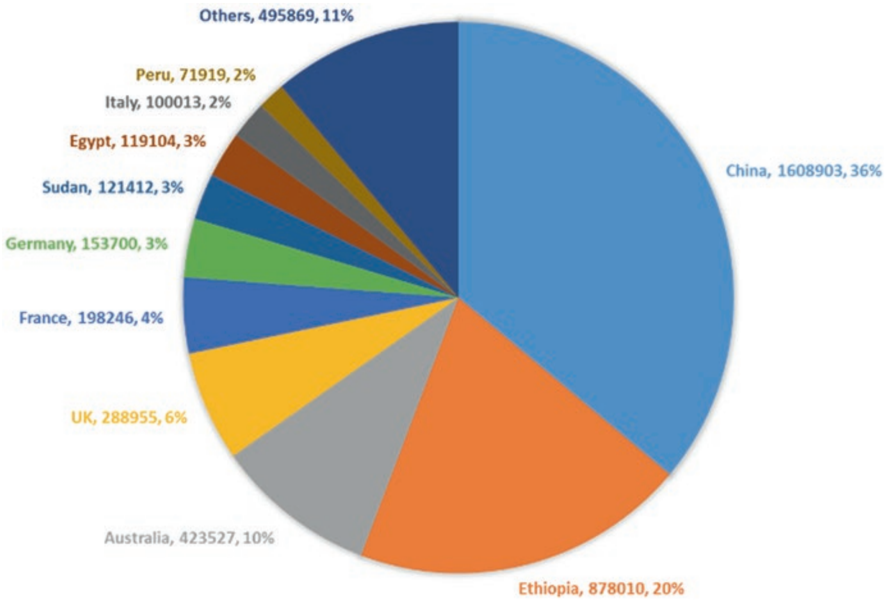

Fig. 7.4 The productivity (mt) of top ten producers in the world for dry faba bean production in 2016

magnitude (20–250 g/100 seeds), making it the largest range in seed size of any angiosperm. Fouad et al. (2018) divided the seeds into three groups: (a) small-seeded type (in southwest Asia), (b) large-seeded type (in the western world) and (c) medium-seeded type (very old and dating back to Neolithic agriculture). Medium-grained species are distributed over a wide area from Spain to the Himalayas (Muratova 1931). Archaeological evidence from Tell Ain el-Kerkh in northwestern Syria indicated that it was the region where faba beans originated and were domesticated in the late tenth century BC (Tanno and Willcox 2006). In addition, 14,000-year-old specimens found in the Mount Carmel region of present-day Israel have been identified as the *lost* ancestors of faba bean (Caracuta et al. 2016).

Muratova (1931) proposed to divide *Vicia faba* into 4 subspecies according to seed size, as *major* (large-seeded type), *equine* (medium-seeded type), *minor* (small-seeded type) and *paucijuga* (small-seeded type). Hanelt (1972) proposed a new classification system (Fig. 7.5), and assigned *paucijuga* as one of the *minor* subspecies of a geographical race and suggested that faba bean had two subspecies *minor* (the oldest) and *faba*. The two varieties of *faba* are *equina* and *faba*. The *minor* variety is divided into *minor* and *tenuis*, *equina* is divided into *equina* and *rugosa*, and *faba* is divided into *faba* and *clausa*.

However, since there is no genetic or sterility barrier between these subspecies, Cubero (1973) believed that they were a single species consisting of four different plant groups. Larger-seeded faba bean are thought to be the result of human selection (Tanno and Willcox 2006). The medium-sized ones were found in the Iberian Peninsula including both Spain and Portugal, and in Central Europe, 5000 years ago. Larger flat-seeded faba beans were not known until 1500 years ago (Ladizinsky 1998).

In the context of cultivar diversification within *Vicia faba*, studies were conducted based on morphological characteristics (Abdalla 1976) and isozyme markers (Jaaska 1997; Polignano et al. 1999) of the variation of selected traits, but revealed no significant discovery of species origin. However, the molecular markers can be used to distinguish the *V. faba* cultivars in different geographical areas. For example, groups of genetic resources can be distinguished by amplified fragment length

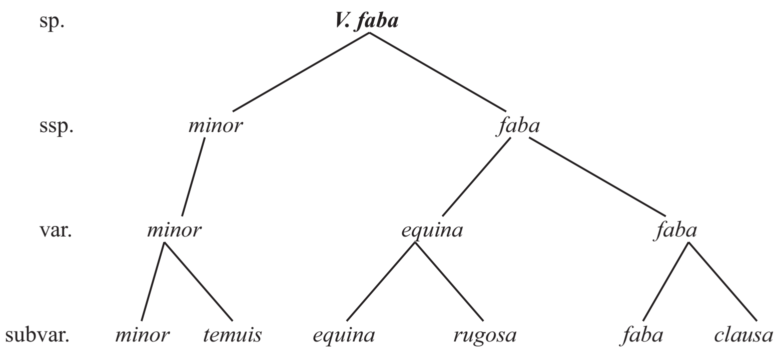

Fig. 7.5 Taxonomy of *Vicia faba* as suggested by Hanelt (1972)

polymorphism (AFLP) genotype data: (a) Asian faba bean genetic resources were divided into a group, and significantly differentiated from genetic groups of Europe and North Africa (Zeid et al. 2003); (b) the faba bean genetic resources from the rest of the world were significantly different to that from China, and the genetic resources of faba bean collected from the spring sowing area of China were significantly different to those from the winter sowing area of China (Zong et al. 2009). In addition, SNP markers were also used to study the genetic diversity within and between faba bean populations, which could distinguish Australian faba bean genetic resources from different geographical sources (Kaur et al. 2014a, b). To date, however, molecular markers have been unable to distinguish populations of different seed sizes (Gol et al. 2017).

7.1.2 Agronomic and Market Important Traits

The size and shape of dried faba bean seeds (Fig. 7.6) varies greatly, with the smallest grain weight 20 g and the largest of more than 200 g. The seed coat may be white, milky white, light green, green, brown, red or purple, and the color of the umbilicus is divided either light gray or black. The number of seeds per pod of faba beans varies from 2–8, and the maximum length of fresh pod can reach 35 cm (Fig. 7.7).

The fresh pods of faba bean exhibit different postures on the stem: uplifted, outspread or drooping (Fig. 7.8). The uplifted plant type is suitable for small pod and small grain varieties of dry faba bean. The outspread pod posture plant type is suitable for large pod and large grain faba bean varieties for vegetable purpose. The drooping pod posture plant type is suitable for the long pod type of faba bean for vegetable purpose. Dry pods of faba bean can be divided into two pod types: semi-soft or hard, according to pod shell hardness (Fig. 7.9). Semi-soft pods are hard to crack when they are dry and ripe, and are often used as an important targeted agronomic trait in faba bean breeding to adapt for mechanized harvesting by reducing the grain loss in the process of harvest.

Fig. 7.6 Dry grain of faba bean. (Photo by Zong Xuxiao)

Fig. 7.7 Long pods of faba bean. (Photo by Zong Xuxiao)

Fig. 7.8 Fresh pod postures on the stem. (Photo by Bao Shiying and He Yuhua)

Fig. 7.9 Pod shell hardness (left: semi-soft pod; right: hard pod). (Photo by Bao Shiying and He Yuhua)

7.1.3 Economic Importance

Faba bean is a leguminous crop rich in protein and well adapt to the arable land under most of the world's climatic conditions. It is widely used for feed and food and is generally considered to have good nutritional value (Katell et al. 2010). Faba bean can be divided into four quality types according to the presence or absence of tannin in the testa and the content of vicine (V) and covcine (C) in the cotyledon. The dietary nutritional value of faba bean varieties depends on the content of tannin, vicine and covicine (VC). Low tannin content usually leads to higher protein and energy digestibility in monogastric animals, and low VC content has a positive impact on the production performance of laying hens and broiler chickens (Katell et al. 2010). In addition to the positive effect of using no-tannin cultivars in single-stomach animal feed, the development of faba bean cultivars with very low VC content has real advantages in the nutritional performance of poultry feed and for the food safety of humans (Katell et al. 2010). The dry grain, fresh seeds and sprouts of faba bean are very nutritional food sources for the human diet, according to analyses by the Institute of Health, Chinese Academy of Medical Sciences (IHCAMS 1981), Table 7.1.

Dry faba bean grain in most producing countries outside China is mainly used for export and for animal feed; and in the traditional faba bean production countries like Egypt, dry faba bean is used as human food. At present, faba bean growers in China mainly focus on the production of fresh pods and the supply of legumes for vegetables. Fresh faba bean seeds after peeling are used in Chinese cuisine. Dried faba bean seeds are mainly used for processing spicy faba bean paste and snack food. Dried fresh stems and leaves of faba beans are good fodder for cattle, sheep and pigs. In addition, faba bean flowers contain a large amount of L-dopa (7% of the

Table 7.1 Nutritional composition of faba bean (per 100 g)

Items	Dry faba bean	Fresh faba bean	Faba bean sprouts
Water (g)	13.0	77.1	63.8
Protein (g)	28.2	9.0	13.0
Lipid (g)	0.8	0.7	0.8
Carbohydrate (g)	48.6	11.7	19.6
Caloric value (kcal)	314.0	89.0	138.0
Crude fiber (g)	6.7	0.3	0.6
Ash (g)	2.7	1.2	2.2
Calcium (mg)	71.0	15.0	109.0
Phosphorus (mg)	340.0	217.0	382.0
Iron (mg)	7.0	1.7	8.2
Carotene (mg)	0	0.15	0.03
V_{B1} (mg)	0.39	0.33	0.17
V_{B2} (mg)	0.27	0.18	0.14
V_{pp} (mg)	2.6	2.9	2.0
V_C (mg)	0	12.0	7.0

dry base), which can be used to make faba bean flower tea, which has purported dietary and therapeutic effects on Parkinson's disease and Alzheimer's disease in the elderly. Increasing demand for fresh faba bean consumption in China, India and other Asian countries has led to greater economic importance of the faba bean industry in those countries. This sets an example for other faba bean producing countries of more diversified usage of faba bean and better consumption of dry and fresh grains of faba bean around the world.

7.1.4 Ecologic Importance

The faba bean has a conical root system; the main root is strong and can reach down 1 m in depth, bringing to the upper soil layer nutrients, especially calcium and phosphorus. There are many lateral roots on the superior meristem of the main root, which are horizontally distributed on the soil surface and extend up to 50–80 cm before descending. Most of the faba bean root system is concentrated in the upper 30 cm of soil. There are many nodules clustered on the main root and lateral root, generally near the surface with a few nodules below 30 cm (Fig. 7.10). Nodules on the main root are large. The development of root nodules is closely related to the

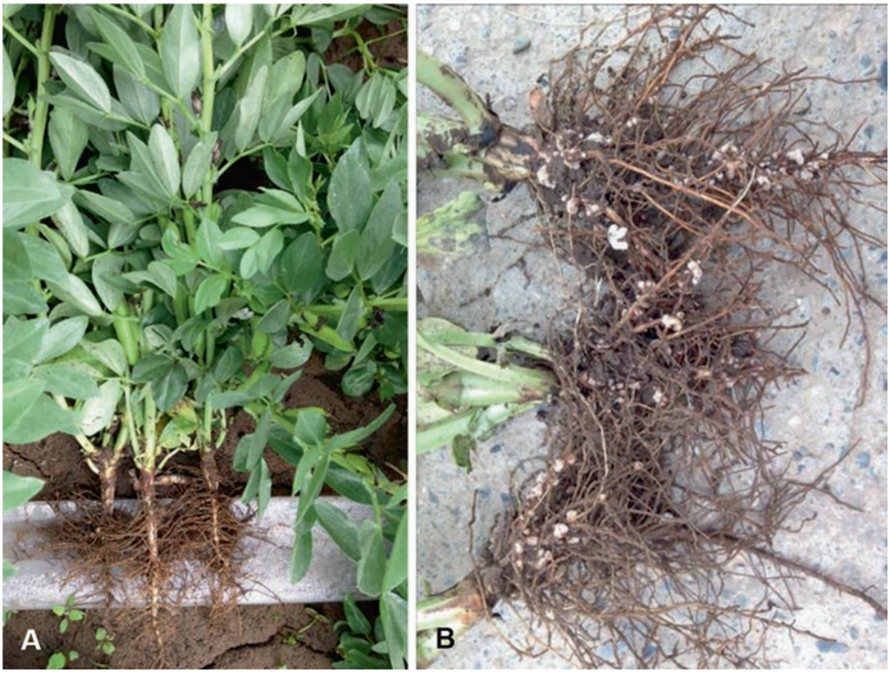

Fig. 7.10 Root system and nodules of faba bean. (**a**) faba bean plants, (**b**) faba bean roots and rhizobia nodules. (Photos by Zong Xuxiao)

growth and yield of faba bean. The rhizobium of *Vicia faba* are associated with other plants of the Fabaceae such as pea, lentil and vetch, and can be inoculated using their rhizobium.

Faba bean is conducive to the healthy development of agricultural ecosystems, such as the renewable input of nitrogen to crops and soil through biological nitrogen fixation, and it benefits the diversification of planting systems. Seasonal fluctuations in the grain yield of faba beans and their gradual integration into traditional farming systems have reduced the importance of the application of nitrogen fertilizer by allowing faba beans to use their robust biological nitrogen-fixation capacity to maintain soil N levels, while cereal based farming systems rely heavily on fossil fuels (N fertilizers, heavy mechanization). Previous studies of faba beans in cropping systems have tended to focus on its occasional use as a spacing crop in intensive rotation of major cereals, but lacked information on the effects of the previous crops on faba beans. *Vicia faba* has the greatest capacity of biological nitrogen fixation among the cold season crops, and its growth and development relies heavily on its nitrogen fixation and adds to the soil a large amount of nitrogen for the rotation crops. As a result, the nitrogen fixation of faba bean maximizes the yield of its subsequent rotation crops, and those benefits are often very high. Several studies have shown significant nitrogen conservation effects (up to 100–200 kg of nitrogen per ha). However, it is necessary to assess the potential risks to the plant-soil systems associated with faba bean cultivation through nitrate leaching or N_2O emissions into the atmosphere as a result of the rapid mineralization of nitrogen-rich residues. It is important to develop improved precautionary measures, such as cash crops, intercropping or no-till techniques, and to provide farmers with rational advice to minimize the adverse environmental impacts of incorporating faba beans into their cropping systems. The extent to which current faba bean yield are changing and the reasons for their reduction need to be studied. Faba beans are likely to be a key component of future farming systems. This will help to address the growing demands for agriculture by consumers and governments to reduce the environmental and climate impacts on agriculture through new and more sustainable ways of producing quality food.

7.1.5 Breeding for Sustainable Agriculture

Faba bean plays a key role in crop rotation systems by reducing energy costs, improving the physical conditions of soil, and reducing pest and weed populations. Despite these advantages, since the 1960s, there has been a general trend of declining hectarage for dried faba bean production globally. At the same time, industrialized, largely cereal-based systems that rely heavily on fossil fuels are replacing traditional agricultural systems (Diego 2010). However, given the limits of fossil energy and a renewed focus on health and the environment, it is time to reassess the potential role of legumes, such as *Vicia faba*, *the king of nitrogen fixation*, as a nitrogen source for future farming systems (Jensen et al. 2010;

Köpke and Nemecek 2010). Faba bean plays an important role in the biosphere and the available nitrogen cycle (Diego 2010), notwithstanding its concomitant low and unstable yields, and susceptibility to biotic (Sillero et al. 2010) and abiotic stresses (Khan et al. 2010; Link et al. 2010). To facilitate wider adoption, faba beans should be improved to make them more attractive to both producers and consumers (Diego 2010). This can be achieved by: (a) adjusting planting methods (Jensen et al. 2010); (b) improvement of integrated pest management strategies (Pérez-de-Luque et al. 2010; Stoddard et al. 2010); (c) creation of major disease resistant genotypes (Sillero et al. 2010) through the development of abiotic stress tolerant genotypes such as overwintering frost (Link et al. 2010) and drought (Khan et al. 2010); (d) genotype development through improved adaptation to environmental change (Patrick and Stoddard 2010) and (e) reduction of the tannin and vicine – convicine contents to improve nutritional quality (Crépon et al. 2010).

In the extensive faba bean germplasm resources preserved, all the traits of interest have significant genetic variation, providing a good resource for faba bean breeding (Duc et al. 2010). Rapid and reliable screening methods have been applied to meet the needs for fungal disease resistance and tolerance breeding programs (Sillero et al. 2006; Tivoli et al. 2006), parasitic weeds (Rubiales et al. 2006) and abiotic stresses (Stoddard et al. 2006). Many of these interesting traits have been incorporated into modern cultivars, but others, many of which are quantitatively controlled by multiple genes, are more difficult to manipulate. Successful application of biotechnology to *Vicia faba* resistance breeding will require reliable biological knowledge of *V. faba* and potential resistance mechanisms. Although achievements have been made in tissue culture and gene transformation, faba beans still lag far behind other crops in biotechnology. Similarly, although important QTLs (quantitative trait loci) studies have been identified (Torres et al. 2006, 2010), they are still insufficient for effective application of marker-assisted breeding (Diego 2010). It is assumed that the genomic region of QTLs in genetic linkage maps have a limited degree of saturation, making it difficult to identify the most closely-connected markers and to determine the exact location of QTLs (Yang et al. 2019). With new improvements in marker technology and the integration of comparative localization and functional genomics, breeding efficiency may soon be improved (Dita et al. 2006; Rispail et al. 2010).

7.2 Cultivation and Traditional Breeding

7.2.1 Current Cultivation Practices

Faba bean can tolerate slightly heavier soils than peas, which makes them more versatile for cropping in a range of arable land conditions. The seed is well able to withstand prolonged cool conditions before germination; however, faba bean is susceptible to drought stress, but early establishment of the spring crop allows development of an extensive root system, which helps to withstand dry conditions. Generally, autumn-sown cultivars, known as winter beans, can be planted in late autumn on heavier and more moisture-retentive soils to allow establishment of the root system before winter. A period of low temperature over winter encourages the production of multiple shoot branches which are compact in early spring until they elongate as temperature rises. Winter beans are planted at a lower density than the spring cultivars to allow for the increased number of stems, all of which are productive. Overwintering of autumn-sown beans effectively makes them more susceptible to foliar diseases caused by fungal pathogens such as *Botrytis fabae* and *Ascochyta fabae* but modern cultivars are much more tolerant of these fungi. Fungal pathogens can also be managed by chemical treatment during the growing season (Anthony 2017).

Due to the wide planting area of faba beans in China, and the differences in climate, soil, topography, socioeconomic development level and farming systems, a range of traditional planting methods have evolved. The typical faba bean-based intercropping system can be summarized as follows:

(a) Faba bean intercropping with wheat. The yield of faba bean and wheat intercropping is 20–30% higher than that of wheat monocropping. In the intercropping of faba bean and wheat, if faba bean is the main crop, 3 rows of faba beans and 1 row of wheat are used; If wheat is the main crop, 1 row of beans and 2–8 rows of wheat are used; The practice of planting half faba bean and half wheat, each of two rows, can be also found.
(b) Faba bean intercropping with maize and sweet potatoes. In the northwest, Yangtze River basin and southern provinces of China, this practice is widely used. Generally, the beds are 1.7–2 m wide, 1–2 rows of faba beans are planted on both sides of the beds, or 2–3 rows of faba beans are planted in the middle of the beds, and maize is sown or transplanted in early April of the next year. The symbiotic period of the two crops is 50–60 days. At the end of May, faba beans are harvested, and then sweet potatoes are planted between rows of maize, thus forming a triple cropping pattern of faba beans, maize and sweet potatoes.
(c) Paddy stubble zero tillage faba bean. In the autumn sowing area, rice stubble follows faba bean with no-tillage cultivation (Fig. 7.11), using the moisture remaining in the soil after rice. At the beginning of the ripening of rice, the faba beans are pressed into the soil at the side of rice roots, trenching and then stripping out of extra moisture (1.5–2.5 m wide seed bed, with a side channel 30–50 cm deep) for the field water supply and drainage conditions, to a good ensure faba bean seedling rate at emergence (Fig. 7.12).
(d) Faba bean for two harvests. Faba bean has strong reproductive ability. In the region along the Yangtze River in Jiangsu province, appropriate faba bean cultivars with early seeding time are made full use of in late autumn and the winter season. Branches are cut for animal feed after 60 days' growth, then branches are harvested again for feeding purpose, and again the following year after fresh pods are collected for vegetable purpose. Due to the early sowing of faba bean,

Fig. 7.11 Rice stubble followed by faba bean with no-tillage cultivation. (Photo by Zong Xuxiao)

Fig. 7.12 Rice-faba bean no-tillage cultivation on 1.5–2.5 m wide seed bed with side channel of 30–50 cm deep. (Photo by Zong Xuxiao)

a strong root system forms before winter, and a large number of regenerative branches grow after mowing before winter, so the fresh faba bean yield is 5–10% higher than that of normal sowing practice. This technique has good dissemination in Jiangsu and Zhejiang provinces, and the central and southwestern parts of China.

7.2.2 Current Agricultural Problems and Challenges

The current agricultural problems and challenges of faba bean in China and elsewhere can be summarized as follows from Bao et al. (2016):

(a) As a minor crop, there are no specific plans for seed industry development for faba bean. Faba bean industrial was developed by local governments or farmers in accordance with the market, and their own will to develop strong adapted, quality seed sources is difficult to guarantee.
(b) Due to large seed size, faba bean seed production cost and farmers' planting cost are high. There is no relevant supportive policy for the development of faba bean seed industry and subsidy measures for the breeding of faba bean cultivars. Seed enterprises are unwilling to develop the faba bean seed industry, which leads to low overall supply rate of fine quality faba bean cultivars.
(c) There is no stable faba bean seed base in all faba bean production areas and regions. Given the natural high variation of the original populations of heterozygous crops, new cultivars of faba bean degenerate rapidly. There is no relatively isolated and stable faba bean seed base, so that the natural degradation of cultivars is fast and seed purity is quite low.
(d) Mechanized seeding, field management and harvest together are the main restricting factors affecting industrial development of faba beans worldwide due to the large seed size and flat irregular shape.
(e) Lack of cultivars for commercial vegetable faba bean production globally. The commercial vegetable faba bean type should have long pods, super large seeds, a soft seed coat, sweet taste and a soft or crisp mouthfeel. Also, the nutritional value should also be optimized.
(f) Lack of promotion of faba bean foods in the super markets. The food industry should follow up with needs for faba bean consumption globally, in developing and developed countries, especially for fresh faba bean based food.

7.2.3 Improvement of Strategies

The faba bean industry is generally weak in most producing countries; improving it is a shared challenge. For fast and healthy development of faba bean industry, Bao et al. (2016) suggest the following strategies:

(a) Integration and development of faba beans with other compatible crop industries. Faba beans have a triple nourishment function for people, livestock and soil. It is necessary to give full play to the advantages of faba beans and integrate them effectively into agricultural production systems. Faba bean occupies a certain key position in the rotation system, including as green manure. Faba bean needs to be integrated into the vegetable industry, and develop in the direction of its acceptance as a high-quality nutritional and healthy diet vegetable, as well as integrated with the forage industry and developed to produce a high quality forage.
(b) In-depth integration of primary, secondary and tertiary industries. Faba bean has an advantage in natural snack food processing, so it is necessary to extend the industrial chain longitudinally. Horizontal expansion of its application fields can improve the diversified industrial system and constantly enhance its value.

(c) Developing light simplified field cultivation methods of faba bean. There is a relatively large labor input in the production of faba beans. Constant change should be made in the mode of production, select and breed new faba bean cultivars suitable for mechanization and to develop machinery and equipment suitable for different production modes of faba beans, promote the in-depth integration of agricultural machinery and agronomy, improve the level of mechanized production, improve production efficiency and reduce production costs.
(d) In top-level design, policy formulation should fully recognize the importance of faba beans in the national economy, both as a fertilizer to improve soil and ensure the effective supply of regional food processing, and as a vegetable as well as a high quality forage grass.
(e) While developing staple crops, it is necessary to give consideration to the development of minor crops, paying more attention to the combination of land use and cultivation, appropriately increasing the planting proportion of faba beans and other crops in the cultivation of farmland, and establish reasonable long-term rotation mechanisms. There should be clear scientific and reasonable crop layout planning, and logical policies and measures for long-term combination of land use and cultivation and sustainable development of agriculture.

7.2.4 Traditional Breeding Methodologies and Limitations

High levels of genotype environmental interaction (G × E) have been demonstrated in *Vicia faba*, particularly in contrast to germplasm pools and across broad environments. Within a germplasm bank, there are also differences in the degree of environmental adaptation among different cultivars. For example, in China, when the winter is long and severe, the cultivars sown in autumn have strong adaptability in winter, and the cultivars sown in spring have strong adaptability in spring. To a large extent, this change can be attributed to the optimal phenological changes in different geographical and climatic regions, but the changes in stress between regions (e.g. dominant diseases) are also important (Duc et al. 2015). Trials in Germany and by ICARDA have shown that central European cultivars produce very low yields in Syria, while Mediterranean cultivars produce well in both environments and bloom early (Kittlitz et al. 1993). So, universally-adapted cultivars of faba bean are widely acceptable, although they are difficult to create by traditional breeding methodologies such as single plant selection and crossbreeding of cultivars according to breeders' experience.

7.2.5 Mutation Breeding

Faba beans are reproductively isolated from all other *Vicia* species. This limits the usefulness of existing germplasm collection, new collection tasks or new methods for generating genetic diversity or genetic variation in faba bean improvement. The two main modern methods for introducing new mutations into faba beans are mutation and genetic transformation. Sjodin (1971) experimented with a series of mutagens, including X-rays, and produced a large number of mutant phenotypes, most of which were determined by recessive alleles targeting the wild allele. Oldach (2011) listed 19 mutant faba bean varieties from 1959–2009. The mutant traits included early maturity, plant structure, yield, dwarfing, protein content, disease resistance and lodging resistance. The main character of mutagenesis is the determination or terminal inflorescence growth habit restricted by the recessive allele of *ti* gene (Duc et al. 2015). Even so, the traditional breeding methodologies have limited the achievement of more and better cultivars for optimized agronomy in different major production areas.

7.3 Germplasm Diversity and Conservation

Germplasm, or genetic resources, refer to the genetic material passed from the parent generation to the offspring generation. For example, landrace, varieties, important genetic materials and wild relatives are all within the scope of germplasm resources (Haussmann et al. 2004).

7.3.1 Germplasm Diversity

According to statistical data, there are 38,360 faba bean accessions conserved in 43 countries and within the CGIAR system (Table 7.2). ICARDA safeguards the largest collection in the world with accessions from 71 countries with a high percentage of unique accessions (Duc et al. 2015). China has collected 5900 faba bean accessions, made up of 65% native and 35% foreign accessions.

Considerable progress has been made on genetic diversity of faba bean. Descriptors and data standards have been published for the criteria on standard evaluation of morphological and agronomic characters (Zong et al. 2006). According to eight morphological traits such as fertility, plant height, stem flowering, the lowest pod, the highest pod, pod number per plant, grain number per plant and yield, 106 faba bean cultivars from Ethiopia and Afghanistan were used for genetic diversity analysis. Results showed that plant height and yield of different source materials have obvious differences (Polignano et al. 1993). Link et al. (1995) carried out genetic analysis with random amplified polymorphic DNA (RAPD) markers on 13 European small-grain, 6 European large-grain and 9 Mediterranean varieties and found that genetic diversity within the small-grain varieties was relatively high. Terzopoulos et al. (2003) conducted statistical data analysis on 15 morphological traits and 7 yield related traits of 55 landrace accessions in Greece, and found that small-grain faba bean was clustered into one group and Mediterranean faba bean were divided into four subgroups. Furthermore, Terzopoulos and Bebeli (2008)

Table 7.2 Major world *Vicia faba* genetic resource collections in 2014

Country	Institute/city	Number of accessions
Syria	ICARDA/Aleppo	10,045
China	CAAS/Beijing	5900
Australia	Australian Grain Gene Bank/Victoria	2445
Germany	Gene Bank IPK/Gatersleben	1920
France	INRA/Dijon	1900
Russia	VIR/St Petersburg	1881
Italy	Genebank/Bari	1876
Morocco	INRA/Rabat	1715
Spain	CNR/Madrid	1622
Poland	IOPG-PA/Poznan	1258
Ethiopia	PGRC/Addis Ababa	1118
Spain	IFAPA/Cordoba	1091
Poland	PBAI/Radzikow	856
Portugal	INRB—IP/Oeiras	788
USA	USDA/Pullman	750
The Netherlands	DLO/Wageningen	726
Bulgaria	IIPGR/Sadovo	692
World total	More than 43 known collections	38,360

analyzed genetic diversity of landrace accessions in Greece through ISSR markers, and found that the pellet types still aggregate into one group, and the Mediterranean *Vicia faba* can be divided into at least two groups. Zeid et al. (2003) analyzed 79 faba bean varieties from Asia, Europe and North Africa with 8 AFLPs, and amplified 477 bands. Further studies have found that cultivars from Asian sources can be grouped into one category, while those from other places have no obvious classification. Zong et al. (2009) used 10 AFLP tags to analyze 243 *Vicia faba* resources (including 39 foreign winter-sowing type accessions, 201 domestic winter sowing type accessions and 3 spring sowing type accessions), and obtained 266 polymorphic bands. Significant differences were found between Chinese and foreign resources, and between spring sowing type and winter sowing type accessions. Zong et al. (2010) used 12 AFLP markers to analyze genetic diversity of 39 domestic spring-sowing type resources, 136 overseas spring-sowing type resources (from Africa, Asia, Europe and Canada) and 41 breeding materials (from ICARDA), and found that there were obvious differences in spring-sowing type resources with geographical distribution, which showed that the Chinese and foreign resources differ significantly. In addition, ICARDA's genetic resources exhibited relatively low diversity in breeding materials.

Wang et al. (2012) used 802 faba bean resources from different regions of the world and 11 ISSR markers to obtain 209 bands with polymorphism, and found that the diversity of resources from Central China was the lowest. Moreover, obvious differences between spring-sowing resources and winter-sowing resources in China again were found. The resources from Zhejiang, Sichuan and Guizhou are quite different from those from other provinces. Furthermore, China's resources are genetically distinct from those of other countries. Gong et al. (2011) analyzed the diversity of 29 *Vicia faba* resources in China and Europe with 11 EST-SSR markers, and found that the genetic diversity of Chinese resources was relatively low, and advised increasing the introduction of foreign resources. In Turkey, 25 polymorphic SSR markers were used to investigate the genetic variation in 22 faba bean genotypes (from ICARDA and Turkey); sufficient genetic diversity among the tested faba bean genotypes (especially those cultivated in Turkey) was observed and could be used in faba bean breeding programs (Tufan and Erdogan 2017).

Kaur et al. (2014a, b) used 768 SNP markers to evaluate 45 faba bean accessions, among which 657 SNP markers were used to obtain bands with polymorphisms. This study found that these beans materials were mainly divided into two major categories (G-I and G- II), and the G-II can be divided into three types (A, B, C). Backouchi et al. (2015) analyzed the levels of polymorphism across 12 Tunisian populations, 3 major and 9 minor from different locations, with morphological traits and RAPD markers. Results showed that the Takelsa population exhibited the highest Nei and Shannon indices, indicating this population was the most heterogeneous, which is ideal for breeding programs). Göl et al. (2017) studied 255 faba bean germplasm accessions with the help of 32 SSR markers. All materials were divided into two categories according to the neighborhood connection algorithm (r = 0.91), and were clustered according to geographical sources and seed size. Population structure was also determined and agreed with the dendrogram analysis in splitting the accessions into two subpopulations. Furthermore, El-Esawi (2017) used SSR markers to evaluate diversity and structure of 35 faba bean genotypes originating from North Africa, East Africa, and the Near East. Structural analysis and cluster analysis revealed that the 35 faba bean genotypes may be assigned to two populations.

7.3.2 Germplasm Conservation

The in situ conservation and evaluation of any plant species depend on its reproductive system. Faba bean is partially cross-pollinated by insects. The reproductive system in the dominant population follows a pattern of interbreeding. The cross-pollination rate varies greatly depending on genotype and geographical location; pollination mainly depends on climatic factors and insect pollinators in the field. Most of the experimental data on the gene flow of faba bean indicate that the conservation and reproduction of faba bean genetic resources must exclude the involvement of insect pollinators. Using insect-proof cages is an effective way to conserve *Vicia faba* genetic resources. When a great number of faba bean genetic resources need to be multiplied and the quantity of each seed sample is often very large, the insect-proof cage is no longer applicable, because of high cost, difficult operation and management, and will also lead to a decline of yield caused by inbreeding recession. The development of germplasm conservation techniques of faba bean depends on maintaining appropriate gene flow between different faba bean accessions during multiplication practices in the field; appropriate isolation crops are needed. According to our field tests in faba bean breeding, in order to reduce gene flow between different accessions or genotypes, the use of a 3-meter isolation distance and biological barrier (rapeseed or rye) can reduce the hybridization between adjacent accessions by more than 95%. For large numbers of faba beans to be planted, the field must be kept at least 50–100 m away from other faba bean fields to maintain seed purity (Bao et al. 2016).

The genetic resources of ex situ collections of faba bean are mainly local landraces and mass selections from landraces, open-pollinated populations, synthetics, inbred lines and hybrids (Duc et al. 2010). The main practice for long-term conservation of ex situ collections is to preserve the original dry seeds and their purified dry seeds in cryogenic and ultra-cryogenic cold storage with different specifications and construction forms (Bao et al. 2016). Faba bean genetic resources are usually conserved in gene banks at −20 °C to −18 °C for long-term strategic safe storage (Zheng et al. 1997). For the medium-term repository, a storage temperature of around 5 °Cis used by the National Genbank of the CAAS (Chinese Academy of Agricultural Sciences, Beijing, China), USDA and ICARDA (Bao et al. 2016).

7.4 Molecular Breeding

7.4.1 Genetic Linkage and QTL Mapping

The role of biotechnology in faba bean breeding can be applied through maker-assisted selection in breeding programs. This relies on breakthrough in-depth studies on faba bean germplasm, high density SSR/SNP based genetic linkage map construction and important traits (QTL) analysis. The construction of genetic linkage maps is an important aspect of genetic research. Until now, most genetic linkage maps of faba bean were based on molecular markers and limited to isozymes, RAPD (random amplified polymorphic DNA), AFLP (amplified fragment length polymorphism) and ITAP (intron targeted amplified polymorphic markers) in the world. The genetic linkage maps of faba bean constructed with SSR (simple sequence repeats) and SNP (single nucleotide polymorphisms) markers are very limited (Ma et al. 2013; Webb et al. 2015). Van de Ven et al. (1991) constructed the first genetic linkage map of faba bean containing markers such as morphological markers, isozyme markers, RFLP and RAPD, which included 17 markers located on 7 linkage groups. Torres et al. (1993) used Vf6 × Vf35 F_2 and Vf6 × Vf173 F_2 populations with isozyme, RFLP, RAPD markers to build a map with 11 linkage groups. Satovic et al. (1996) constructed a linkage map, which included 157 markers (1 morphological trait, 9 isozymes, 147 RAPD) and 48 linkage groups, 6 of which were distributed on specific chromosomes and covered about 850 cM of the faba bean genome. Patto et al. (1999) built a faba bean integrated genetic map by using Vf6 × Vf27 F_2 population and 116 markers containing 1 morphological character, 7 isozymes, 105 RAPD and 3 grain protein gene.

Orobanche crenata F. (broomrape) is a root parasitic plant, and can devastate completely faba bean crop production all along the Mediterranean Coast; it is necessary to cultivate resistant faba bean cultivars to overcome this problem. Roman et al. (2002) constructed a linkage map with 16 linkage group and used Vf6 (sensitive) × Vf136 (resistance) F_2 population, with 121 markers containing 117 RAPD, 2 isozymes, and grain protein gene. They detected 3 QTLs related to *Orobanche* resistant, namely *Oc1*, *Oc2* and *Oc3*, showing phenotypic variation. Furthermore, Roman et al. (2004) constructed one integrated map with 192 markers including 2 morphological markers, 6 isozymes, 3 grain protein genes, 176 RAPD and 4 SSR markers, and a total length of 1559 cM; the mean distance between markers was 8 cM. Diaz-Ruiz et al. (2009a, b) tested Vf6 × Vf136 RIL populations to study hairy broomrape resistant QTLs. They found two resistant loci *Of1* and *Of2*, one located in the chromosome I explaining 7% of the phenotypic variation, and the other one located in the chromosome III explaining 9% of the phenotypic variation. Diaz-Ruiz et al. (2010) used the same Vf6 × Vf136 RIL populations with 165 individuals to build a map containing 277 markers (238 RAPDs, 4 isozymes, 5 ESTs, 1 SCAR, 6 SSRs, 2 STS, 21 ITAPs). As a result, the map containing 21 linkage group and 2856.7 cM. Subsequently, QTL mapping detected 4 positive genes, in which *Oc2* and *Oc3* were consistent with previous studies, and 2 new environment-dependent loci *Oc4* and *Oc5* were identified. Gutierrez et al. (2013) used a 29H × Vf136 RIL population with 165 individuals. As a result, the map containing 172 markers, 29 linkage groups and 1402.1 cM. Subsequently, QTL mapping was carried out and found 7 QTL loci, *oc7–oc13*.

Ascochyta fabae Speg. blight is an important fungal disease. Roman et al. (2003) used Vf6 (resistance) x Vf136 (sensitive) F_2 populations with 196 individuals. As a result, the map contained 121 markers, 16 linkage groups and 1445.5 cM. Two resistance QTLs, *Af1* and *Af2*, were identified by QTL mapping, which accounted for 46% of phenotypic variation. Avila et al. (2004) used 29H × Vf136 F_2 populations to construct linkage map including 103 markers, 18 linkage groups and a total length of 1308 cM. After QTL mapping, 6 positive loci were found *Af3–Af8*. Among them, *Af3*, *Af4*, *Af5* and *Af7* were correlated with disease-resistant phenotypes of stems and leaves, while *Af6* was correlated with disease-resistant phenotypes of leaves and *Af8* was correlated with disease-resistant phenotypes of stems. Diaz-Ruiz et al. (2009a, b) constructed a genetic linkage map with 277 markers and 21 linkage groups covering 2856.7 cM of the genome. *Af1* and *Af2* were associated with resistance to *Ascochyta* blight, including *Af1* located in chromosome III and *Af2* located on chromosome II. In total, they explained 24% and 16% of the phenotypic variation of leaf and stem, respectively.

Arbaoui et al. (2008) used a F_6 RIL population to build genetic maps and QTL mapping. As a result, the map contained 132 markers and 21 linkage map covering 1635.39 cM of the genome. Five QTLs related to frost resistance and three sites related to fatty acid content were detected. Ellwood et al. (2008) used Vf6 × Vf27 RIL populations containing 94 individuals. As a result, they constructed a genetic linkage map containing 127 ITAP markers and 12 linkage groups covering 1685.8 cM of the faba bean genome. Cruz-Izquierdo et al. (2012) used Vf6 × Vf27 RIL populations containing 124 individuals and constructed a genetic linkage map covering 1875.1 cM of the faba bean genome with 258 markers (167 ITAP, 3 RGA, 11 SSR, 71 RAPD, 2 isozymes, 3 seed proteins, 1 morphological marker). Subsequently, QTL mapping was performed for flowering time, flowering length, pod length, number of single pod seeds and number of single pod ovules, and it was found that 12 QTLs could be detected for 2 years. Satovic et al. (2013) integrated different populations Vf6 × Vf27 RIL, Vf6 × Vf136 RIL, 29H × Vf136 RIL and 11 F_2. They constructed an integrated genetic linkage map containing 729 markers including 69 universal markers, covering 4602.0 cM of the faba bean genome, and the average genetic distance between the markers was 6 cM. Our group used 128 SSR markers to construct a new map based on Chinese cultivars. This map contained 15 linkage groups. The length was 1587 cM and the average distance between markers was 12.4 cM (Ma et al. 2013). Moreover, a new integrated linkage map contained 465 SSR loci distributed among 7 linkage groups and spanning a length of 4516.75 cM with an average distance 9.71 cM between adjacent loci were constructed this year (Yang et al. 2019). El-Rodeny et al. (2014) developed an integrated map with 552 markers, covering a total length of 684.7 cM in the genome. Webb et al. (2016) developed a new map containing 687 SNP markers which were placed on six linkage groups. Ocaña-Moral et al. (2017) developed a set of SNP markers by RNA-sequencing. 92 new SNP markers were combined with previous data set to obtain the most complete map of 2796.91 cM including 257 loci assembled into 19 LGs in the 29H × Vf136 faba bean population.

7.4.2 In Vitro Regeneration and Genetic Transformation

Successful application of biotechnology in plant breeding requires an efficient method of in vitro regeneration. So far, there have been only a few successful attempts related to regeneration and tissue culture of faba bean. The first reported stable *Vicia faba* germline transformation used in vitro regeneration of *Agrobacterium*-infiltrated (non-meristematic) internode stem segments (Böttinger et al. 2001). Another study reporting transgenic *V. faba* event was infiltrated excised (meristematic) embryo axes with *Agrobacterium* and successfully recovered stable transgenic lines (Hanafy et al. 2005). However, both methods have a low primary conversion efficiency and rely on a slow and highly manual process of micrografting a putative transgenic bud material onto a non-transgenic root. Despite extensive research since the 1960s, it is difficult to establish a reliable faba bean regeneration system (Duc et al. 2015).

The main obstacle to genetic transformation of *Vicia faba* is the lack of effective and stable plantlet regeneration systems. The most widely used method of transferring foreign genes into dicotyledons is *Agrobacterium*. However, the use of *Agrobacterium*-mediated transgenic method to produce transgenic plants based on stem segments, mature embryo discs and cotyledon nodes have been reported (Bottinger et al. 2001; Hanafy et al. 2005; Jelenic et al. 2000). The biolistic blast gene delivery system was used to establish a regenerative and microprojectile-mediated transformation system. Although the main obstacles to transgenic faba bean plants appear to have been overcome, the number of transgenic plants introduced so far remains limited. Two successful studies used this method to improve protein quality. Gnanasambandam et al. (2012) and Hanafy et al. (2013) were the first to report evidence that *PR10a*, a gene-enhancing salt and/or drought tolerance in potato, was transferred into faba bean through the *A. tumefaciens*-mediated transformation system, which has the same effect in faba bean.

More recently, by preparation of gene cassettes for β-1, 3-glucanase from barley, chitinase from bean and cryIA (b) from *Bacillus thuringiensis* (BT), pBI-ChiBt and pBI-ChiGlu recombinant plasmid vectors (pBI121 based vector) were made and have been introduced into the *A. tumefaciens* strain LBA4404 that was subsequently used for faba bean transformation (Gorji et al. 2014). Results indicate that embryogenic calli are well suited as objective material for *Agrobacterium tumefaciens*-mediated transformation in faba bean. A total of 17 well-established shoots were transferred to new MLS medium including suitable antibiotics, of which 6 independent transgenic plants were successfully rooted on kanamycin containing selection media and then transferred to soil after 20 days (Gorji et al. 2014). Four plants out of the above mentioned 6 putative transgenic plants displayed the targeted end part of the *chit* transgene and *nos* terminator (Gorji et al. 2014). Subsequently, *bgn*13.1 and *cryIA (b)* genes sequences were amplified by PCR using specific primers from the 3 transgenic plants and the other 3 plants did not have these fragments (Gorji et al. 2014); this proved the successful construction of a relatively effective and reliable faba bean transgenic platform.

7.5 Conclusion and Prospects

7.5.1 An Overview of the Current Status

As a cool season legume crop, faba bean plays a critical role in improving cereal-based systems and soil fertility, and helps to develop sustainable cropping systems that involving faba bean, as it is preeminent in terms of biological nitrogen fixation efficiency. Breeding programs for resistance to abiotic stresses (early or late drought, heat, winter-hardy et al.) as well as to pests and diseases (broomrape, *Sitona* weevils, leaf miners, bruchids, pathogenic fungi) have made good progress at ICARDA and in European countries. In China, more than 110 faba bean cultivars were commercially registered at the national or provincial levels over the past 40 years. Since 2008, 43 new faba cultivars were registered (Table 7.3), almost all of them are large seeded type with 100-seed weight of over 120 g, with dual usage for dry and fresh seeds, except for the traditional dry grain cv. Zhijinxiaocandou from Guizhou province. The newly registered faba bean cultivars were bred mostly by traditional crossing methods and supplementary single plant selection.

Table 7.3 Faba bean cultivars registered in China since 2008

Cultivar name	Registered time (Y.M.D)	Provincial breeding program location
Lincan 6	2008.04.01	Gansu
Lincan 7	2009.03.27	Gansu
Lincan 8	2009.03.27	Gansu
Lincan 9	2011.03.04	Gansu
Lincan 10	2013.03.26	Gansu
Lincan 11	2015.04.13	Gansu
Lincan 12	2015.04.13	Gansu
Zhijinxiaocandou	2016.06.21	Guizhou
Jizhangcan 2	2009.12.29	Hebei
Ecandou 1	2015.10.26	Hubei
Sucan 1	2012.08.07	Jiangsu
Sucan 2	2012.08.07	Jiangsu
Tongcanxian 6	2016.06.07	Jiangsu
Tongcanxian 7	2012.08.07	Jiangsu
Tongcanxian 8	2016.06.07	Jiangsu
Tongcanxian 9	2012.08.07	Jiangsu
Qinghai 13	2009.12.10	Qinghai
Qingcan 14	2011.11.22	Qinghai
Qingcan 15	2014.02.07	Qinghai
Chenghu 15	2013.08.01	Sichuan
Chenghu 18	2009.07.01	Sichuan
Chenghu 19	2010.06.18	Sichuan
Chenghu 20	2014.07.31	Sichuan
Chenghu 21	2016.07.20	Sichuan
Yundou 9224	2008.01.10	Yunnan
Yundou 825	2009.01.16	Yunnan
Yundou 853	2009.12.16	Yunnan
Yundou 690	2012.09.29	Yunnan
Yundou 95	2012.08.27	Yunnan
Yundou 470	2014.06.09	Yunnan
Yundou 06	2016.01.18	Yunnan
Yundou 459	2016.12.15	Yunnan
Fengdou 22	2016.12.15	Yunnan
Fengdou 21	2016.12.15	Yunnan
Fengdou 20	2016.09.06	Yunnan
Fengdou 19	2016.09.06	Yunnan
Fengdou 18	2016.01.18	Yunnan
Fengdou 17	2014.06.09	Yunnan
Fengdou 16	2012.08.27	Yunnan
Fengdou 15	2011.11.09	Yunnan
Fengdou 14	2009.12.16	Yunnan
Fengdou 12	2011.03.15	Yunnan
Fengdou 11	2008.01.10	Yunnan

Although the dry faba bean production area was slightly reduced in the world (Fig. 7.1) and China (Fig. 7.2), the vegetable production of faba bean is increasing in the world (Fig. 7.13a) and in China (Fig. 7.13b) with very high yield potential (Fig. 7.13c) (FAOSTAT 2018), despite of that data are not available after 2008 on the FAO website. The market driven production of vegetable faba bean has increased in production area of China, and most of fresh pods of faba bean were provided to large cities like Shanghai, Nanjing, Hangzhou, Hong Kong, et al. at the price of over 1 USD per kg in March and April. This encouraged farmers to expand the sowing area for fresh pods production of faba bean, and breeders to pay more attention to vegetable cultivar breeding in China. According to statistics from the National Center for Extension of Agronomic Techniques, Ministry of Agriculture, China, the area of vegetable and faba bean cultivation in China expanded to 430,000 ha (6.42 million mu) in 2014 (Li et al. 2017). However, in 2005, the FAO database ceased inclusion of vegetable faba bean after 2005. The world total vegetable production area was only 0.20 million ha (Fig. 7.13a), and there were only 10,000–20,000 ha of vegetable production area in China at that time (Fig. 7.13a).

The fresh pod has become very popular in the local markets in China over the past 10 years (Fig. 7.14), as local residents and farmers became consumers of fresh faba beans. The rapid expansion of fresh faba bean sowing areas was mainly driven by large demand for fresh faba bean market. Vegetable faba bean took one-third of whole faba bean production area in 2014 in China, and now it occupies nearly half of the total area. Therefore, vegetable type is the right direction for faba bean industry in China, and probably for the whole world as well.

7.5.2 Current Research Initiatives and Recommendations for Future Research

Progress in faba bean genomics still lags behind other legume crops. Nevertheless, a wide range of genomic and post-genomic resources are being developed to boost genetic research and breeding applications. Different molecular marker sets, such as SSRs and SNPs, have been developed and used to construct more saturated linkage maps in order to identify genes or QTLs controlling major agronomic and stress related traits. Current efforts are focused on the development of highly accurate selective breeding tools, using NGS methods and RNA-seq technologies to refine the maps with functional markers. Moreover, translational genomics, based on the collinearity with model and related species, opens the possibility to identify candidate genes underlying agronomic important traits. Finally, a faba bean functional consensus map will be constructed to integrate all the previously-published genes and QTLs. The combination of these and new tools together with a close link between academic research and commercially-focused breeding programs may help researchers to find genes of interest and to speed the release of more competitive faba bean cultivars in the near future (Duc et al. 2015).

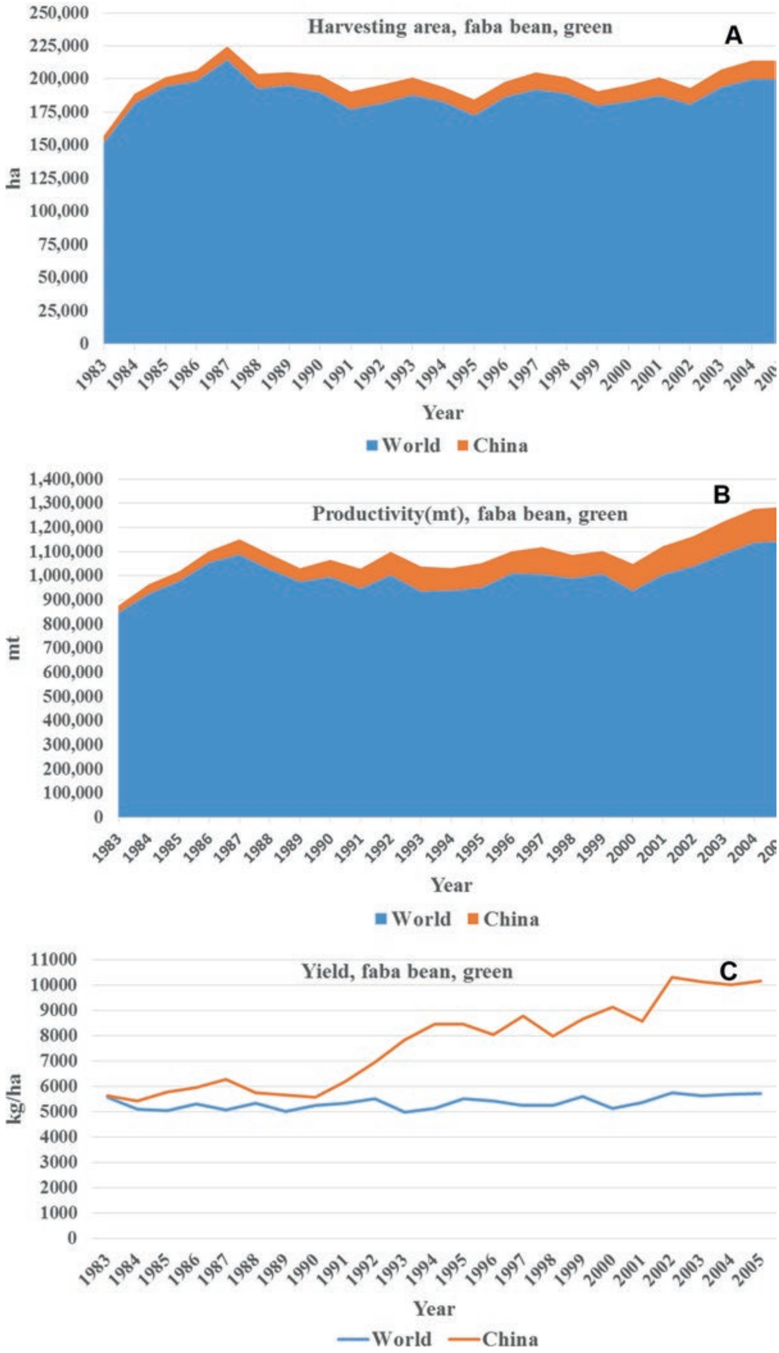

Fig. 7.13 Vegetable faba bean harvest area (**a**), productivity (**b**) and yield (**c**) in the world and China. (Source: FAOSTAT 2018)

Fig. 7.14 Fresh pods of faba bean selling in local market in Yunnan province, China. (**a**) Fresh faba bean pods in a free market, (**b**) Fresh faba bean seeds, (**c**) Fresh faba bean pods in a bag after harvesting, and (**d**) Fresh faba bean long pod type after harvesting. (Photo by Zong Xuxiao)

Currently, faba bean breeding has a large number of objectives to achieve, and the priorities depend on regional stress factors and market forces. As a result of climate change, stronger demands exist for genetic resistance to abiotic stresses (early or late drought, heat, frost, winter-hardy, waterlogging) as well as to pests and diseases (*Orobanche crenata*, *Sitona* weevils, leaf miners, bruchids and pathogenic fungi) in new geographic zones (Duc et al. 2015). Potential novel food uses of faba beans need to be addressed, as fresh vegetables, and also strengthened demands for low vicine and covicine, high protein and low tannin content genotypes. Inevitably, when the breeder needs to add more objectives to an existing program, either more resources have to be allocated to cover it or overall progress slows down. In addition to large, characterized and structured genetic resources collections, rapid breeding methods and translational omics will help to streamline the breeding progress, so more of the objectives can be met. Considering the coming needs for the faba bean industry in the world, future breeding objectives of faba bean should include winter hardiness, heat tolerance, herbicide resistance, double-zero (low content of vicine and covicine), BNF (biological nitrogen fixation) efficiency, high photosynthetic efficiency, better flavor and palatability, dual usage both for forage grass and for green pods, as well as a favorable market price.

In the future, faba bean breeding would be more predictable than traditional breeding by genome editing technology, although it will heavily rely on in vitro regeneration systems. Once a stable and reliable in vitro regeneration system of faba bean achieves a breakthrough, the possibility of ideal phenotypic outcomes will be increased dramatically by CRISPR/Cas-induced gene or regulatory element rather than by natural or chemical/physical-induced variants such as EMS mutagenesis or radiation induced mutation.

Appendices

Appendix I: Research Institutes Relevant to Faba Bean

Institution	Specialization and research activities	Contact information and website
Institute of Crop Sciences, Chinese Academy of Agricultural Sciences	Genetic resources and genomic studies, genetic improvement of faba bean, pea and other pulse crops	No. 12. Zhong Guan Cun South street, Haidian district, Beijing, China. http://ics.caas.cn/
Institute of Grain Crops, Yunnan Academy of Agricultural Sciences	Faba bean and pea breeding and agronomy	No. 2238, extension line, Beijing road, Panlong district, Kunming city, Yunnan province, China. http://www.ynicri.cn/
Institute of Crop Breeding and Cultivation, Qinghai Academy of Agriculture and Forestry	Faba bean breeding and agronomy	No.97, Ningzhang Road, Chengbei district, Xining city, Qinghai province, China. http://www.qhnky.com/
Institute of Crops, Sichuan Academy of Agricultural Sciences	Faba bean and pea breeding and agronomy	No.20, Jingju Temple Road, Jinjiang District, Chengdu city, Sichuan province, China. http://www.chinawestagr.com/zwyjs/

(continued)

Institution	Specialization and research activities	Contact information and website
Nantong Institute of Agriculture, Jiangsu	Faba bean breeding and agronomy	Yanjiang Road, Changjiang Town, Rugao city, Nantong city, Jiangsu province, China. http://yj.jaas.ac.cn/
Linxia Institute of Agriculture, Gansu	Faba bean breeding and agronomy	Hongyuan Xincun road, Linxia city, Linxia Hui Autonomous Prefecture, Gansu province, China
Australian Temperate Field Crops Collection – pulses and oilseeds	National Plant Genetic Resource Centres Vicia (vetches and faba bean)	Department of Primary Industries, Victoria. http://www.pulseaus.com.au/
Genebank, ICARDA	Faba bean genetic resources	ICARDA, Egypt. http://www.icrisat.org
International Center for Agricultural Research in the Dry Areas (ICARDA)	Faba bean breeding	ICARDA, Beirut, Lebanon. http://www.icrisat.org
Virology Laboratory, ICARDA	Virus Diseases of Food Legume Crops in WANA Region (Detection & Control)	ICARDA, Lebanon. http://www.icrisat.org
Department of Primary Industries, Biosciences Research Division, Grains Innovation Park	Faba bean genetic resources and breeding	Private Bag 260, Horsham, Victoria 3401, Australia. http://www.pir.sa.gov.au/home
Department of Plant Breeding, Spanish National Research Council	Faba bean genetic resources and breeding	Apdo. 3092, Córdoba E-14080, Spain. http://www.csic.es/
Sydney Institute of Agriculture, The University of Sydney	Faba bean breeding and agronomy	Sydney, Australia. https://sydney.edu.au/agriculture/
Tamworth Agricultural Institute, New South Wales Department of Primary Industries	Research on viral diseases of faba bean in Australia's Northern Grain Region	RMB 944, Tamworth 2340, Australia. https://www.dpi.nsw.gov.au/
Department of Primary Industries, Biosciences Research Division, VABC	Faba bean researches	1 Park Drive, Bundoora, Victoria 3083, Australia
Laboratoire de Biologie Moléculaire des Relations Plantes-Microorganismes	Rhizobium-legume symbiosis, faba bean	Toulouse, France. http://www.ara.inra.fr/en
INRA, Research Unit – Genetics & Ecophysiology of Grain Legumes (UR-LEG)	Faba bean breeding	Dijon, France. http://www.ara.inra.fr/en
John Innes Centre	Faba bean research and breeding	Norwich, UK. https://www.jic.ac.uk/
School of Agriculture, Policy and Development, University of Reading	Faba bean research and breeding	Whiteknights, UK. http://www.reading.ac.uk/

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Institution	Specialization and research activities	Contact information and website
School of Agriculture, Food and Wine, The University of Adelaide	Faba bean research and breeding	Waite Campus, Glen Osmond, South Australia 5064, Australia. https://sciences.adelaide.edu.au/
School of Agriculture & Food Systems, Faculty of Land & Food Resources, University of Melbourne	Biotechnology to cropping and horticultural industries, including faba bean	Melbourne, Australia. https://research.unimelb.edu.au/
N.I.Vavilov Research Institute of Plant Industry	Faba bean genetic resources	St. Petersburg, Russia. http://vir.nw.ru/index.htm
Western Regional Plant Introduction Station, US Department of Agriculture-Agriculture Research service, Washington State University	Faba bean genetic resources and breeding	Pullman, Washington State, USA. https://www.ars.usda.gov/pacific-west-area/pullman-wa/
Grain Legume Genetics and Physiology Research Unit, US Department of Agriculture, Agricultural Research Service, Washington State University	Research on faba bean diseases, rhizobium in the US	Pullman, Washington State, USA. https://www.ars.usda.gov/pacific-west-area/pullman-wa/
Alberta Agriculture and Rural Development, Edmonton	Research on faba bean diseases, and breeding in Canada	Edmonton, Alberta, Canada. https://www.alberta.ca/ministry-agriculture-forestry.aspx

Appendix II: Faba Bean Genetic Resources

Cultivar	Important traits	Cultivation location
Qingcan 1	Seedlings erect, young stem light green. Main stem green, square. leaves upright, plant compact. Racemes purplish red, flag purplish red, veined pale brown, winged purple, with a black central disk, keel purplish. Mature pod yellow. Seed coat glossy, translucent, umbilical black. Creamy white, medium to thick. A hundred grains weigh about 200 g. Crude protein content was 31.19%, starch 37.2%, fat 0.96%, crude fiber (dry base %) 8.1%. Spring, middle and late ripening varieties. During the production test from 2007–2008, the average yield was 4445.25 kg/ha.	Suitable for planting in irrigated land with elevation of 2300–2600 m in Qinghai, Gansu, Tibet provinces in China.
Linxi 1	The plant height was 100.0 ~ 120.0 cm. Primary leaves ovoid, green, stipules pale green, compound leaves oblong, average number of leaflets 4–5. Main stem anthesis 6 ~ 7, terminal anthesis 10 ~ 11, flag white, pale brown veins, white wings, keel green. There were 8.0 ~ 9.0 effective pods per plant, and the pod was in the semi-erect pod state. The pod was of large pod type, with fresh pod length of 15.2 ~ 17.5 cm, pod width of 3.5 ~ 5.0 cm, mature pod length of 10.0 ~ 10.5 cm, and pod width of 2.5 ~ 3.0 cm. Each pod contains 1.0 ~ 3.0 granules. Mature pods are dark brown. Seed coat light green, dull, umbilical black, broad thin – shaped. Fresh grain length: 3.5 ~ 4.0 cm, width: 2.50 ~ 3.05 cm; seed length: 2.4 ~ 2.5 cm, width: 1.70 ~ 1.75 cm, 100-seed weight: 195.0 ~ 200.0 g, crude protein content: 28.85%, starch content: 46.24%, fat content: 1.227%, crude fiber content: 7.099%. It belongs to semi – winter, middle and early maturity, and its growth period is 96 ~ 104 d. From 1999–2000, the average dry seed yield was 2512.2 kg/ha after multi-point identification in Qinghai province. In 2000, the average fresh pod yield was 15132.7 kg/ha after participating in the production test and demonstration of faba bean in Qinghai province.	Faba bean autumn sowing area and spring sowing area can be planted, in China.
Qinghai 12	Plant height 104.4 ~ 145.3 cm. Primary leaves ovoid, green; stipules pale green. Compound leaves long elliptic, average number of leaflets 4 ~ 5. Flowers with white flag, pale brown veins, white wing, with a black disk in the center, green keel.14 ~ 15 effective pods per plant. Pod set in semi-erect form. Pod length 10.0 ~ 12.0 cm, pod width 2.0 ~ 2.4 cm. Each pod contains 2.1 ~ 2.3 grains. Mature pod black. Seed coat glossy, translucent, umbilical black. Creamy white, medium to thick. The seeds were 2.1 ~ 2.3 cm long, 1.7 ~ 2.0 cm wide, and 100 seeds weighed 195.0 ~ 200.0 g. The content of crude protein was 26.50%, starch 47.58%, fat 1.47% and crude fiber 7.37%. Spring, medium maturity variety, growth period 110 ~ 125 d. From 2001–2002, the average yield of 5070.0 kg/ha was increased by 8.18% compared with that of Qinghai 10. From 2003–2004, the average yield of 4218.0 kg/ha was increased by 6.7% compared with that of Qinghai 10.	It is suitable for planting in the irrigated agricultural area with an elevation of 2000–2600 m and the middle mountain dry land, in Qinghai province and northwest China.

(continued)

Cultivar	Important traits	Cultivation location
Qinghai 11	Plant height 140.0 ~ 145.0 cm. Primary leaves ovoid, green; stipules pale green. Compound leaves long elliptic, average number of leaflets 4 ~ 5. The main stem starts with 4 ~ 5 knots and ends with 11 ~ 12 knots. Flag white, pale brown veins, white pterygium, with a black central disk, keel greenish white. There are 20 ~ 25 effective pods per plant. Pod set in semi – erect form. Pod length 7.5 ~ 9.0 cm, pod width 2.5 ~ 2.7 cm. Each pod contains 1.8 ~ 2.0 capsules. Mature pod black. Seed coat glossy, translucent, umbilical black. Creamy white, medium to thick. The seeds were 2.13 ~ 2.22 cm in length, 1.88 ~ 2.00 cm in width and 190.0 ~ 195.0 g in weight. The content of crude protein was 25.66%, starch was 45.35%, fat was 1.38% and crude fiber was 6.20%. Spring, medium maturity variety, growth period 110 ~ 120 days. From 1999–2000, the average yield of 4333.5 kg/ha was increased by 12.3% compared with the control. From 2001–2002, the average yield of 5293.5 kg/ha was increased by 18.9% compared with the control.	It is suitable for planting in irrigated agricultural areas below 2600 m above sea level and on high water land, in Qinghai province and northwest China.
Lincan 7	It is belonging to medium big grain varieties, spring, growth period of 120 d or so, plant height 140 cm, branch 1–3, 1 cm thick stems, young stem color green, leaf blade elliptic, leaf color shallow green, shallow purple flowers, pod height 25 cm in the beginning, pod number per 10–18, each pod 2–3 grain, grain number per 20–40 grains, pod 11 cm long, 2.1 cm wide, pods grain of 2.3 cm long, 1.65 cm wide, hundred grain weight 186.9 g, grain full neat, kind of milky white skin, hilum black. The protein content was 29.04%, lysine 1.81%, starch 42.7%, tannin 0.59%. Resistant to root rot, like fertilizer and water. In 2007, the yield was 3810–5025 kg/ha in 5 stations, and the average yield was 4497 kg/ha, which was 12.36% higher than CK, and the increase was 9.06–14.3%.	Suitable for Gansu, Qinghai, Ningxia, Inner Mongolia, Xinjiang, Sha'anxi, Sichuan Aba spring faba bean production areas in China.
Lincan 10	Belong to medium big grain varieties, plant type is compact, plant growth and tidy, spring, growth period about 120 d, plant height 125 cm, branch 1–3, 1 cm thick stems, young stem color green, leaf blade elliptic, leaf color shallow green, shallow purple flowers, pod height 25 cm in the beginning, pod number per 10–18, each pod 2–3 grain, grain number per 20–40 grains, pod 11.5 cm long, 2.2 cm wide, pods grain of 2.3 cm long, 1.65 cm wide, hundred grain weight 182.56 g (try the province average) for 2 years, The seeds are plump and neat, the seed coat is milky white, and the seed navel is white. According to the test report of agricultural testing center of Aansu Academy of Agricultural Sciences, contains 10.93% water, 31.76% crude protein, 1.01% lysine, 54.661% starch, 0.863% crude fat and 0.601% tannin. From 2011–2012, the 2-year average yield was 2982 kg/ha, increasing 12.5% compared with Lincan 5 and 24.16% compared with Lincan 2.	Suitable for Gansu, Qinghai, Ningxia, Inner Mongolia, Xinjiang, Sha'anxi, Sichuan Aba spring faba bean production areas in China.

Maya Candou	Plant height: 130.0 ~ 140.0 cm. Primary leaves ovoid, green; stipules pale green. Compound leaves long elliptic, average number of leaflets 4 ~ 5. Flowers with white flag, pale brown veins, white wing, with a black disk in the center, green keel. The effective pod number per plant was 14 ~ 18, pod was hypo erect, pod length was 8.0 ~ 10.4 cm, pod width was 1.8 ~ 2.0 cm, pod size was 1.9 ~ 2.0, mature pod was black and brown. Seed coat milky white, shiny, translucent, umbilicus black, medium thickness, granule like horse teeth, seeds 2.3 ~ 2.5 cm long, 1.3 ~ 1.4 cm wide, 100 seeds weight 130.0 ~ 140.0 g. The content of crude protein, starch and crude fat was 28.2, 47.3 and 1.48%, respectively. It belongs to spring and medium mature varieties, with growth period of 110 ~ 120 days. From 2002–2003, he participated in the regional identification test of horse tooth faba bean, with an average yield of 4231.8 kg/ha, and an average yield increase of 6.1% compared with the control.	It is suitable for planting in the irrigated agricultural area with an elevation of 2500 ~ 2900 m and the middle mountain dry land, in western part of China.
Tong Can Xian 7	The whole growth period was about 220 d (the growth period of fresh pod was about 209 d). The seedling stage growth potential is prosperous, the plant high school and so on slants, resists the fertilizer to resist to fall, the straw green seed is ripe, does not crack the pod, is ripe good. In general, the height of the adult plant was about 96 cm, with many branches, 4.6 effective branches per plant, 15.2 pods per plant, among which 19.5% was one pod and 80.5% was more than two pods. The fresh pod was 11.81 cm long and 2.55 cm wide. Fresh seeds were 3.01 cm long and 2.18 cm wide. In the trial area, the fresh weight of 100 pods was 2500 g, the fresh seed weight was 379.3 g, the design and color of light purple flowers (partial white flowers), the dry seed coat was white (slightly greenish white excessive color at the time of harvest), the black navel, the seeds were large, and the dry seed weight was about 205 g. High quality, high protein and starch content, protein (dry base) content of 29.7%, fat 1.2%, starch (dry base) content of 53.8%. In the 2-year regional experiment, the average yield of fresh pod was 17.78 mt/ha, which was 7.44% higher than that of CK (a local variety). Fresh seeds/pods weight averaged 33.94%. Fresh seed yield was 6.04 mt/ha, 9.32% higher than that of CK. From 2010–2011, the high-yielding cultivation experiment and demonstration of this variety showed that the average fresh pod yield was 18.73 mt/ha, and the dry seed yield was 3.07 mt/ha.	Wide adaptability, can be in Jiangsu, Zhejiang, Shanghai, Fujian, Anhui, Hubei, Chongqing, Sichuan and other autumn sowing faba bean ecological areas, especially suitable for suburban food faba bean cultivation.
Tongcanxian 6	Winter, medium maturity varieties, the whole growth period of 220 d, coastal areas of fresh pods on the market in late April to mid-May, early 2 ~ 3 d than Japan CK (Japan Cun Can). Seedling flourishing, plant height of 85 cm, purple flowers. There were 3.9 effective branches per plant, 9 pods per plant, one pod accounted for 33.6%, and more than two pods accounted for 66.4%. The pods were 10.4 cm long and 2.8 cm wide, with an average weight of 2241.5 g. The fresh seeds were 3.0 cm long and 2.2 cm wide, and the 100-grain weight of the fresh seeds was 429.6 g. Dry seeds weigh about 200 g and contain 30.2% crude protein. Black navel, seed coat light purple, can be used for purity identification. In 2005, the fresh pod yield was 15.72 mt/ha, ranking the first among the tested varieties, and the yield was 36.8% higher than that of Japan CK. The yield of fresh seeds was 4.95 mt/ha, which was 30.95% higher than that of CK, ranking first. Fresh seeds/pods weight averaged 31.5%.	Wide adaptability, can be in Jiangsu, Zhejiang, Shanghai, Fujian, Anhui, Hubei, Chongqing, Sichuan and other autumn sowing faba bean ecological areas, especially suitable for suburban food broad bean cultivation.

(continued)

Cultivar	Important traits	Cultivation location
Tong Can Xian 8	The whole growth period of broad bean was about 220 d (the growth period of fresh pod was about 208 d). The seedling stage growth potential is prosperous, the plant high school and so on slants, resists the fertilizer to resist to fall, the straw green seed is ripe, does not crack the pod, is ripe good. In general, the height of the adult plant was about 94 cm, with many branches, 5.15 effective branches per plant, 14.7 pods per plant, of which one pod accounted for 23.5%, and more than two pods accounted for 76.5%. The fresh pod was 11.26 cm long and 2.49 cm wide, and the fresh seed was 2.83 cm long and 2.06 cm wide. The average 100 fresh pods weight was 2346 g, and the average fresh seed weight was 379.5 g. Light purple flowers (white flowers), black umbilical, and white seed coat of dry seeds were larger, and the dry seed weight was about 195 g. Good quality, high protein and starch content, protein content of 27.9%, fat 1.2%. The average yield of fresh pod was 17.42 mt/ha, which was 5.31% higher than that of Japan CK. Fresh seeds/pods weight averaged 33.26%. Fresh seed yield was 5.83 mt/ha, 5.43% higher than the control. From 2010–2011, the high-yield cultivation experiment and demonstration of this variety showed that the average fresh pod yield was 18.08 mt/ha, and the dry seed yield was 2.98 mt/ha.	Wide adaptability, can be in Jiangsu, Zhejiang, Shanghai, Fujian, Anhui, Hubei, Chongqing, Sichuan and other autumn sowing broad bean ecological areas, especially suitable for suburban food broad bean cultivation.
Haimen Daqingpi	Winter, medium maturity varieties, the whole growth period of 221 d. Plant shape compact, erect growth, stout stem, plant high school, general plant height of 90 cm, purple flowers. There were many branches, 4.5 branches per plant, 12.2 pods per plant, 1.6 seeds per pod, and the pod length was 8.0 cm. The seeds are large, flat, broad and thin, 2.03 cm long and 1.52 cm wide, green and shiny seed coat, black umbilicus, slightly uplifted at the base, generally weighing about 115 ~ 120 g. Dry seed protein content of 25% ~ 30%, crude fat 1.68% ~ 1.98%, cold – resistant, disease – resistant, ripe good. Can be mono cropped, but also with corn, cotton, vegetables, medicinal materials, such as inter-planting. The yield of this variety is 2700 kg/ha in mono cropping and 2250 kg/ha in inter-planting with cotton and corn. High yield cultivated plot, mono cropping yield 3300 kg/ha, inter-planting 2700 kg/ha.	Broad adaptability, can be in the Jiangsu broad bean ecological area and the Yangtze river in the middle and lower reaches of broad bean ecological area, can also be in suburban counties for high-quality fresh broad bean cultivation.
Jian Li Xiao Can Dou	Winter, late maturity varieties, the whole growth period of 212 d. Prostrate growth type, plant height 157.7 cm, color white/purple; The number of stems and branches per plant was 4.2, the number of pods per plant was 30.5, the length of pod was 7.77 cm, and the number of single pod was 2.36. Seed coat dark green, green, navel black, brown, granular thick; 100 dry seeds weigh 61.73 g. Good yield and stability. Average dry grain yield 41.10 g per plant; The cultivated yield in the plot is 2195 ~ 2996 kg/ha.	Wide adaptability, in the Yangtze river basin autumn sowing areas can be planted production.

Yundou 825	It is an autumn sowing medium – ripe large – grain variety. 188–202 d during the whole growth period, with unlimited flowering habits, the seedlings branched upright and plant height of 101.5 cm; Plant type compact, young stem green, mature stem brown yellow, medium branching force, average branching number 2.95 branches/plant; Small foliage shape oval, round leaves yellow green color, design and color is white, the pod hard, pod shape oblate bucket, fresh green pods and mature pods for shallow brown, skin white, hilum white, cotyledon yellow-white, grain shape wide thick, 9.9 pods per plant and single pod 1.30 grain, the 100 grain weight of 144.9 g and 20.2 g grain weight per plant, dry grain starch content 49.74%, crude protein content 24.12%, and 61.2% of the total sugar content, tannin content 0.025%; Because the total sugar content is high, the tannin content is low, the processing quality is extremely excellent. The average dry grain yield of 3892.1 kg/ha was 10.76% higher than that of CK. Field production experiment of dry grain yield 3430–3591 kg/ha; The average yield was 4670 kg/ha, with an increase rate of 1.1–15.3%.	Faba bean producing areas and similar habitats in Yunnan province at an elevation of 1100–2300 m.
Fengdou 13	It is an autumn sowing medium – ripe large – grain variety. Whole growth period 185 d, unlimited flowering habit; Seedlings branched upright, plant height of 78.25–99.42 cm; young stem purplish red, mature stem brown yellow. The average branch number was 4.1 branches/plant. Small foliage long elliptic, leaf light green color, design and color is purple, pod quality thin, tender pod shape oblate bucket, pod 8.67 cm long, bright green pods and mature pods for shallow brown, skin white, hilum white, cotyledon yellow-white, grain shape wide thick, 10.0 pods per plant and single pod 1.7 grain, the 100-grain weight is 138.5 g and 21.3 g grain weight per plant, dry grain starch content is 30.4%, crude protein content is 40.6%. Belong to high protein content variety. The average dry grain yield of the regional test in Yunnan province was 4419.45 kg/ha, 4.78% higher than that of CK. Field production experiment on average 4119.3 kg/ha, dry grain yield increase rate was 20.76%.	Yunnan province, 1600–2200 m above sea level. And similar habitat area cultivation.
Fengdou 10	It is an autumn sowing medium – ripe large – grain variety. Whole growth period 180 d, unlimited flowering habit; Seedling branches erect, plant height 96.5–139.6 cm; Young stem green, mature stem brown yellow; The average branch number was 4.1 branches/plant. Small foliage shape long oval, round leaf color is green, design and color is white, the pod hard, pod shape oblate bucket, pod 9.5 cm long, bright green pods and mature pods for shallow brown, skin white, hilum white, cotyledon yellow-white, grain shape wide thick, 9.5 pods per plant, single pod 1.81 grain, the 100-grain weight 133.2 g, 18.1 g grain weight per plant, dry grain starch content 49.68%, crude protein content is 28.19%, belong to high protein content variety. The average dry grain yield of the regional test in Yunnan province was 4080 kg/ha, which was 7.1% higher than that of the control variety 8010. Dry grain yield an average of 4620 kg/ha in field production experiment, increase production rate of 7.6–19.2%.	Broad bean producing areas in Yunnan province with an elevation of 1300–2100 m; And similar habitat area cultivation.

(continued)

Cultivar	Important traits	Cultivation location
Yundou 324	It is an autumn sowing medium – ripe large – grain variety. The whole growth period was 193 d, the flowering habit was unlimited, the branch of seedlings was semi-erect, the branch force was strong, and the average branch number was 3.7 branches/plant. Plant height 80–100 cm, compact plant, young stem lilac red, mature stem brownish yellow, small leaves ovoid, leaves yellow-green, flowers lilac, pod hard, pod oblate barrel; Fresh pod green, mature pod light brown; Seed coat green, seed hilum green; Granule width and thickness, cotyledons yellow and white; Single plant 9.92 pod, single pod 2.39 grain, 100-grain weight 132 g, single plant grain weight 31.4 g, dry grain starch content 45.88%, crude protein content 25.59%, tannin content 0.06%, fresh grain soluble sugar content 13.6%. It is a kind of vegetable with high quality. Strong frost resistance and moderate drought resistance. Field production experiment dry grain yield 3723–4596 kg/ha, the average yield of 4159 kg/ha, increase production rate of 7.5 42.1%, fresh pod yield 20,535–33,000 kg/ha.	Suitable for Yunnan, Sichuan and Guizhou areas with an altitude of 1100–2400 m for autumn sowing, and 1800–3100 m for spring sowing and summer sowing. It can be cultivated in autumn sowing in Jiangsu and Zhejiang, central China and spring sowing in Gansu and Qinghai, 20–30 days earlier than local varieties.
Chengjiang Dabeidou	It is an autumn sowing medium – ripe large – grain variety. Whole growth period 186 d, unlimited flowering habit; Seedling branches semi creeping, plant height 107.5 cm; young stem green, mature stem brown yellow; The average branch number was 2.96. Plant type compact, small leaf shape long oval, green leaf color, white flower color, hard pod, pod shape oblate barrel, fresh pod greenish-yellow, mature pod light brown, seed coat white, umbilicus white, black, cotyledon yellow-white, grain width and thickness, single plant 11.1 pod, single pod 1.60 seeds, 100-seed weight 131 g, single plant grain weight 20.6 g. Field production dry grain yield 3372–4635 kg/ha, the average yield of 4003.5 kg/ha, compared with the local cultivation of other similar local varieties, the average increase rate of 5.3%	Broad bean producing areas in Yunnan province with an altitude of 1300–1900 m; And similar habitat conditions of regional cultivation.

Yundou Zao 7	It is an autumn sowing early maturing large-grain variety. The whole growth period was 152–188 d, the flowering habit was unlimited, the seedlings branched upright, the plant height was 80.0 cm. Green stems, mature stem brown yellow, the branch power is strong, the average branch number 4.85 branch/plant, pod is hard, pod shape oblate bucket, fresh green pods and mature pods beige, seed coat is white, hilum white, cotyledon yellow-white, grain shape wide thick, 10.2 pods per plant, single pod 1.49 grain, the 100-grain weight is 130.6 g, per plant grain weight 16.2 g, dry grain starch content is 41.67%, the crude protein content is 26.8%. The dry grain yield is 4200–6600 kg/ha in the field production experiment; The average yield of 4400 kg/ha, increase production rate of 30–72.9% to the CK, the highest fresh pod yield is 23,100 kg/ha.	In Yunnan province, in the normal season is below the elevation of 1600 m, or the cultivation in the production area of off-season faba bean at the elevation of 1100–2400 m, and the cultivation in the region similar to the habitat.
Yundou 147	It is an autumn sowing medium – ripe large – grain variety. Whole growth period 190 d, unlimited flowering habit, seedling branching creeping, plant height 79.08 cm, plant type compact; The average branch number was 3.64. The young stem was green, the mature stem was red-green, and the leaf color was dark green. Leaflets are long and round, white in design and color, hard in pod, flat in pod shape, greenish-yellow in fresh pod, light brown in mature pod, white in seed coat, black in umbilicus, yellow-white in cotyledon, broad and thick in grain shape, 11.4 pods per plant, 1.93 seeds per pod, 127.38 g in 100 seeds, 23.68 g in single plant, starch content 47.69% in dry seeds, 26.21% in crude protein. Strong frost resistance, moderate drought resistance. The average yield of the regional experiment in Yunnan province was 3475.5 kg/ha, which was 21.7% higher than that of the control species 8010. 3028–4812.5 kg/ha in field production experiment, the average yield of 3920 kg/ha, increase production rate of 11.2–41.5%.	Suitable for Yunnan province elevation 1100–2400 m autumn sowing, 1800–3100 m summer sowing faba bean producing areas, and similar habitat area planting.
Chenghu 19	Medium and early maturing varieties, growth period 183 d. Unlimited pod bearing habit, vigorous growth, upright growth. Young stem light purple, mature stem green, plant height 114.9 cm. Main stem branched 2.4, leaf color is dark green, elliptic, flower purple. Single plant bearing 25.4 pods, 7.0 cm long, 2.6 cm wide, hard pod, slightly curved, mature pod black, single pod number of 2 or more. The newly harvested dry seeds were narrow and thick in shape, with pale green seed coat, black umbilicus, and 100-seed weight of 112.5 g. The dry grain protein content was 32.5% and the fat content was 1.25%. During the regional test in Sichuan province from 2007–2008, the average yield was 1859 kg/ha, which was 12.1% higher than that of the control Chenghu 10. In the production test in Sichuan province in 2008, the average yield was 2153 kg/ha, which was 15.3% higher than that of the control Chenghu 10, and the yield at Neijiang point reached 2196 kg/ha.	It is suitable for planting in different farming systems in Sichuan province.

(continued)

Cultivar	Important traits	Cultivation location
Chengdu Dabai	Early maturity variety, growth period 170 d. Habit of bearing unlimited pods and growing upright. Young stem light purple, mature stem green. The plant was 103 cm tall, with 4 main stem branches, dark green leaves, oval leaves and purple flowers. Each plant had 20.8 pods, with a pod length of 6.5 cm and a width of 3.1 cm, hard pod, straight pod and black mature pod. The newly harvested dry seeds were broad and thick, with milky seed coat, mostly white navel and a few black navel, and the weight of 100 seeds was 106.9 g. Protein content in dry grains was 28.4%. General output 1500 kg/ha, minimum 1275 kg/ha, maximum 1875 kg/ha.	Slopes of hilly area, with wet sand soil, yellow soil, in winter growing areas.
Zhijin Xiaoqingpi	Winter, middle and late ripening varieties, whole growth period 209 day. Semi creeping growth type, plant height 60.7 cm, flowers purplish red; The number of stem branches per plant was 2.40, the number of pod bearing per plant was 9.70, the pod length was 6.63 cm, and the number of single pod was 2.23. Seed coat light green, seed navel black, granular thick; Dry seeds weigh 70.93 g. Good yield and stability. Average dry grain yield per plant 22.34 g; The cultivated yield in the plot is 2300 ~ 2760 kg/ha.	Wide adaptability, in the Yangtze river basin autumn sowing areas can be planted for better production.

References

Abdalla MMF (1976) Natural variability and selection in some local and exotic populations of field beans, *Vicia faba* L. Zeitschr Pflanzen 76:334–343

Anthony JB (2017) Peas and beans. In: Atherton J (ed) Crop production science in horticulture (series). CABI, Oxfordshire, pp 66–93

Arbaoui M, Link W, Satovic Z, Torres A-M (2008) Quantitative trait loci of frost tolerance and physiologically related trait in faba bean (*Vicia faba* L.). Euphytica 164:93–104

Avila CM, Satovic Z, Sillero JC et al (2004) Isolate and organ-specific QTLs for *Ascochyta* blight resistance in faba bean (*Vicia faba* L.). Theor Appl Genet 108:1071–1078

Backouchi IZ, Aouida M, Khemiri N, Jebara M (2015) Genetic diversity in Tunisian populations of faba bean (*Vicia faba* L.) based on morphological traits and molecular markers. Genet Mol Res 14(3):7587–7596

Bao SY, Zong XX, Zhu ZD et al (eds) (2016) Broad bean production technology. Beijing Education Press, Beijing, pp 22–75

Birch ANE, Tithecott MT, Bisby FA (1985) *Vicia johannis* and wild relatives of the faba bean: a taxonomic study. Econ Bot 39(2):177–190

Böttinger P, Steinmetz A, Schieder O et al (2001) *Agrobacterium*-mediated transformation of *Vicia faba*. Mol Breed 8:243–254

Burstin J, Gallardo K, Mir RR et al (2011) Improving protein content and nutrition quality. In: Pratap A, Kumar J (eds) Biology and breeding of food legumes. CABI New Delhi, New Delhi, pp 314–328

Caracuta V, Weinstein-Evron M, Kaufman D et al (2016) 14,000-year-old seeds indicate the Levantine origin of the lost progenitor of faba bean. Sci Rep 6:37399. https://doi.org/10.1038/srep37399

Cernay C, Ben-Ari T, Pelzer E et al (2015) Estimating variability in grain legume yields across Europe and the Americas. Sci Rep 5:11171

Crépon K, Marget P, Peyronnet C et al (2010) Nutritional value of faba bean (*Vicia faba* L.) seeds for feed and food. Field Crop Res 115:329–339

Crews TE, Peoples MB (2004) Legume versus fertilizer sources of nitrogen: ecological tradeoffs and human needs. Agric Ecosyst Environ 102:279–297

Cruz-Izquierdo S, Avila CM, Palomino C et al (2012) Comparative genomics to bridge Vicia faba with model and closely-related legume species: stability of QTLs for flowering and yield-related traits. Theor Appl Genet 125(8):1767–1782

Cubero JI (1973) Evolutionary trends in *Vicia faba*. Theor Appl Genet 43(2):59–65

Díaz-Ruiz R, Gutierrez MV, Rubiales D et al (2009a) Mapping of quantitative trait loci controlling *Orobanche foetida* Poir. resistance in faba bean (*Vicia faba* L.). Afr J Biotechnol 8:2718–2724

Díaz-Ruiz R, Satovic Z, Ávila CM et al (2009b) Confirmation of QTLs controlling *Ascochyta fabae* resistance in different generations of faba bean (*Vicia faba* L.). Crop Pasture Sci 60:353–361

Díaz-Ruiz R, Torres AM, Satovic Z et al (2010) Validation of QTLs for *Orobanche crenata* resistance in faba bean (*Vicia faba* L.) across environments and generations. Theor Appl Genet 120:909–919

Diego R (2010) Faba beans in sustainable agriculture. Field Crop Res 115:201–202

Dita MA, Rispail N, Prats E et al (2006) Biotechnology approaches to overcome biotic and abiotic stress constraints in legumes. Euphytica 147:1–24

Duc G, Bao S, Baum M et al (2010) Diversity maintenance and use of *Vicia faba* L. genetic resources. Field Crop Res 115:270–278

Duc G, Jelena MA, Pascal M et al (2015) Faba bean. In: De Ron AM (ed) Handbook of plant breeding, vol 10, grain legumes. Springer, Dordrecht, pp 141–178

El-Esawi MA (2017) SSR analysis of genetic diversity and structure of the germplasm of faba bean (*Vicia faba* L.). C R Biol 340(11–12):474–480

Ellwood SR, Phan HT, Jordan M et al (2008) Construction of a comparative genetic map in faba bean (*Vicia faba* L.); conservation of genome structure with *Lens culinaris*. BMC Genomics 9:380

El-Rodeny W, Kimura M, Hirakawa H et al (2014) Development of EST-SSR markers and construction of a linkage map in faba bean (*Vicia faba*). Breed Sci 64:252–263

El-Sherbeeny MH, Robertson LD (1992) Protein content variation in a pure line faba bean (*Vicia faba*) collection. J Sci Food Agric 58(2):193–196

FAOSTAT (2018). http://www.fao.org/faostat/en/#data

Fouad M, Mohammed N, Aladdin H et al (2013) Faba bean genetics and genomics and their use in breeding program. In: Mohar S, Tracey B (eds) Genetic and genomic resources for grain legume improvement. Elseiver Insight, London, pp 113–136

Fouad M, Hu JG, O'Sullivan DM et al (2018) Breeding and genomics status in faba bean (*Vicia faba*). Plant Breed. https://doi.org/10.1111/pbr.12644

Gnanasambandam A, Paull J, Torres A et al (2012) Impact of molecular technologies on faba bean (*Vicia faba* L.) breeding strategies. Agronomy 2(3):132–166

Göl Ş, Doğanlar S, Frary A (2017) Relationship between geographical origin, seed size and genetic diversity in faba bean (*Vicia faba* L.) as revealed by SSR markers. Mol Gen Genomics 292:991–999

Gong YM, Xu SC, Mao WH, Hu QZ, Zhang GW, Ding J, Li ZY (2011) Generation and characterization of 11 novel est derived microsatellites from *Vicia faba* (Fabaceae). Am J Bot 97:e69–e71

Gorji AH, Zolnori Z, Jamasbi A et al (2014) Transformation fava beans by *Agrobacterium* using *Chitinase*, *Glucanase* and *CryIA (b)* genes. Int J Adv Sci Eng Inf Technol 4(2):14–17

Griffiths DW, Lawes DA (1978) Variation in the crude protein content of field beans (*Vicia faba* L.) in relation to the possible improvement of the protein content of the crop. Euphytica 27(2):487–495

Gutiérrez N, Palomino C, Satovic Z et al (2013) QTLs for *Orobanche* spp. resistance in faba bean: identification and validation across different environments. Mol Breed 32:909–922

Hanafy M, Pickardt T, Kiesecker H et al (2005) *Agrobacterium*-mediated transformation of faba bean (*Vicia faba* L.) using embryo axes. Euphytica 142:227–236

Hanafy MS, Antar El-Banna A, Schumacher HM et al (2013) Enhanced tolerance to drought and salt stresses in transgenic faba bean (*Vicia faba* L.) plants by heterologous expression of the *PR10a* gene from potato. Plant Cell Rep 32:663–674

Hanelt P (1972) Die infraspezifische Variabilität von *Vicia faba* L. und ihre Gliederung. Genet Resour Crop Evol 20(1):75–128

Haussmann BG, Parzies HK, Prester T et al (2004) Plant genetic resources in crop improvement. Plant Genet Res 2(1):3–21

IHCAMS (1981) Institute of Health, Chinese Academy of Medical Sciences: food composition sheet, pp 22–23

Jaaska V (1997) Isoenzyme diversity and phylogenetic affinities in *Vicia* subgenus *Vicia* (Fabaceae). Genet Resour Crop Evol 44(6):557–574

Jelenic S, Mitrikeski PT, Papes D et al (2000) *Agrobacterium*-mediated transformation of broad bean *Vicia faba* L. Food Technol Biotechnol 38(3):167–172

Jensen ES, Peoples MB, Hauggaard-Nielsen H (2010) Faba bean in cropping systems. Field Crop Res 115:203–216

Johnston J, Bennett M, Rayburn A et al (1999) Reference standards for determination of DNA content of plant nuclei. Am J Bot 86(5):609–613

Katell C, Pascal M, Corinne P et al (2010) Nutritional value of faba bean (*Vicia faba* L.) seeds for feed and food. Field Crop Res 115:329–339

Kaur S, Cogan N, Forster J, Paull J (2014a) Assessment of genetic diversity in faba bean based on single nucleotide polymorphism. Diversity 6:88–101

Kaur S, Kimber RB, Cogan NO et al (2014b) SNP discovery and high density genetic mapping in faba bean (*Vicia faba* L.) permits identification of QTLs for *Ascochyta* blight resistance. Plant Sci 217–218:47–55

Kew (2017) Science's data and resources plant DNA C-values database
Khan HR, Paull JG, Siddique KHM, Stoddard FL (2010) Faba bean breeding for drought tolerance: a physiological and agronomic perspective. Field Crop Res 115:279–286
Kittlitz EV, Ibrahim KIM, Ruckenbauer P et al (1993) Analysis and use of interpool-crosses of Mediterranean and Central European faba beans (*Vicia faba* L.) – performance of Mediterranean and Central European faba beans in Syria and Germany. Plant Breed 110:307–314
Köpke U, Nemecek T (2010) Ecological services of faba bean. Field Crop Res 115:217–233
Ladizinsky G (1998) Origin of agriculture. In: Ladizinsky G (ed) Plant evolution under domestication. Springer, Dordrecht, pp 1–60
Li L, Yang T, Liu R et al (2017) Food legume production in China. Crop J 5(2):115–126
Link W, Dixkens C, Singh M et al (1995) Genetic diversity in European and Mediterranean faba bean germplasm revealed by RAPD markers. Theor Appl Genet 90:27–32
Link W, Balko C, Stoddard FL (2010) Winter hardiness in faba bean: physiology and breeding. Field Crop Res 115:287–296
Ma Y, Bao S, Yang T et al (2013) Genetic linkage map of Chinese native variety faba bean (*Vicia faba* L.) based on simple sequence repeat markers. Plant Breed 132:397–400
Multari S, Stewart D, Russell WR (2015) Potential of fava bean as future protein supply to partially replace meat intake in the human diet. Compr Rev Food Sci Food Saf 14(5):511–522
Muratova VS (1931) Boby (*Vicia faba* L.). Izd. Instituta rastenievodstva, Leningrad
Ocaña-Moral S, Gutiérrez N, Torres AM, Madrid E (2017) Saturation mapping of regions determining resistance to *Ascochyta* blight and broomrape in faba bean using transcriptome-based SNP genotyping. Theor Appl Genet 130(11):2271–2282
Oldach KH (2011) Mutagenesis in food legumes. In: Pratap A, Kumar J (eds) Biology and breeding of food legumes. CABI, Oxfordshire, pp 418–420
O'Sullivan DM, Angra D (2016) Advances in faba bean genetics and genomics. Front Genet 7:150. https://doi.org/10.3389/fgene.2016.00150
Patrick JW, Stoddard FL (2010) Physiology of flowering and grain filling in faba bean. Field Crop Res 115:234–242
Patto MCV, Torres AM, Koblizkova A et al (1999) Development of a genetic composite map of Vicia faba using F_2 populations derived from trisomic plants. Theor Appl Genet 98:736–743
Pérez-de-Luque A, Eizenberg H, Grenz JH et al (2010) Broomrape management in faba bean. Field Crop Res 115:319–328
Polignano GB, Uggenti P, Scippa G (1993) The pattern of genetic diversity in faba bean collections from Ethiopia and Afghanistan. Genet Resour Crop Evol 40:71–75
Polignano GB, Alba E, Uggenti P, Scippa G (1999) Geographical patterns of variation in Bari faba bean germplasm collection. Genet Resour Crop Evol 46(2):183–192
Rispail N, Kaló P, Kiss GB et al (2010) Model legumes to contribute to faba bean breeding. Field Crop Res 115:253–269
Román B, Torres AM, Rubiales D et al (2002) Mapping of quantitative trait loci controlling broomrape (*Orobanche crenata* Forsk.) resistance in faba bean (*Vicia faba* L.). Genome 45:1057–1063
Román B, Satovic Z, Avila CM et al (2003) Locating genes associated with *Ascochyta fabae* resistance in *Vicia faba* L. Aust J Agric Res 54:85–90
Román B, Satovic Z, Pozarkova D et al (2004) Development of a composite map in *Vicia faba*, breeding applications and future prospects. Theor Appl Genet 108:1079–1088
Rubiales D, Pérez-de-Luque A, Fernández-Aparicio M et al (2006) Screening techniques and sources of resistance against parasitic weeds in grain legumes. Euphytica 147:187–199
Satovic Z, Torres AM, Cubero JI (1996) Genetic mapping of new morphological, isozyme and RAPD markers in *Vicia faba* L. using trisomics. Theor Appl Genet 93:1130–1138
Satovic Z, Avila CM, Cruz-Izquierdo S et al (2013) A reference consensus genetic map for molecular markers and economically important traits in faba bean (*Vicia faba* L.). BMC Genomics 14:932. https://doi.org/10.1186/147-2164-14-932

Sillero JC, Fondevilla S, Davidson J et al (2006) Screening techniques and sources of resistance to rusts and mildews in grain legumes. Euphytica 147:255–272
Sillero JC, Villegas-Fernández AM, Thomas J et al (2010) Faba bean breeding for disease resistance. Field Crop Res 115:297–307
Sjodin J (1971) Induced morphological variation in *Vicia faba* L. Hereditas 67:155–180
Stoddard FL, Balko C, Erskine W et al (2006) Screening techniques and sources of resistance to abiotic stresses in cool-season food legumes. Euphytica 147:167–186
Stoddard FL, Nicholas AH, Rubiales D et al (2010) Integrated pest management in faba bean. Field Crop Res 115:308–318
Tanno KI, Willcox G (2006) The origins of cultivation of *Cicer arietinum* L. and *Vicia faba* L.: early finds from Tell el-Kerkh, north-west Syria, late 10th millennium BP. Veg Hist Archaeobotany 15(3):197–204
Temesgen T, Keneni G, Sefera T, Jarso M (2015) Yield stability and relationships among stability parameters in faba bean (*Vicia faba* L.) genotypes. Crop J 3(3):258–268
Terzopoulos PJ, Bebeli PJ (2008) Genetic diversity analysis of Mediterranean faba bean (*Vicia faba* L.) with ISSR markers. Field Crop Res 108:39–44
Terzopoulos PJ, Kaltsikes PJ, Bebeli PJ (2003) Collection, evaluation and classification of Greek populations of faba bean (*Vicia faba* L.). Genet Resour Crop Evol 50:373–381
Tivoli B, Baranger A, Avila CM et al (2006) Screening techniques and sources of resistance to foliar diseases caused by major necrotrophic fungi in grain legumes. Euphytica 147:223–253
Torres AM, Weeden NF, Martín A (1993) Linkage among isozyme, RFLP and RAPD markers in *Vicia faba*. Theor Appl Genet 85:937–945
Torres AM, Román B, Avila C et al (2006) Faba bean breeding for resistance against biotic stresses: towards application of marker technology. Euphytica 147:67–80
Torres AM, Avila CM, Gutiérrez N et al (2010) Marker-assisted selection in faba bean (*Vicia faba* L.). Field Crop Res 115:243–252
Tufan H, Erdogan C (2017) Genetic diversity in some faba bean (*Vicia faba* L.) genotypes assessed by simple sequence repeats. Biotechnol Biotechnol Equip 31(1):29–35
Ven W, Waugh R, Duncan N et al (1991) Development of a genetic linkage map in *Vicia faba* using molecular and biochemical techniques. Asp Appl Biol 27:49–54
Wang HF, Zong XX, Guan JP et al (2012) Genetic diversity and relationship of global faba bean (*Vicia faba* L.) germplasm revealed by ISSR markers. Theor Appl Genet 124:789–797
Webb A, Cottage A, Wood T et al (2015) A SNP-based consensus genetic map for synteny-based trait targeting in faba bean (*Vicia faba* L.). Plant Biotechnol J 14(1):177–185
Webb A, Cottage A, Wood T et al (2016) A SNP-based consensus genetic map for synteny-based trait targeting in faba bean (Vicia faba L.). Plant Biotechnol J 14(1):177–185
Yang T, Jiang JY, Zhang HY et al (2019) Density enhancement of a faba bean genetic linkage map (*Vicia faba* L.) based on simple sequence repeats markers. Plant Breed 138:207–215. https://doi.org/10.1111/pbr.12679
Zeid M, Schön CC, Link W (2003) Genetic diversity in recent elite faba bean lines using AFLP markers. Theor Appl Genet 107(7):1304–1314
Zheng ZJ, Wang SM, Zong XX (eds) (1997) Food legumes in China. China Agriculture Press, Beijing, pp 53–92
Zong XX, Bao SY, Guan JP et al (2006) Descriptors and data standard for faba bean (*Vicia faba* L.). China Agriculture Press, Beijing, pp 1–70
Zong XX, Liu XJ, Guan JP et al (2009) Molecular variation among Chinese and global winter faba bean germplasm. Theor Appl Genet 118(5):971–978
Zong XX, Ren JY, Guan JP et al (2010) Molecular variation among Chinese and global germplasm in spring faba bean areas. Plant Breed 129:508–513
Zong XX, Yang T, Liu R (eds) (2019) Food legumes guidance. China Agricultural Science and Technology Press, Beijing, pp 4–9