Faba Bean in China: State-of-the-art Review

Special Study Report

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International Center for Agricultural Research in the Dry Areas

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Preface

Faba bean has a long production history in China. It is extensive in distribution, plentiful in germplasm resources and varied in cultivation pattern. Much valuable experience has been accumulated by the farmers and agricultural scientists. Since the establishment of the People's Republic of China, the government has paid a lot of attention to faba bean research. In the last 10 years, germplasm resources, breeding of new varieties, cultural practices and basic theoretical research of faba bean were included in the State Research Plans. These back up the development of faba bean production technically. Although the growing area of faba bean has been reduced on a large scale since the 1960s because of overpopulation, limitation of land and increase of crop index, the yield per unit area has increased because of the cultivation of recommended varieties, adoption of better cultural techniques and higher input. The area planted to faba bean in some provinces and municipalities, on the other hand, has been gradually enlarged. Therefore, the planting area and total output of faba bean in China still account for half of the world's total. The yield per unit area is also above the world's average.

With support and aid from the International Center for Agricultural Research in the Dry Areas (ICARDA), this book—Faba Bean in China: State-of-the-Art Review—was written and edited. The book looks systematically on the development history of faba bean in China, as well as the production technology, theoretical research, germplasm resources, genetics and breeding, cultivation, diseases, insect pests and utilization.

A special debt of gratitude is owed to the leaders and researchers from the Zhejiang Science Committee, the Crop Institute and the Information Institute of Zhejiang Academy of Agricultural Sciences. Their generous help enabled publication of the book in a short time. Acknowledgement should also be given to Dr M.C. Saxena from ICARDA for his numerous suggestions. Finally, sincere gratitude is extended to the scientists of the Germplasm Resource Institute of the Chinese Academy of Agricultural Sciences, Yunnan and Qinghai Academy of Agricultural Science, Linxia Institute of Agricultural Science for their help, as well as Zheng Kangle, Chen Jianping, Wang Aimin, Li Shaoxiong, Yang Changdeng, Zhuang Jieyun, Zhu Ge, Gen-Zhang and Min Li for their strenuous efforts in translating the book from Chinese to English.

The English edition of this book will be the first specialized work that introduces foreign readers to the production, technical and scientific research of faba bean in China. It is hoped that it will play a role in the promotion of international knowledge exchange and cooperation in research. In compiling the book, deficiencies were unavoidable. Any criticism or suggestion will be appreciated.

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Chapter 1. General Survey

The Origin and Spread of Faba Bean

Faba bean (*Vicia faba*) is a cultivated species belonging to the wild pea genus (*Vicia*) of the Leguminosae family. There are different opinions on its origin: *V. faba* Major may have originated in North Africa, and *V. faba* Minor at the south of the Black Sea in Asia, but Long *et al.* (1989) believed that faba bean originated from the Far East. From there it was spread with the development of culture and commerce to: 1) Europe, 2) along the coast of North Africa to Spain, 3) along the Nile River to Ethiopia, where it had its secondary center of origin, and 4) from Mesopotamia into India. Afghanistan is also a secondary center of origin. However, Vavilov (1936) of Soviet Russia discovered a primitive type of faba bean with small pods and seeds at the intersection of Himalaya and Hindu Kush, and proposed that faba bean originated from Central Asia. He found that there was a gradual increase in the faba bean's size from Central Asia westward along the mountains to Iran, Turkey, the Mediterranean and Spain. Because faba bean in Sicily and Spain was seven to eight times larger than that in Kabul, Afghanistan, he concluded that areas along the coast of the Mediterranean Sea and Ethiopia should be the secondary origin of faba bean. Later, some scientists (Anonymous 1980; Li 1984) believed that faba bean originated from Central Asia (30-40°N), with Kabul, the capital of Afghanistan, as the center.

Faba bean was originally known as "hu dou" in China. According to the Chinese Agronomy Legacy by Li (1958), records in the "Tai Ping Reign-Period Imperial Encyclopedia" of the Song Dynasty (960 to 1279 A.D.) indicated that faba bean was introduced into China during the West Hun Dynasty (Hun Dynasty 206 B.C. to 219 A.D.), when Zhang Qian brought back the hu dou" from abroad, where he visited as an envoy. The Encyclopedia also recorded that "now it is found all over the country, especially in central Sichuan, where people still call it hu dou." This indicates that the cultivation of faba bean in China has a 2000-year history. The name "faba bean", however, did not appear until the Song Dynasty. It can be found in the "Gazetteer of Yi Du" by Zhu (1057) and the "Illustrated Pharmacopoeia" by Su (1061). The plant form and cultivation method of faba bean described in these two books are in complete accordance with that of the present. However, in the Li Jiang River Basin of Yunnan Province, there is a local variety of faba bean called the 'La Shi Quing Bei Dou', which is claimed to have a long history of cultivation. Furthermore, there are wild faba beans in Bin Chuan. Therefore, the origin of faba bean needs further study.

Faba Bean Production in China Versus the World

China is the largest faba bean producer in the world. Its faba bean acreage dropped from

60% of the world's total before the 1980s to 50% in recent years. The yield of faba bean per unit area in China is close to that of the average yield in the world, and China's total output is 50% of the world's total production (Table 1). Thus, any fluctuation in the production of faba bean in China affects the world's faba bean production.

Development and Status of Faba Bean Production in China

Brief Review of Development

It was in the 1950s that China's faba bean cultivation area reached its peak of nearly 2.7 million hectares with a total output of 3 million tonnes and an average yield of 1125 kg/ha. After the 1960s, with the reform of farming systems, especially the development of the triple-cropping system in the southern rice-growing area, the old spring grain of the single rice-cropping system was gradually replaced by the new triple-cropping system: spring grain (rapeseed) and double crops of rice. With the success and popularity of the early maturing crops like barley and rapeseed, the cultivated area for faba bean continually declined. In the seven main provinces (Yunnan, Sichuan, Hubei, Jiangsu, Zhejiang, Shanghai, Qinghai) for faba bean production, the crop occupied 1.48 million hectares in the 1950s, but by the mid-1980s, the area had dropped to 780 000 ha. In Zhejiang Province, the growing area was between 100 000 and 190 000 ha before 1956, with a peak of 191 000 ha in 1952, accounting for 20-25% of the cultivated area for spring grain. In the 1970s, however, the area dropped to 80 000 ha, and in the mid- and late-1980s it was about 60 000 ha, which was about 10% of the total area for spring grains.

To compare China's faba bean production with that of the world, data are quoted from the FAO Production Yearbooks (Table 2). Although some figures are estimates, we can still see the trend of development.

Table 2 shows that from 1969 to 1971 the average faba bean harvesting area was 3.597 million hectares, but in 1988 it was 1.7 million hectares. This represents a decrease of 1.897 million hectares, i.e. 52.7%. In the same period, the harvesting area of faba bean in other countries fell from 1.799 to 1.571 million hectares. The decrease was only 228 000 ha, i.e. 1.3%. Obviously, the sharp decrease in the harvesting area of faba bean in China is the main reason for the decrease of the world's production area for this crop.

The main reasons for the rapid decrease of cultivated faba bean area in China are as follows: first, the improvement of varieties cannot keep up with the reform of faiming systems. With the increase of the multiple crop index, early and medium maturity varieties of autumn-sown crops like barley, wheat, rape and faba bean must be grown after the two crops of rice so that a high annual yield can be secured. Unfortunately, the growing period for faba bean is so long that it cannot be adapted to the reformed farming system.

Table 1. Faba bean area, yield and production in the main faba bean growing countries/continents.

	Area (1000 ha)				Yield (kg/ha)				Production (1000 kg)			
	1979-81	1986	1987	1988	1979-81	1986	1987	1988	1979-81	1986	1987	1988
The world	3685	3213	3288	3271	1162	1366	1400	1443	4284	4389	4603	4720
China	2267	1700†	1700†	1700†	1161	1294	1362	1382	2633	2200†	2316†	2350†
Ethiopia	327	260†	360†	360†	1458	1444	1333	1500	476	520†	480†	540†
Morocco	165	196	211	207	560	1096	603	1123	97	215	127	232
Egypt	103	129	136	140†	2134	3474	3666	3571	219	448	499	506
Europe	354	294	318	297	1355	1870	2111	2070	480	811	672	614

Source: FAO Production Yearbook Vol. 42 (1988).
† = estimate.

Table 2. Trend of faba bean production in China and the world.

	China			The world		
Year	Area (1000 ha)	Yield (kg/ha)	Production (1000 kg)	Area (1000 ha)	Yield (kg/ha)	Production (1000 kg)
1975	3840	1133	4350	5478	1131	6156
1976	3900	1128	4400	5492	1133	6225†
1977	4000	1113	4450	5534	1103	6101†
1978	5300	1019	5400	6823	1026	7000
1979	5400	1174	5500	6900	1017	7017
1980	2300	1136	2700	3705	1180	4373
1981	2200	1136	2500	3540	1138	4028
1982	2250	1156	2600	3699	1142	4274
1983	1920	1198	2300	3311	1198	3966
1984	1800	1347	2425	3258	1321	4302
1985	1700	1353	2300	3155	1321	4170
1986	1700	1294	2200	3213	1366	4389
1987	1700	1362	2316	3288	1400	4603
1988	1700	1382	2350	3271	1443	4720
1969-71	3597	1020	3670	5396	1056	6655
1974-76	2300	1058	2433	3886	1070	4156
1979-81	2267	1161	2633	3685	1162	4284

Source: FAO Production Yearbooks.
† = estimate.

Second, its yield is neither stable nor high, and the potential for yield increase is low. During the 1950s, in Zhejiang Province, the yield of faba bean per unit area was higher than that of barley and wheat, with the average yield reaching 645 kg/ha. In 1985, faba bean yield had risen to 2145 kg/ha. On average, it increased by 43.4 kg/ha annually, but wheat increased by 67.5 kg/ha and barley 73.5 kg/ha.

Third, the progress of scientific technology is slow. There are few new varieties, and improvement in cultural techniques is slow. Nowadays, even the conventional varieties and traditional practices of cultivation are still being used in many regions.

Fourth, the economic value of faba bean is relatively low, because of inadequate processing and utilization options. All these reduce the enthusiasm of farmers for growing faba bean.

Faba Bean Producing Regions in China

China has a vast faba bean cultivated area, which extends from the Da Xing An Range in Inner Mongolia in the north to Tibet in the southwest, from Xinjiang in the northwest to Guangdong in the south, and from the Lassa River Valley at 3800 m above sea level to the coastal areas in the southeast (Fig. 1). Based on latitude, elevation, length of growing season, cropping systems, methods of cultivation and the characteristics of varieties, faba bean planting areas in China can be clearly classified into two mega-environments: the southern autumn-sown region and the northern spring-sown region (Fig. 2). There are also areas where faba bean is not adapted. The autumn-sown faba bean region can be divided into three subregions: 1) middle and lower Yangtze River Basin, 2) southwestern China, and 3) southern China. The spring-sown faba bean region can be further divided into four subregions: 1) areas along the Great Wall, 2) western Loess Plateau, 3) foothills of the Qingling and Tianshan Mountains, and 4) Qinghai-Tibet Plateau.

Li (1989) conducted a study on faba bean production in China based on sowing time, accumulative temperature ($\geq$ 7.5°C) during the growing period, the annual mean temperature, average temperatures in January and July, natural and production conditions, and geographic proximity. By using the fuzzy-cluster analysis, he divided China's faba bean production areas into 2 megaregions, 6 regions and 11 subregions.

Autumn-sown production region

This is the main faba bean producing region in China. It includes Yunnan, Sichuan, Hubei, Hunan, Jiangsu, Shanghai, Zhejiang, Anhui, Fujian, Guangdong, Guangxi, Guizhou and Jiangxi Provinces of the southern half of China. This region occupies about 90% of the total faba bean area and provides over 80% of the total Chinese production. The region is diverse in latitude, elevation, temperature and precipitation.

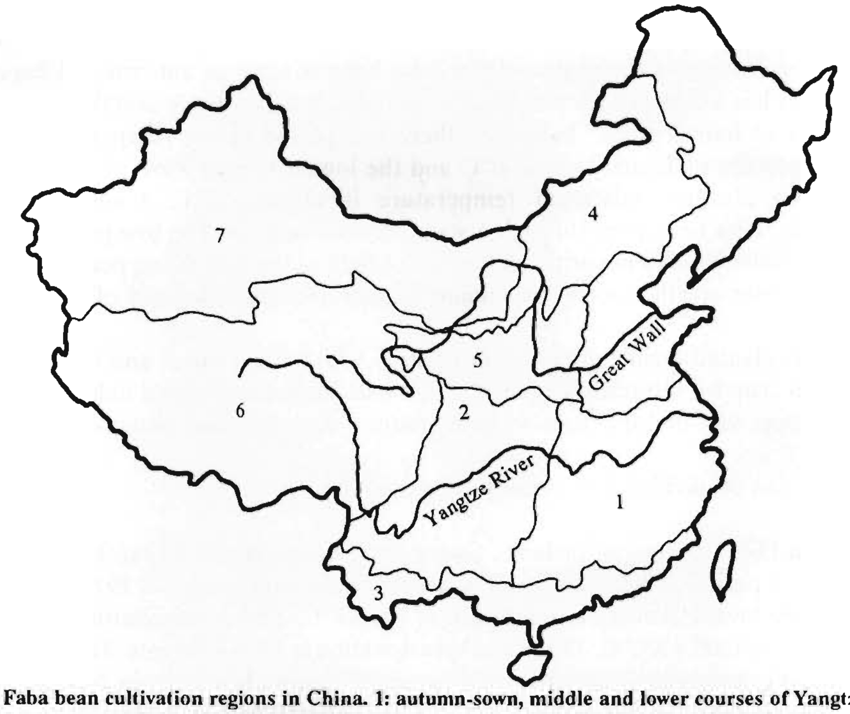

Fig. 1. Faba bean cultivation regions in China. 1: autumn-sown, middle and lower courses of Yangtze River; 2: autumn-sown, southwest China; 3: autumn-sown, south China; 4: spring-sown, along the Great Wall; 5: spring-sown, west of Loess Plateau; 6: spring-sown, Qinghai-Tibet Plateau; 7: spring-sown, Qilianshan-Tianshan foothills.

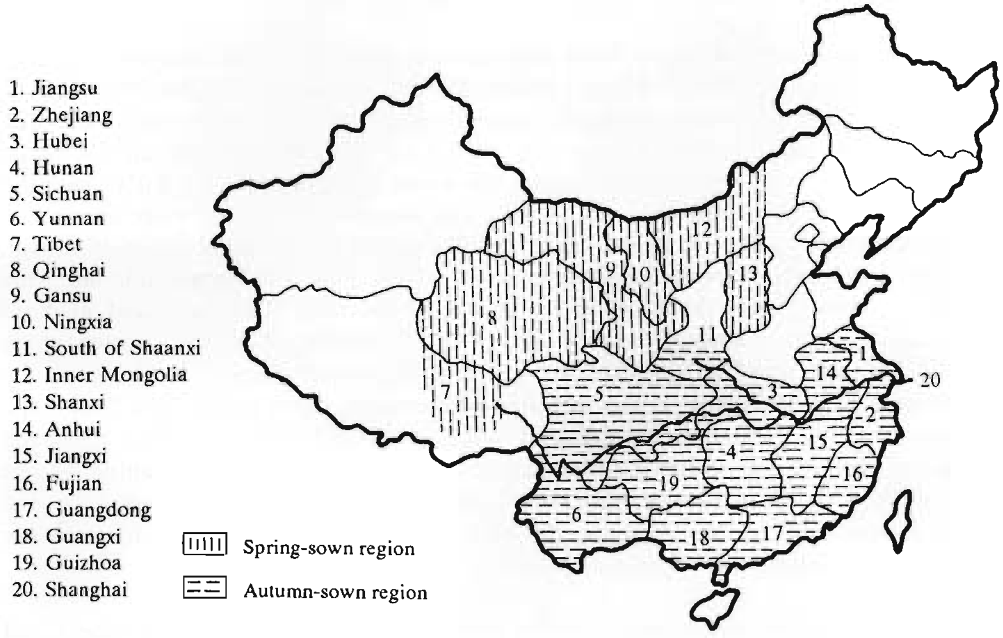

Fig. 2. Distribution of spring- and autumn-sown faba bean crops in China.

The common feature of the region is that faba bean is sown in autumn and harvested in summer. It has a long growth period of > 200 days. It is popularly said that "faba bean drinks water of four seasons." In winter, there is a period of low temperatures with a mean temperature in January above 0°C and the lowest temperature of -3 to -7°C on average. The absolute minimum temperature is above -10°C. Under these low temperatures, faba bean goes through a stage of vernalization. The low precipitation in autumn, excessive rainfall in spring, deficiency of light in the pod-filling period, and frost damage in winter are the factors explaining the low and unstable yield of faba bean.

Faba bean is planted mainly after rice in rotation with barley, wheat and rape. It is also the principal crop for intercropping with cotton and linseed in rain-fed fields. It is a soil-improving crop with multiple uses as grain, fodder, vegetable and manure.

This region can be divided into three subregions:

1. Southern Hilly Subregion: includes Guangdong, Guangxi and Fujian Provinces with a frost-free period of 300-325 days. The annual mean temperature is 19.6-21.8°C, with an average lowest January temperature of 7.6-9.7°C. The accumulative temperature above 5°C is 1300-1500°C. The annual precipitation is 1300-1694 mm. However, since faba bean is grown in the dry period, it needs irrigation. It is sown in November and harvested in April the following year with a total growth period of 140-160 days. Early ripening semi-dwarf varieties like 'Tudouzai', 'Laxing 73' and 'Guangpu No. 3' are grown. The rotation is rice with faba bean/barley.

2. Middle and Lower Yangtze River Subregion: includes Shanghai, Zhejiang, Jiangsu, Jiangxi, Fujian, Anhui, Hubei and Hunan Provinces between latitudes 28 and 30°N. This is one of the main production regions, taking up 37.4% of the total faba bean production area. It has a frost-free period of 220-280 days. Its annual mean temperature is 11.5-17.5°C. In January, the mean temperature is 2.0-5.0°C, with the lowest mean temperature of -1.2 to 2°C. The accumulative temperature above 5°C of the growth period is 1200-1300°C and the annual precipitation is 988-1596 mm. Faba bean is sown from mid-October to early November and harvested in late May the following year; the growing period is 200-230 days. The early and medium maturity varieties such as the well-known 'Cixi Dabaican', 'Tianjiqing', 'Sunbaidou', 'Quingyidou' and 'Xiaoqingdou' are grown. The sowing rotation is rice with faba bean/barley. In Hunan, Hubei and Jiangxi Provinces, there is also faba bean/rape and faba bean/wheat intercropping. It should be noted that Nantong and Yancheng areas in the north of Jiangsu Province, located at the margin of the autumn-sown region, are comparatively different with relatively low temperatures. In the dendrogram of cluster analysis, the two areas are grouped alone, forming the Northern Jiangsu sub-subregion.

3. Southwestern Hilly Subregion: includes Yunnan, Guizhou and Sichuan Provinces, and the Jiangzhong Prefecture of Shanxi Province. This is also one of the main production regions with 42.1% of the total faba bean cultivated area in China. It has 220-300

frost-free days with an annual mean temperature of 14.7-16.2°C. In January, the mean temperature is 4.9-7.7°C, with the lowest average of 1.4-2.4°C. The annual precipitation is 947-1174 mm. Faba bean is sown in October and harvested in May with a growth period of about 210 days. Early and medium maturity varieties such as 'Chenghu No. 9', 'Kunming Baipidou', 'Xiangyundou' and 'Fugecandou' are grown. Crop rotation is rice with faba bean. Faba bean may also be intercropped with wheat.

The Jiangzhong Prefecture in Shanxi Province has a slightly lower temperature than Yunnan, Guizhou and Sichuan Provinces, but the production conditions are similar to those in Sichuan Province. It is classified as Jiangzhong sub-subregion.

Spring-sown production region

This region is vast, including Gansu, Inner Mongolia, Qinghai, Shanxi, Shaanxi and Ningxia Provinces, and Tibet Autonomous Region. The area under faba bean cultivation is only about 10% of the total sowing area but its yield per unit area is relatively high. Thus it contributes about 14% of the national faba bean output. Gansu, Inner Mongolia, Qinghai and Shanxi have relatively concentrated faba bean areas, and so have Tibet, Shaanxi and Ningxia.

The common features of this region are: there is only one single crop each year, and if faba bean is planted, it is sown in spring (March or April) and harvested in autumn (August). Despite the short growing season, it can still go through vernalization at a relatively high temperature, and blossom and set pods under mild temperatures. Furthermore, the daylength is long and intensity of illumination is strong, conditions that are quite favorable for seed development. Therefore, faba bean yield is relatively high and stable.

This region can be divided into three subregions:

1. Southwestern Gansu and Qingzang Plateau Subregion: the production area of the large-seed type of faba bean. It includes Tibet, Qinghai, Southwestern Gansu and the Longzhong area between latitudes 34-37°N and 1500-4300 m above sea level. Its annual mean temperature is 5.7-9.1°C, and the mean temperature in July is 15.1-23.5°C. The cumulative temperature (≥ 5°C) of the growth period is 1300-1500°C. The annual precipitation is 277-445 mm. It has 100-180 frost-free days and 2600-3000 hours of sunlight. Faba bean is sown between mid-February and early April, and harvested in August or September, with a total growth period of 150-180 days. Varieties such as 'Linxia Maya', 'Huangyuan Maya', 'Lassa No. 1', 'Qinghai No. 3', 'Drodaidou', 'Shenglicandou' and 'Hezhengcandou' are selected for production. The crop rotation is faba bean/wheat or faba bean/wheat/wheat.

2. Northern Inland Subregion: includes Inner Mongolia, Hebei, Shanxi, Ningxia, Hetao area and the Gansu Hexi Corridor between latitudes 38°N and 44°N. It extends along both sides of the Great Wall at 800-1600 m above sea level. Its annual mean temperature is 5.8-12.9°C, and the mean temperature in July is 21.9-26.6°C. The

accumulative temperature (≥ 5°C) of the growing period is 1700-1900°C. Annual rainfall is 203-550 mm unevenly distributed. The Gansu Hexi Corridor gets a total rainfall of less than 100 mm. Faba bean is sown between mid-March and mid-May, and harvested in July or August with a total growing period of 97-130 days. The varieties used in production are 'Damaya' and 'Dabanmaya'. This area is also further divided into the Great Wall district, the Hetao district and the Gansu Hexi Corridor district.

3. Northern Xinjiang Subregion: includes the areas to the south and north of Tian Shan Mountain in Xinjiang Autonomous Region with a continental dry and semi-arid climate. Wheat and maize are the dominant crops. The planting area of faba bean is relatively small. Its annual mean temperature is 5.6-13.9°C, and the mean temperature in July is 23.5-32.7°C. The annual average precipitation is 16-278 mm.

Based on the study of faba bean production by Li (1989), there is no cultivation of faba bean in places where the mean temperature is < 0°C in January and > 24°C in July, no matter what the elevation or latitude are. Areas where the mean temperature is > 0°C in January belong to the autumn-sown region, and areas with the mean temperature < 0°C in January and < 24°C in July are considered to be in the spring-sown region. In China, the demarcation of the spring-sown region in the north and the autumn-sown region in the south is at 33-34°N (33°N in the west and 34°N in the east). The Qinling Mountains and Huai River form the natural demarcation. West of this demarcation, the elevation is higher, and it decreases toward the east. Strictly speaking, the Yangtze River Valley is an autumn-sown area, but the Zhujiang River Valley in southern China is a winter-sown area. In Yunnan Province, there are high mountains and plateaus, deep valleys and low plains, with different climates. Therefore, faba bean can be seen in almost every season. The spring-sown region extends from the middle of Liaodong Peninsula northwestward along the Great Wall, Jibe, Shaanbe, the border area of Shaanxi and Gansu, and western Sichuan, and ends in Yunnan. Areas north and west of this region where summer is hot, winter is severely cold and long, and spring and autumn are too short, are not suitable for faba bean growing.

Based on the abovementioned study, the division of faba bean production areas in China is similar to the ecotypic division of faba bean germplasm (CAAS 1984; Anonymous 1987).

Production Potentials and Developmental Prospect of the Main Production Areas

Although faba bean is widely grown in China, the main production area is relatively concentrated. The autumn-sown crop is mainly concentrated in Yunnan, Sichuan, Hubei, Hunan, Jiangsu, Zhejiang and Guangdong Provinces, and the spring-sown crop is grown mainly in Gansu, Inner Mongolia and Qinghai Provinces. In each province, there are concentrated cultivation areas as well. Yield per unit area in the spring-sown region is higher than that in the autumn-sown region. According to statistics of 1985, the average yield in the spring-sown region reached 2255 kg/ha. Shanxi and Inner Mongolia gave the highest yields, 3150 kg/ha and 3000 kg/ha, respectively. In the autumn-sown region, the average yield is 1642 kg/ha. Jiangxi, Shanghai and Zhejiang Provinces were among the highest, reaching 2820, 2625 and 2160 kg/ha, respectively.

In both the spring-sown and autumn-sown regions, there were some extraordinary examples of high yield. In Cixi, Zhejiang Province, the average yield reached 3840 kg/ha for 6666 ha in 1988. In Qidong, Jiangsu Province, the average yield was 3988 kg/ha for 19 500 ha in 1978. In Kunming, Yunnan Province, the average yield was 4800 kg/ha for 20.5 ha. In 1980, Gonghe County in Qinghai Province achieved the highest record so far for faba bean yield in China by sowing 70-74 new varieties. The average yield reached 9700 kg/ha for 0.08 ha (Cheng 1984). These figures indicate that there are great potentials for the increase of faba bean production.

The major areas of faba bean production mainly concentrate in the southern paddy-growing region where there are dense populations and limited arable land with the multiple crop index reaching above 200%. These are also the high yield areas for rice and other cash crops. Because of the long growth period, insufficient new varieties and the sluggish improvement in cultivation techniques, faba bean lacks the potential to compete with other major crops. As a result, the cultivated area for faba bean has decreased rapidly. Since the 1980s, with the exception of Yunnan, Gansu and Qinghai Provinces, where faba bean acreage has recovered, the areas under faba bean production continue to drop in other provinces. According to preliminary statistics from seven provinces, including Jiangsu, Zhejiang, Shanghai and Sichuan, the area under faba bean in the mid-1980s was 780 000 ha, which was just half of that in the 1960s. Clearly, in most regions the increase of total faba bean output cannot depend on the increase of cultivated areas. New varieties and improvement in cultural practices are needed to increase yield per unit area. Meanwhile, attention should be paid to the utilization and processing of faba beans to raise its economic value.

First, headquarters should be set up in all the main faba bean production areas to provide leadership, revolutionize production and popularize the new varieties and new techniques.

Second, breeding and introduction of new and improved varieties should be speeded up. During the "8th Five-Year Project," scientific research should be carried out to help speed up the breeding of new varieties based on germplasm collection and selection from local varieties done in the "7th Five-Year Project." New and better varieties can also be obtained by various means such as crossbreeding and mutation breeding. These new varieties need to be adapted to different ecotypic areas, be resistant to diseases and have high yield to replace the old local ones. This is the most economical and effective means to increase total faba bean output.

Third, input should be greatly increased, and cultivation techniques be improved. Input mainly refers to fertilization. Fertilizer application techniques should be improved, and special attention be given to the application of phosphorus, potassium and trace elements. Meanwhile, based on the characteristics of the new varieties and the ecological conditions of different areas, one should sow at the optimal time with the proper planting density and cultivation practices, in order to increase the present average yield of 1000 kg/ha to above 1500 kg/ha.

Fourth, food and fodder industries should be developed using faba bean as the raw material. Not only should the conventional products of faba bean be improved, the development of new products, such as faba bean protein, starch and fibrous powder should be carried out. Attention should be given to the composite use of faba bean to increase its economic value and demand.

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Chapter 2. The Status and Role of Faba Bean Production

Faba bean plays an important role in the national economy and agricultural production because of its high nutritional value and various ways of utilization.

The Nutritive Value of Faba Bean

People in China obtain their protein intake mainly from leguminous crops. Faba bean contains about 30% protein (twice as much as that of cereals), and some varieties even reach over 40%. Among the edible leguminous bean crops, it is next to soybean in terms of protein content. Faba bean protein contains the eight essential amino acids that the human body cannot synthesize. Except for tryptophan and methionine, the contents of the other six amino acids are high, especially lysine, which is twice as high as that in cereal grains. In terms of flour, lysine content is four times as high. Therefore, faba bean is being recommended as a new source of plant protein, and is receiving attention in some European and African countries. The vitamin content in faba bean is higher than that of rice and wheat too. Tables 3, 4 and 5 compare the nutritive values of faba bean with other staple cereal crops (Majie 1982; Liang 1988).

Table 3 shows that faba bean is a leguminous crop rich in starch, high in protein and low in fat. The total amount of the eight essential amino acids in faba bean is 3.3 times that in wheat, and 2.95 times that in maize (Table 4). Its lysine content is 7.7 times that of wheat and 6.4 times that of maize, and surpasses the content in meat.

Duan (1988) compared the amino acid content in faba bean protein powder with the composition recommended by FAO/WHO in 1973. Faba bean contains sulfur amino acid (methionine + cystine) and tryptophan, which are only 55.1-56.8% and 80.1-58.2% of the FAO/WHO amounts, respectively (Table 6). In order to make up for these deficiencies, faba bean can be cooked with other ingredients in meal preparation. This allows the different ingredients to complement each other, making the amino acid composition more similar to that required by human bodies, and thus raising the utilization efficiency of the available protein.

Table 3. Comparison of nutritive values of some crops (units/100 g).

Crop	Protein (g)	Fat (g)	Carbo-hydrate (g)	Calorie	Calcium (mg)	Phos-phorus (mg)	Iron (mg)	Thia-mine Vit. B1 (mg)	Ovo-flavin (mg)	Nicotinic acid (mg)
Rough rice	9.0	2.0	75	354	84	290	2.0	0.35	0.09	3.5
Wheat flour	9.9	1.8	75	356	38	268	4.2	0.46	0.06	2.5
Yellow maize	8.5	4.3	73	365	22	210	1.6	0.34	0.10	2.3
Soybean	36.3	18.4	25	411	367	571	11.0	0.79	0.25	2.1
Pea	34.6	1.0	58	239	84	400	5.7	1.02	0.12	2.7
Faba bean	28.2	0.8	49	316	71	340	7.0	0.39	0.27	2.6

Source: He Weinong (1981). Statistics Used in Agriculture. Agricultural Publishing House.

Table 4. Essential amino acid content in some crops (units/100 g).

Crop	Dry matter (g)	Crude protein (g)	Total amino acid (mg)	Lysine (mg)	Trypto-phan (mg)	Methio-nine (mg)	Thero-nine (mg)	Valine (mg)	Leucine (mg)	Isoleu-cine (mg)	Phenyla-lanine (mg)
Wheat flour	87	10.7	2.94	0.26	0.12	0.15	0.33	0.45	0.76	0.38	0.49
Maize	88	8.4	3.29	0.31	0.07	0.15	0.37	0.42	1.27	0.28	0.42
Soybean	88	37.9	13.66	2.29	0.46	0.41	1.65	1.80	3.63	1.61	1.80
Pea	82	20.9	7.47	1.94	0.21	0.17	0.79	1.02	1.48	0.92	0.94
Faba bean	87	31.0	9.71	2.00	0.21	0.17	1.27	1.38	2.40	1.06	1.22

Source: Food and Health Institute of Chinese Academy of Medicine (1977).

Table 5. Comparison of lysine content in some crops.

	Lysine content			
	Grams/100 g protein	% WHO† formula	Grams/100 g flour	% maize flour
Rice	3.20	58	0.27	79
Wheat	2.80	51	0.34	100
Maize	3.00	55	0.34	100
Faba bean	6.63	121	1.50	441
Pea	6.79	123	1.56	459
Green lentil	6.80	124	1.58	465

† World Health Organization recommended formula.
Source: Acta Crops Science (1988).

Table 6. The comparison of amino acid content in faba bean protein powder with the composition recommended by FAO/WHO.

	Amino acid content (mg/g protein)		
Amino acid	Refined faba bean protein powder	Crude faba bean protein powder	Recommended by FAO/WHO
Histidine	28.61	29.08	30
130 Leucine	51.57	50.28	40
Leucine	93.96	85.18	70
Lysine	71.39	71.29	55
Methionine + cystine	19.28	19.88	35
Phenylalanine + tytosine	96.02	93.80	60
Treonine	39.63	40.34	40
Tryptophan	8.01	5.82	10
Valine	53.94	51.97	50

The Role of Faba Bean in the National Economy

Faba Bean as a Staple Food and as the Raw Material for Manufacturing Food Items

Faba bean can be taken as a staple food as well as a subsidiary food. Agronomist Xu Guangqi (1562 to 1633) in the Ming Dynasty evaluated faba bean as "the best of all crops and it can meet the urgent needs of farmers" because it can be cooked for food or fried to serve with tea. In the Qing Dynasty (1644 to 1911), the "Picturesque Reference Book of Plants" suggested that "green faba bean can be taken as vegetable, and ripe seeds can be cooked with rice, or ground into flour or parched as nuts, or mixed with wheat to make pudding cake." Even today, faba bean is still one of the main staple foods in the border zone of China. It is also one of the principal summer grain crops in the southern paddy-growing area. As staple food, faba bean can be mixed with flour and maize flours to make into various kinds of noodles and the mixture of faba bean flour and wheat flour can be processed into delicious and nutritious bread (Li 1958).

Faba bean is a good raw material for manufacturing a great variety of traditional subsidiary food items such as vermicelli, noodles, soy sauce, pepper sauce, protein powder, starch, fibrous powder, Wuxiang bean and Lanhua (orchid) beans. Apart from these, it also can be processed into other nutritious food items by means of technology and the productive value is 3-5 times as much as that of the primary product. A faba bean processing industry of bilateral relationship has been set up between Qinghai county in Gansu and Shanghai, and between Ming county and Sichuan Province. In Maji village of Kangle county, the amount of faba bean being processed into noodles has reached 2 million kg annually, which is about 1/4 of the total output of faba bean in this country.

The Importance of Faba Bean as a Fodder Crop

The use of faba bean as fodder has had a long history in our country. As early as in the Northern Song Dynasty (960 to 1279 A.D.), Su (1061) in the "Illustrated Pharmacopoeia" recorded that faba bean was "good for feeding cattle and horses" and "its leaves can be used for feeding livestock." According to recent research, protein in faba bean for pigs reaches 80.14% (the digestive rate). It is higher than that of wheat, maize and sweet potato. The digestive rate per kg is 2.76 times that of wheat, 5.5 times that of maize and 4.8 times that of sweet potato. A recent survey (Liu *et al.* 1989) shows that a hectare of faba bean is enough for raising 10-15 pigs or 1-2 dairy cows that produce 15 kg of milk/day. If faba bean seed is used with other cereal fodder crop, the conversion rate of the fodder can be significantly increased. The stems, leaves and pods after harvesting and the residue dregs after food processing can be a good quality fodder for livestock.

From the analysis by the Institute of Animal Science and Chinese Academy of Agricultural Science, it is found that the protein content in faba bean stems and leaves is 6.0-17.6%. The Agricultural Bureau at Long Chang county, Sichuan province, carried out an experiment by ensiling the fresh faba bean seedlings in plastic bags, which helps to dispel the bitter and astringent taste and make them more appetitizing and digestible for the pigs and cows (Long 1989). If it is used to feed dairy cows, it can raise the milk output (Long 1989). Also, according to the survey done by Yang (1989) at the Dali Institute of Agricultural Sciences, Dali, Yunnan Province, the faba bean stems, leaves, dry straw and leaf chaff (grown in fields with straw and weeds) from the 0.13 ha high-yield land or 0.3 ha medium-yield land had an average yield of 4500 kg/ha in the You Suo district, Wen Van county. Here faba bean is fed to the dairy cattle, who give 10 kg of milk daily and its output value is about 2.87 times that of the primary product of faba bean (including the planting of faba bean and manual labor involved in rearing cattle). In recent years, the area for faba bean cultivation has increased from 1327 ha in 1979 to 1647 ha in 1983, and the number of dairy cows increased from 1876 head in 1979 to 5507 in 1983.

Faba bean as fodder should be used together with other cereal fodder and their proper ratio should be kept. According to the research by Fu *et al.* (1987) the ratios of 18, 22 and 26% of faba bean were added, compared with the basic ration. The result showed that additions of 22 and 26% faba bean are the best in terms of the daily increase of weight per pig, as well as feed conversion efficiency and lean meat percentage. Faba bean is highly digestible and has a high crude protein content. If used as fodder, it can increase the weight of pigs quickly and yet the amount of fat content is lower. The best ratio of faba bean as fodder to raise pigs is no more than 20% before they are 60 days old and can increase up to 26% during the "fattening period."

The Export of Traditional Products for Foreign Exchange

Among the exported agricultural products, some well-known faba bean varieties and well-processed faba bean products have a good market; for example, Huang Yuan 'Maya' from Qinghai, Linxia 'Maya' from Gansu and Cixi 'Dabaican' from Zhejiang. They are not only exported to Southeast Asia and Japan, but also to Kuwait, Lebanon, Egypt, France, Italy, Australia and Canada. In Qidong county, Jiangsu province, faba bean varieties and processed products reached over 70 000 tonnes in recent years. They have become one of the main products for export to obtain foreign currencies. However, faba bean export from China has various limits and setbacks, such as the decrease in cultivated area and poor handling. For instance, in 1959, the exportation in Gansu Province reached 25 000 tonnes, but in the 1970s it fell to several thousand tonnes. Only in recent years has the export amount gradually increased with the recovery of production and the control of diseases. At present, the export amount is about 10 000 tonnes.

Faba Bean as an Important Vegetable Crop

There is a custom of using green faba bean as a vegetable in China. The fresh green faba bean is rich in nutrition, delicious in taste and low in cost. It is a good dish in early summer. The famous dish "Southern Cherry Meat" in the South of China is made from pork chop strips with faba bean, cooked in red wine yeast and then garnished with cherries before serving. The poet, Yang Wanli, in the Southern Song Dynasty (960 to

1279 A.D.), had 132 descriptions of the pleasant flavor and color of the green faba bean in the poem "The Ode of Faba Bean." According to recent scientific analysis (Li 1958), the green faba bean contains protein, sugar, various minerals and vitamins (Table 7). Apart from being used as a fresh vegetable, green faba bean can be frozen and canned for export.

"Bean sprouts" are faba beans soaked in water for 1-2 days for germination; then the testa are removed before cooking with other ingredients. This is cheap and handy for all seasons. The bean sprouts also can be processed to become "Lanhua Bean" after deep frying in oil or cooked to become "Wuxiang Bean." The bean sprout is one of the earliest water-cultivated vegetables in China.

Table 7. The nutrient content of faba bean.

	Green bean	Bean sprout
Water (g)	77.10	63.80
Protein (g)	9.00	13.00
Fat (g)	0.70	0.80
Carbohydrate (g)	11.70	19.60
Energy (large calorie)	89.00	138.00
Crude fibre (g)	0.30	0.60
Ash (g)	1.20	2.20
Calcium (mg)	15.00	109.00
Phosphorus (mg)	217.00	382.00
Iron (mg)	1.70	8.20
Carotene (mg)	0.15	0.03
Vitamin B1 (mg)	0.33	0.17
Vitamin B2 (mg)	0.18	0.14
Vitamin C (mg)	12.00	7.00

Source: Health Institute of Chinese Academy of Medicine (1981).

The Medical Effects of the Faba Bean Crop

The medical effects of the faba bean crops were long ago recorded in China. Wang (1621) said in his book "Assembly of Perfumes" that faba bean "has a sweet-bitter taste." It can soothe the stomach and internal organs and ease unpleasant feelings caused by alcoholism. According to the research of medical science (Fu 1990), the seed, stems, leaves, seedcoat, flowers and pod shells have medical effects. They are mainly for invigorating the spleen, promoting diuresis to eliminate wetness-evil, treating dropsy, hemostasis, stopping diarrhea and having some antineoplastic effect.

Some people who eat faba bean may develop favism disease, symptoms of which may start appearing 5-24 hours after the consumption of faba bean. This disease develops only in humans who have congenital deficiency of enzyme glucose-6-phosphate dehydrogenase in erythrocytes (red blood cells). It is believed that favism is caused by vicine present in faba bean seed, which causes oxidation of reduced glutathione in erythrocytes in the absence of glucose-6-phosphate dehydrogenase, thus leading to hemolytic anemia. The rate of this illness varies from region to region and race to race. In China, this problem occurs occasionally when people eat the green faba bean in late spring and early summer. It is advisable not to eat uncooked fresh faba bean. For dry faba beans, it is better to soak them in water, which should be changed several times before cooking. The two traditional popular Chinese medicinal herb prescriptions for treating the abovementioned illness are: (1) Baitouweng 60 g, Chequiancao 30 g, Fengweicao 30 g, Mianyinchen 15 g. It should be decocted for 2 hours in water and then drunk as tea. (2) Tinai 60 g, Chequiancao 30 g, Fengweicao 30 g, Yinchen 15 g together with 1200 ml water decocted to about 800 ml and sugar added to taste.

The Role of Faba Bean in Agricultural Production

An Important Crop to Improve Soil

By means of nitrogen fixation, the faba bean bacteria can enrich the soil. The nitrogen-fixing capacity of faba bean varies with soil, production level and variety. According to reports, the average amount of nitrogen fixation in faba bean is 222 kg/ha, which is 195% that of soybean. It is second only to alfalfa (229.35 kg/ha). According to the analysis by the Agricultural Science Institute in Ningxia, Gansu Province (Anonymous 1980), the amounts of rapidly available nitrogen, phosphorus and potassium in the soil after the planting of faba bean were 591.3, 344.1 and 377.9 kg/ha, respectively, which were 220, 121.6 and 111.9% those of wheat. From 1978 to 1982, the Soil and Fertilizer Institute of Yunnan Academy of Agricultural Science (Anonymous 1984) carried out experiments of crop rotation (rice/wheat and rice/faba bean) in soils of high-, medium- and low-yield fields. The results show that apart from a small increase of total nitrogen and organic matter contents in the soil of the high-yield field due to the rice/faba bean rotation, there was also a significant increase in the soil of medium- and low-yield fields (Table 8). If rice and tobacco were planted after faba bean is harvested, there would be higher yield with lower input and lower cost. This experiment indicates that as a result of rotation of faba bean/rice crops, the nitrogen, phosphorus, potassium and organic matter contents in the soil are higher than that of the wheat/rice rotation (Table 9).

Besides the nodules of nitrogen-fixing bacteria, a lot of stem, leaf and root residue remained in the soil, thus increasing the organic matter content and improving the soil structure. According to the analysis by Shi (1989) of the Agricultural Board in Qidong, Jiangsu Province, the leaves, pods and roots remaining in the soil have reached 11 888

Table 8. The effect of different crop rotations on soil nitrogen and organic matter contents.

Soil yield type	Initial total N (%)	Initial OM† (%)	Wheat-rice rotation		Bean-rice rotation	
			Total N (%)	OM (%)	Total N (%)	OM (%)
Low	0.13	2.15	0.12	2.04	0.19	3.51
Medium	0.22	4.43	0.20	4.27	0.24	5.34
High	0.24	5.31	0.21	5.27	0.24	5.50

† OM = organic matter.

Table 9. The effect of crop rotation on soil nutrient content.

Rotation	Total N (%)	Total P_2O_5 (%)	OM (%)	Alkaloid N (mg/100 g)	Readily avail. P_2O_5 (ppm)	Readily avail. K_2O (ppm)
Faba bean/rice	0.304	0.15	5.94	21.4	64.3	241.0
Wheat/rice	0.243	0.13	4.35	17.1	53.8	161.6

± 2648 kg (fresh weight) and 1917 ± 350 kg (dry weight) under the production level that yields 1125 kg/ha. If faba bean is continuously cultivated for 2 years, the organic matter content in the cultivated layer is 2.034%, total nitrogen is 0.168%, readily available phosphorus is 21 ppm and potassium is 57.5 ppm. These are higher than that of a bean/wheat rotation, with an increase of the organic matter content by 8.25%, total nitrogen by 8.39%, readily available phosphorus by 110% and potassium by 3.64%, and they are higher than the rotation of barley/wheat. After 2 years of continuous cultivation, organic matter increased by 16.23%, total nitrogen by 15.86%, readily available phosphorus by 7.14% and potassium by 19.79%. According to research on the spring faba bean by Dong (1983), the residual root content was 693 kg/ha, leaves 618 kg/ha and fresh nodules 175.5 kg/ha, equivalent to the organic matter content of 22 500-30 000 kg farm manure. Therefore, the cultivation of faba bean is an effective measure for improving soil fertility.

An Important Green Manure Crop

There is vigorous competition between food and manure in the rice- and cotton-growing areas in China due to limited land and dense population. It is restrictive enough that only green manure is grown extensively. In most areas, it is common practice to use green faba bean as a vegetable and its stems and leaves as green manure. This kind of green manure takes up about 1/3-1/2 of the faba bean area so that the need of green manure for cotton and cereals would be solved. In some rice belts, faba bean and green manure are grown, i.e., faba bean together with Chinese vetch.

In the autumn-sown area along the Yangtze River Valley, after the harvesting of faba bean, the stems or stocks are cut into pieces and plowed back to the soil as green manure for early rice. At present the area for this kind of practice in Zhejiang and Shanghai takes up about 1/3-1/2 of the total area for faba bean cultivation. Generally speaking, the output of faba bean as green manure amounts to 15 000-30 000 kg/ha. Analysis shows that 100 kg of fresh stocks of faba bean contain 1.16 kg total nitrogen, 0.3 kg phosphorus and 0.9 kg potassium. In terms of chemical fertilizer, 1000 kg of fresh stems, roots and leaves are equivalent to 55.4 kg of ammonia sulphate, 16.8 kg of superphosphate and 18.0 kg of potassium sulphate. Usually the early maturing varieties are used as the green faba bean manure.

In Zhejiang Province, there is even the practice of growing Chinese vetch as the green manure together with faba bean. The mixed growing area in Pinghu county, in 1978, reached 1133 ha. This practice of cultivation provides green manure and seeds of faba bean and Chinese vetch. When Chinese vetch is grown with faba bean, the output of green manure is about 20% higher than when it is grown on its own. The assessment done by the Datong Agricultural Science Station in Jianshan county, Zhejiang province, indicates that the yield of the stems and leaves from faba bean is 29 235 kg/ha and of Chinese vetch 29 626 kg/ha, for a total of 58 851 kg/ha, while the fresh grass of Chinese vetch cultivation alone is 40 500 kg/ha. Thus, mixed cropping produced a 45.2% yield increase. The seed yield of Chinese vetch from the field is 375 kg/ha, and that of faba bean is 457.5 kg/ha. The yield of faba bean is higher than that of just growing Chinese vetch while the yield of Chinese vetch seeds is about the same when grown with faba bean. Furthermore, the production rate is stable and generally above 45 000 kg/ha.

Enhancement of Barley, Wheat, Rice and Cotton Yields

In the southern cotton-growing area, faba bean is generally intercropped with barley or wheat. Thus the land and solar energy can be fully used and these crops of biological and ecological variability can complement one another, so that the disease can be relieved and the yield increased. Research by Shi (1989) shows that intercropping of faba bean, barley or wheat can decrease faba bean red Botrytis faba spot disease, brown spot and powdery mildew of wheat. Its yield is about 15% higher than that of single cropping. If faba bean is grown after or interplanted with cotton, the soil fertility is improved and cotton yield is significantly increased. According to the survey by the Agricultural Board in Qitong county, Jiangsu province from 1978 to 1983, each cotton stand has 12% more bolls when cotton grows after faba bean than when grown after wheat. The increase is 75 840 bolls/ha and the 100-boll weight increases by 23.9 g. The survey on the maize area shows that rotation of faba bean/maize is better than that of wheat/maize. The maize has 35.6 grains/ear, an increase of 11.9% and grain weight is increased by 12.88%.

The early maize cultivar has yielded 922.5 kg/ha, an increase of 23.43%; yield of late maize cultivar has risen to 1020 kg/ha, an increase of 24.96%.

The cultivation of rice after faba bean indicates that its yield is clearly higher than that of rice after wheat. The popularization centre of agricultural technique in Dali city, Yunnan province shows that rice planted after faba bean reaches yields of 6563-7650 kg/ha, whereas rice grown after wheat yields only 4568-5025 kg/ha. In fields of a high-yield area, rice grown after faba bean generally yields 7500-10 500 kg/ha, whereas rice grown after wheat yields only 6000-9000 kg/ha. So, there is an increase of about 1500 kg/ha.

In contrast with wheat and rape production, faba bean is a low-input crop. Liu *et al.* (1989) found that wheat yielding 3000-6000 kg/ha, contrasted with faba bean yielding 1500-3000 kg/ha, had 103.7-141.2% more input and its output was only 62.0-57.5% higher. The ratio for input and output for faba bean is 1:2.67-1:3.1, while that of wheat is 1:1.66-1:2.46. The production costs of seed/kg for wheat are 20.7-54.3% higher than that of faba bean; a working day output value and daily economic income are less than that of faba bean (Table 10).

Li (1984) in Changsha, Hunan province carried out the experiment of cropping system reform in order to seek to change the system of rotation of rice/rice/manure which does not meet the fodder need for animal husbandry and to try to increase the energy conversion rate from the field to animal husbandry. He made a synthetic evaluation of three factors (energy, protein, ratio) in the economic products from eight cropping systems by the method of squared figure. He found that rice/rice/faba bean was the best, followed by rice/rice/pea and maize with soybean intercropping rice. Rice/rice/manure crop and soybean/rice were the worst (Table 11). Contrasting rice/rice/faba bean with rice/rice/manure, it was found that the utilization rate of solar radiation for rice/rice/faba bean was 26.7% higher, or 13.8% higher in terms of calculation of economic and energy yield. The rate of digestibility for the pig in the rice/rice/faba bean intercropping area was 13.8% higher, digestible crude protein was 106.7% higher and the ratio of energy and protein was 62. The fodder conversion ratio of energy-protein under proper condition in feeding pigs was 14.4% higher than for conventional fodder (rice, chaff and vegetable). From the accumulation of dry matter by photosynthesis to the formation of pork, the conversion rate of energy was increased by 30.2%. This can further promote the development of animal husbandry (Table 11).

According to the cost calculation of agricultural products from 263 farming families during 1983 to 1987 in Qirtong county, Jiangsu province, the average yield by intercropping with faba bean is 2331 kg/ha. Although 418.5 kg less than yields from intercropping with wheat or barley (2749.5 kg), the economic income/ha of faba bean is 1111.5 yuan, 189.3 yuan more than wheat or barley (922.7 yuan). The input/ha of faba bean is 475.3 yuan, 201.9 yuan less than that of wheat or barley (677.2 yuan). The net profit/ha of faba bean is 546.75 yuan, 360.6 yuan more than 186.15 yuan of barley or wheat.

Table 10. Comparison of input and output of faba bean and wheat.

Crop	Yield (kg/ha)	Input: Labor	Input: Materials[†]	Input: Total	Output: Seed	Output: Straw	Output: Total	Input rate	Seed cost	Output value per day	Income per day
Faba bean	100	100	100	100	100	100	100	2.67	100	100	100
	200	100	100	100	100	100	100	100	100	100	100
Wheat	200	238.8	269.4	303.7	209.3	33.3	162.0	1.66	154.3	67.7	39.8
	400	186.2	295.1	241.2	209.3	16.7	157.5	2.48	120.7	84.6	68.5

[†] Materials included seed, chemical fertilizers, insecticides and water costs.

Table 11. The comparison of benefits/mu† for eight kinds of cropping system.

Cropping system	Energy of biological yield (10^{12} cal.)	Energy of grain yield (10^{12} cal.)	a Digestible energy for pig (10^{12} cal.)	b Digestible crude protein (kg)	a/b (10^{12} cal./kg)	c Metabolic energy for chicken (10^{12} cal.)	d Crude protein (g)	d/c ($g/10^{12}$ cal)	General evaluation as fodder: General	General evaluation as fodder: Pig	General evaluation as fodder: Chicken	Overall rate
Rice/rice/manure	4767	2449	1834	16.4	112	1289	44536	35	7	5	6	6
Rice/rice/rape	5281	2825	1949	26.6	73	1372	57100	42	5	4	5	1
Rice/rice/barley	5840	2791	2106	22.9	92	1464	57856	40	4	3	4	5
Rice/rice/pea	5897	2782	2095	31.9	66	1490	63812	43	3	2	2	4
Rice/rice/faba	5924	2788	2087	33.9	62	1475	66152	45	1	1	2	2
Soybean/rice	4398	2102	1514	47.6	12	1097	73387	67	6	1	1	7
Maize/rice	5831	2670	2126	20.7	103	1715	50387	29	5	4	4	5
Maize/soybean/rice	5410	2520	1920	38.9	49	1494	68069	46	2	1	1	3

† 1 hectare = 15 mu.

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Chapter 3. Basic Research on Faba Bean

Research on Genetics

Genetic Correlation and Path Analysis Studies on Quantitative Traits of Faba Bean

Genetic correlations between quantitative traits

Research on inheritance and correlation of quantitative traits provides an important theoretical base for faba bean breeding. Chinese scientists conducted many studies on these aspects. The results of different authors were essentially similar, although different varieties and different numbers of entries were used, and the cultivation and ecological conditions were different in their experiments. The results of six authors on correlation of important agronomic traits with faba bean yield are summarized in Table 12.

Table 12. Correlation coefficients between important traits of faba bean and yield.

Growth duration (days)	100-seed weight	Plant height	No. pod-bearing branches/ plant	No. pods/ plant	No. seeds/ plant	Pod length	Reference
0.82*							Zhang (1989)
	0.29*	0.55**	0.85**	0.65**	0.72**		Li and Huang (1983)
0.32*		0.74**	0.57**		0.94**		Li *et al.* (1987)
					0.67**		Huang (1984)
	0.34*				0.79**	0.80**	Gu (1986)
				0.42**	0.59**		Lang (1985)

*,** significant at $P < 0.05$ and $P < 0.01$, respectively.

Table 12 shows that the relationships between number of seeds/plant and number of pods/plant with yield are close. From these studies, estimates of variation in different quantitative traits were obtained. Traits with wide variations were: number of pods/plant, number of seeds/plant, pod length and number of seeds/pod. Li and Huang (1983) carried out a cluster analysis on 10 main traits of economic importance among 50 faba bean varieties, and constructed the dendrogram of these quantitative traits (Fig. 3). The following points could be obtained from the figure:

1. The cluster consisting of pod width and 100-seed weight was formed earliest, followed by the cluster of pod-bearing branches and yield. Number of seeds/plant, number of pods/plant or pod-bearing branches and yield were later clustered together.

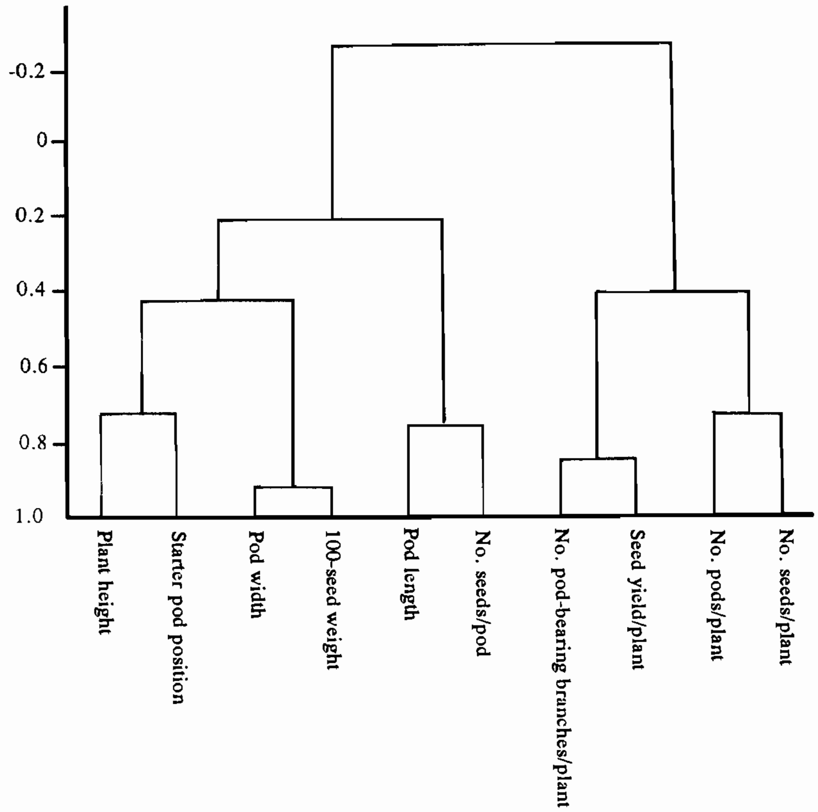

Fig. 3. Dendrogram of quantitative traits in faba bean.

2. The 10 traits analyzed could be clustered into five closely related groups: pod width and 100-seed weight; number of pod-bearing branches and yield; plant height and starter pod position; pod length and number of seeds/pod; number of pods/plant and number of seeds/plant. The close relationships between wider pod and larger seed, larger pod and more seeds/pod, and more pods and more seeds are expected. Starter pod position also appeared to be an associated trait of plant height.

Li and Huang (1983) also estimated "the genetic correlation contribution" of 10 quantitative traits in 50 varieties, and showed that number of pods/plant, pod width and number of seeds/plant gave the largest contribution (Table 13). Variations in the three traits would cause relatively large variations in other traits. However, the variations in number of seeds/pod, plant height and starter pod position would have relatively little influence on other quantitative traits.

Table 13. Genetic correlation contributions of different traits in faba bean.

	Seeds				Pods				Plant	
	No./ pod	No./ plant	100-seed weight	Wt./ plant	No./ plant	Width	Length	Starter pod posn.	Height	No. pod-bearing branches
Genetic correlation contribution	2.522	3.680	3.311	3.102	4.108	3.834	3.541	2.128	2.309	2.665
Summation of genetic correlation contribution	0.868	0.384	0.603	0.702	0.133	0.256	0.497	1.000	0.942	0.787

Path analysis on main agronomic traits to yield

In Changsa, Hunan Province, Zhang (1989) conducted a path analysis based on the correlation analysis of eight main agronomic traits among 69 varieties in three successive years. Figure 4 shows the direct and indirect effect of various traits on yield and the interrelationships. The direct effect of pod width on yield was the greatest with a coefficient of 1.60, followed by 100-seed weight (0.92), number of pods/plant (0.92) and number of seeds/plant (0.70). Direct effects of the eight traits arranged in order of their coefficients are: pod width > 100-seed weight > number of pods/plant > pod length > number of seeds/plant > growth duration > pod-bearing branches > plant height. Pod length, plant height and pod-bearing branches showed negative effects. The order according to indirect total effects was essentially the same as that based on direct effects. The indirect total effect of pod width was the greatest, followed by 100-seed weight and number of pods/plant, so pod width, 100-seed weight and number of pods/plant are the most important traits for yield improvement.

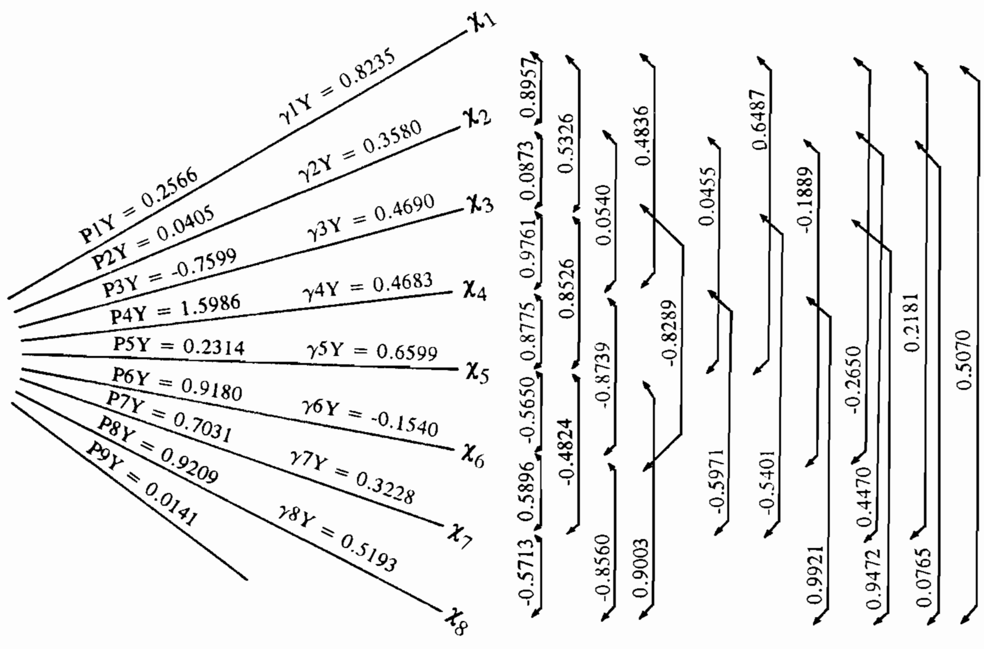

Fig. 4. The pathway of main economic traits to yield in faba bean. X1, period of duration; X2, plant height; X3, pod length; X4, pod width; X5, number of effective branches; X6, number of pods/plant; X7, number of seeds/plant; X8, 100-seed weight.

Gu and Xia (1987) of the Shanghai Agriculture College conducted a genetic correlation and path analysis on nine yield-related traits in 25 new elite lines of faba bean developed by themselves. Variance analyses showed that line differences in yield, 100-seed weight, number of seeds/plant and pod length were all significant. The directions of phenotypic correlation and genetic correlation were the same. The genetic correlation coefficient (r_g) between number of seeds/plant and yield was 0.790. The correlations of 100-seed weight with number of seeds/plant and yield were negative, r_g = -0.785 and -0.822, respectively. The r_g of pod length with yield was 0.505.

The genetic path coefficient analysis (Table 14) showed that number of seeds/plant had the largest direct (path coefficient = 1.622) and indirect influences on yield. The indirect path coefficient to yield of 100-seed weight and pod length through number of seeds/plant was -1.273 and 0.936, respectively. The absolute values of the three path coefficients were greater than the absolute values of all other traits. The direct genetic path coefficient of 100-seed weight to yield was 0.699. The indirect genetic path coefficient of number of seeds/plant to yield through 100-seed weight was 0.549. In comparison, the direct genetic path coefficient of pod length to yield, and the indirect genetic path coefficients of number of seeds/plant and 100-seed weight to yield through pod length, were smaller.

The above research indicated that number of seeds/plant, number of pods/plant and number of pod-bearing branches are the most important yield-related traits.

Table 14. Genetic path coefficients of 100-seed weight (x_1), number of seeds/plant (x_2) and pod length (x_3) to yield (y).

Item	1 ⟶ y	2 ⟶ y	3 ⟶ y
x_1 , 1 ⟶	0.699	-1.273	-0.248
x_2 , 2 ⟶	-0.549	1.622	-0.283
x_3 , 3 ⟶	0.353	0.936	-0.491

Correlation of Yield Components in the F_2 Generation

Lang (1985) investigated yield components among an F_2 population of faba bean, and showed that the coefficients of variation for number of pods/plant and number of seeds/plant were the greatest (Table 15). The correlation coefficients of single plant yield with the yield components were all significant (Table 16). The correlation coefficient between number of pods/plant and number of seeds/plant was the largest (0.83). The correlations of seed weight with number of pods/plant, number of seeds/plant and number of seeds/pod were negative. It was suggested that number of pods/plant is the key in the selection within F_2 populations for yield.

Table 15. Degrees of segregation for different traits in an F_2 population of 3000 individuals.

Trait	Mean ± SD	CV (%)	Range
No. pods/plant	7.2 ± 3.16	43.8	24 (1-25)
No. seeds/plant	18.7 ± 8.13	43.6	65 (1-66)
No. seeds/pod	2.7 ± 0.93	31.7	34.5 (0.5-35)
100-seed weight (g)	9.2 ± 3.36	36.3	26.2 (1-27.2)
Single plant yield (g)	15.3 ± 6.25	40.9	61.3 (0.7-62)
No. pod-bearing branches/plant	2.2 ± 0.82	36.3	5 (1-6)
No. pod-bearing nodes/plant	7.1 ± 2.89	40.9	21 (1-22)
No. pods/node	1.1 ± 0.45	41.7	8.9 (0.13-9)

Table 16. Correlation coefficients between single plant yield and yield components, and among the components based on 3000 individuals in an F_2 population.

Item	No. pods/ plant	No. seeds/ plant	No. seeds/ pod	100-seed weight	No. pod-bearing branches/ plant	No. pod-bearing nodes/ plant	No. pods/ node
Single plant yield	0.415**	0.587**	0.233**	0.293**	0.250**	0.288**	0.144**
No. pods/plant		0.834**	-0.225**	-0.419**	0.143**	0.655**	0.350**
No. seeds/plant			0.218**	-0.440**	0.083**	0.561**	0.320**
No. seeds/pod				-0.439**	-0.095**	-0.160**	-0.079**
100-seed weight					0.210**	-0.267**	-0.185**
No. pod-bearing branches/plant						0.478**	-0.346**
No. pod-bearing nodes							-0.311**

** $P<0.01$.

Heritability and Genetic Advance

Heritability is the ratio of genetic variations to phenotypic variations. Li and Huang (1983) studied 10 traits in 50 faba bean varieties and found that heritabilities of pod length, pod width and plant height were relatively high (> 80%, Table 17). However, heritabilities of traits more closely related to yield were less than 80%. They could be arranged in order of heritabilities: number of seeds/pod > 100-seed weight > starter pod position > number of pods/plant > number of seeds/plant > number of pod-bearing branches > single plant yield, so it would be difficult to select effectively for these traits in early generations. Favorable variations of such quantitative traits were expected to be fixed by successive selections.

Table 17. Estimates of genetic and phenotypic variances, and heritabilities for different traits of faba bean.

	Trait†									
	I	II	III	IV	V	VI	VII	VIII	IX	X
Genetic variance	3.42	0.04	144.36	0.22	504.60	7.86	21.6	90.43	0.29	42.10
Phenotypic variance	10.56	0.12	465.16	0.74	1795.02	28.75	80.46	354.27	0.83	263.77
Heritability (%)	91.47	82.17	81.61	76.45	64.17	60.87	58.76	62.31	37.11	24.06

† I, pod length; II, pod width; III, plant height; IV, no. seeds/pod; V, 100-seed weight; VI, starter pod position; VII, no. pods/plant; VIII, no. seeds/plant; IX, no. pod-bearing branches; X, single plant yield.

Li *et al.* (1987) found that the broad-sense heritabilities of 17 traits in faba bean were all less than 70%. The heritabilities were maturity 67.9%, seed width 67%, seed length 65.3%, plant height 62%, seed thickness 55% and node number 51.2%. The heritabilities of the remaining 11 traits were less than 50%. It was suggested that heritabilities in faba bean were lower than in other crops.

Genetic advance measures the effect of selection. Wang (1987) analyzed preliminarily the genetic advances of 17 traits under different selection intensities. Among yield-related traits, the expected genetic advances of number of branches/plant, number of seeds/plant and single plant yield were greater, suggesting better results of selection on these traits. For example, under a selection intensity of 20%, 0.5 branch could be increased on average by selection on number of branches, 3.55 seeds increased by selecting number of seeds/plant and 3.01 g of seed increased by selecting single plant yield. For other traits with smaller genetic advances, selection could be made under a 5% selection intensity.

Research on Basic Biology

Natural Out-crossing

Faba bean often behaves as a cross-pollinated crop. An understanding of its out-crossing is important in breeding and cultivation. Gong (1985) studied the natural out-crossing of faba bean by using two complete-dominant alleles, black/white hilum and purple/white flower, as markers under alternate planting of male and female parent rows and of male and female parent plants for six successive years in different weather conditions in

Shanghai. The female parent was 'Jia Ding San Bai Dou' with white hilum and seed. The male parents included 'Qi Dou No. 1', 'Mao Ban Qing', 'Xing Zhu Dou' and 'Dou Jia Dou' with black hilum. In addition to different hilum color, flower color was used as a marker. Purple is dominant to white. The average out-crossing of faba bean was 36.6% with fluctuations of 25.8-56.1% among years (Table 18).

Table 18. The natural out-crossing of faba bean (1980 to 1985, Shanghai).

	Out-crossing (%)	
Year	Range	Average
1980	27.86 - 44.36	36.50
1981	16.67 - 50.00	31.57
1982	23.75 - 28.27	25.75
1983	41.67 - 91.67	56.14
1984	4.35 - 71.43	39.01
1985	0.03 - 78.37	38.04

Out-crossing of faba bean decreases as the distance between plant rows increases. It was found to decrease to about 10% as the distance increased to 66 cm, and decreased to < 5% as the distance increased to more than 3 m. Out-crossing also varies for different sections on a single plant. The out-crossing percentages in lower and upper sections are usually higher than in the middle section.

Out-crossing is also affected by other factors such as variety characteristics, weather conditions and amount of bees available. It is important to understand well the natural out-crossing for breeding, propagation and cultivation for high yield.

Flower Bud Differentiation

Shen (1984) observed the process of flower bud differentiation of faba bean, the relationship between flower bud differentiation on the main stem and on the branches, and the influence of cold temperatures on flower bud differentiation by means of different sowing times during 1980 to 1983 in Shanghai. Although flower bud differentiation is a successive process (Fig. 5), for the convenience of description, it can be divided into three stages:

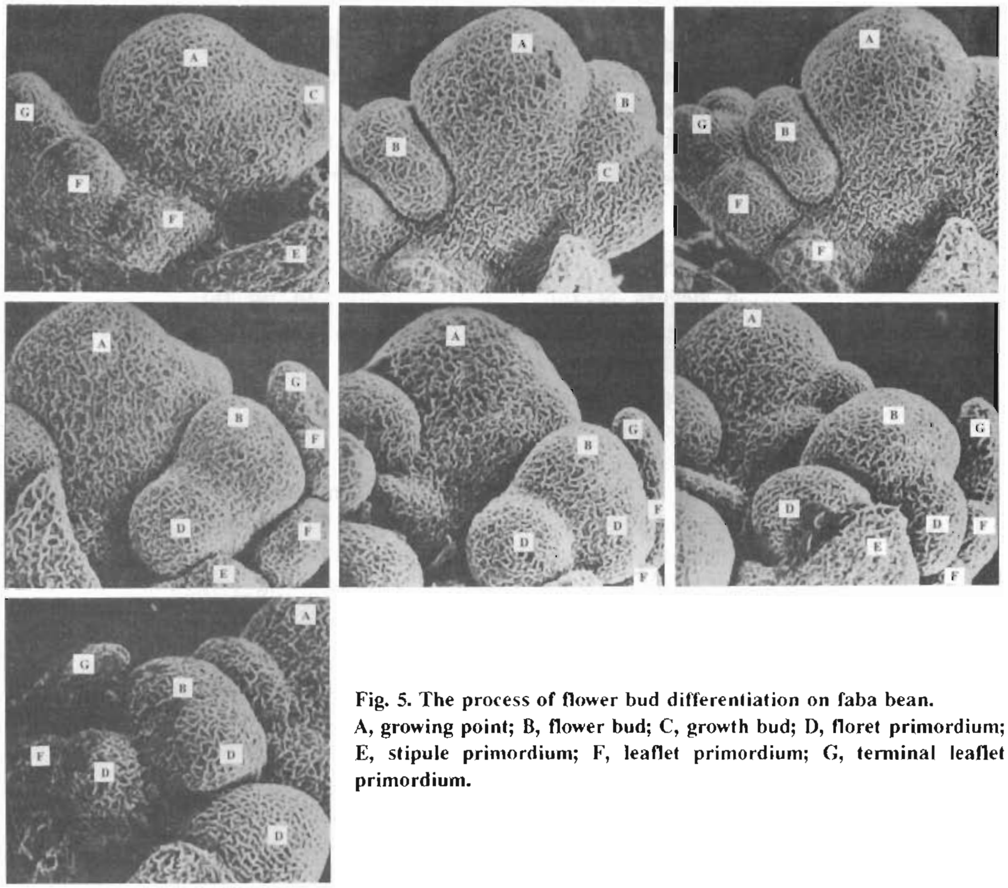

Fig. 5. The process of flower bud differentiation on faba bean.
A, growing point; B, flower bud; C, growth bud; D, floret primordium; E, stipule primordium; F, leaflet primordium; G, terminal leaflet primordium.

Flower bud primordium

When flower bud differentiation begins, round and small protrusions which are called flower bud primordia occur between the growing point and the leaf primordium. The leaf primordium is growing at the same time. The flower bud primordium is above the leaf primordium, and is wrapped by the leaf primordium. It takes about 22 days from planting to flower bud differentiation, when the first leaf of the plant has expanded completely.

Floret primordium

Three days after the flower bud primordium reaches its maturity, the first floret primordium protrusion occurs at the basal part followed by three to six floret primordium protrusions from lower to upper parts on the same branch.

Differentiation and maturing of flower structures

The order of the flower structure differentiation is: pistil, calyx, stamen and corolla.

Flower bud differentiation is closely correlated to temperature. The flower bud differentiates fastest when the mean daily temperature is 13°C. At this temperature, the growth of the plant is optimal and is not prone to injury by low temperature. Flower bud differentiation is delayed when the temperature is higher or lower than 13°C, so it is important to determine the optimal sowing time for high yield.

Tang (1983) observed under the microscope the flower bud differentiation of the inflorescence on the main stem and inflorescence of the first five layers of flowers on the 1st branch from the basal node of early, medium and late spring-sown varieties in Xining, Qinghai Province in 1982 and 1983. According to the order of occurrence of various flower structures and the development of reproductive cells, they divided the differentiation into seven stages: differentiation of floret primordium, differentiation of calyx-tube primordium, differentiation of pistil and stamen primordium, differentiation of petal primordium (establishment of the basic structure), anther formation, tetrad formation, and pollen development and maturing.

The process of flower bud differentiation differs in different varieties. In spring varieties of early and medium maturity the inflorescence starts to differentiate when the 7th leaf node has differentiated during seed germination and seedling emergence. In varieties of late maturity, 2-3 leaf nodes differentiate after germination, and the inflorescence starts to differentiate as the upper leaf nodes differentiate. During germination, varieties of early and medium maturity already have 2-3 layers of flowers differentiated, but only 1-2 layers in varieties of late maturity. From 10 to 13 layers of flowers usually have differentiated at the flower bud emergence stage. In spring varieties, pod-setting usually takes place in the first 12 layers, and most of the flowers above the second floret on each layer are abortive. On average, differentiation of an inflorescence in the early variety 'Shen Li Can Dou' takes 2.1 days. It takes 2.5 days in the medium-maturity variety 'Qinghai No. 3' and 2.7 days in the late variety 'Can 124'. Thus, the differentiation is slow with late maturity.

Flower bud differentiation on the main stem is usually earlier than on branches. In some plants the flower buds on the 1st branch of the 1st basal leaf node differentiate simultaneously with flower buds on the main stem. The order of the flower bud differentiation among branches is in accordance with the order of branch emergence. Flower buds differentiate earlier on branches that have emerged earlier. The differentiation of flower buds on branches of different nodes occurs in sequence from the bottom to the top of the plant. On primary branches of the same node, it occurs in the sequence from the base to the tip of the branch.

Characteristics of Branching

Faba bean has a strong branching ability, which is controlled by the genotype and environment. According to Yu and Zhang (1979), branches appeared on the 1st node when the 4th leaf emerged on the main stem. When sown earlier (25 September), the number of branches reached 20-25. When sown later (5 November), there were 5-10 branches, but only 2-3 branches appeared when sown in early spring. In faba bean, branches occur on the cotyledon node, and they are called cotyledon-node branches. There are usually two cotyledon-node branches. Branches that emerge from the main stem are primary branches. Branches that develop from primary branches are secondary branches, and those grown from secondary branches are tertiary branches. Under cultivated field conditions, tertiary branches are rare. Primary branches on the 1st node of the main stem are the 1st-node branches. Branches on the 2nd, 3rd and 4th nodes are called 2nd-, 3rd- and 4th-node branches, respectively. More branches emerge on the 1st and 2nd nodes. The number of branches is obviously less on the 3rd node. Branching above the 4th node is rare. Branching of faba bean is illustrated in Figure 6.

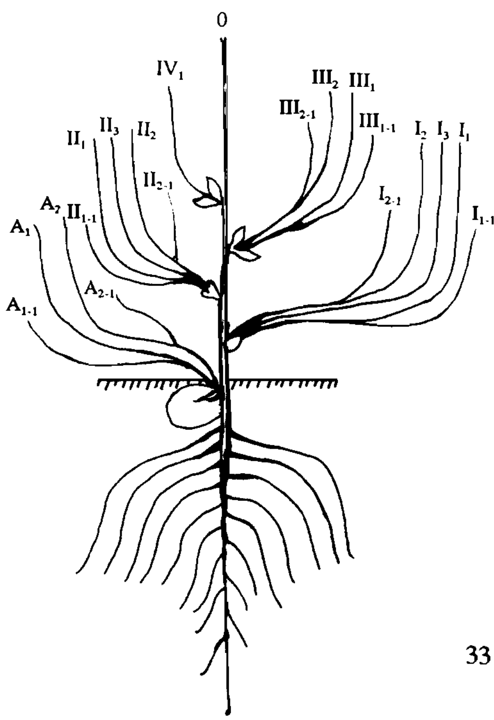

Fig. 6. Branching model of faba bean.

Branching is closely related to the length of the vegetative growth phase. The longer the vegetative phase, e.g., by earlier sowing, the more branches there are, and vice versa. Branching mainly occurs before and during the winter. Branching is rare after winter. Wu and Jing (1988) observed in Nanjing that the percentage of pre-winter branching to total branching/plant was 46.4-74.6%, winter branching was 13.5-33.4%, and post-winter branching was 0-24.0%. The percentage of pod-bearing branches was 30-50% in those branches developed before winter, 50-100% in those developed during winter and 0-33.3% in those developed after winter.

Characteristics of the Root System

Roots physically support the plant, and are the important organ for taking up water and nutrition. Roots of faba bean also possess symbiotic nitrogen-fixing ability, so it is essential to investigate the characteristics of the root system.

Preliminary observations were made on the inception and growth characteristics of the tap root, lateral roots and nodules of autumn-sown faba bean by Liu and Yu (1988) of the Central China Agricultural College. The test materials were local small-seed varieties, which were sown in clay loam soil on 28 October. Observations of two successive years showed that radicle emergence occurred when the seed germinated. The tap root elongated through the radical cap 5-7 days after sowing, and was more than 50 cm long at blooming stage. In sandy loam soil, Yu and Zhang (1979) had observed that the tap root could penetrate to a depth of 100-120 cm at the end of March. The growth of the tap root was fastest at seedling stage before winter, with an average daily growth of 7.35 cm. This rate was 18-fold that of the increase in plant height, resulting in the absolute dominance of the underground parts. This trend reversed after winter. At blooming stage, plant height was nearly the same length as the tap root (Table 19).

Faba bean has abundant lateral roots, which can emerge from the tap root and the plumule buried in the soil. The lateral-root extrusions appear on the tap root when the seedling emerges and turns green. At the end of November, i.e., a month after sowing, the lateral roots occupy more than 60% of the total root mass, 80-90% of which were produced during 2nd and 3rd leaf stages (branching stage). The average daily transverse growth of laterals during these stages reaches 1.4-2.3 cm. On average, there are more than 85 primary laterals/plant during the blooming stage. Laterals can penetrate to a depth of 45 cm. However, 50-60% of the laterals are in the arable layer of 0-10 cm depth. The laterals expand transversely to more than 50 cm, which is nearly the length of the tap root. According to Yu and Zhang (1981), some laterals distribute horizontally near the soil surface around the tap root, then grow obliquely for 45-80 cm before they grow downward. These laterals can reach a depth of 75-100 cm. However, most of the root system distributes in the surface soil around the tap root within a depth of 30-40 cm. Secondary laterals are produced when the second complete leaves expand, forming a strong lateral system.

Table 19. **The growth of tap root of faba bean at different growth stages.**

Date	Growth stage	Plant height (cm)	Tap root length (cm)	Tap root diameter (cm)	Daily increase of tap root (cm)	Length of tap root: plant ht.
4 Nov	Seed-coat split	0.3	0			
7 Nov	Pre-emergence of seedling	0.5	7.8	0	2.50	14.60
9 Nov	Seedling emergence	1.2	22.5	0.12	7.35	18.57
14 Nov	2nd complete leaf	1.9	25.4	0.24	0.58	12.73
18 Nov	3rd complete leaf	4.7	27.8	0.28	0.60	4.87
30 Nov	4th complete leaf	8.5	32.0	0.32	0.35	2.76
6 Jan	6th complete leaf	11.6	48.0	0.31	0.43	3.14
26 Mar	Blooming	47.5	51.2	0.65	0.04	1.08

Rhizobia enter the root at the 3rd leaf stage and the emergence of the 4th leaf stage. Small extrusions occur on the tap root at the 4th leaf stage. Granule-like nodules form at the 5th leaf stage. Nodules continue to grow on the tap root, while small granule-like nodules form on laterals at the 6th leaf stage. After the 7th leaf stage, nodule number and size increase. After the 9th leaf stage, nodules become ginger-like tubers. Nodules in the faba bean root system, especially the nodules with high nitrogen-fixing efficiency, are distributed mainly on the tap root (Fig. 7).

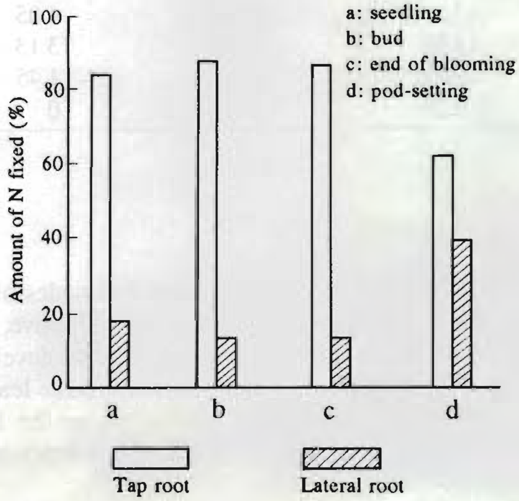

Fig. 7. Amount of fixed nitrogen in nodules on tap root and laterals of faba bean at different growth stages.

Research on Physiology and Biochemistry

Leaf Development

The cotyledon provides nutrients for germination, seedling emergence and seedling growth until the appearance of the 12th leaf on the main stem, then the nutrients in the cotyledon are used up. There are two peaks for nutrition depletion from the cotyledons: (1) from seeding to seedling emergence (3rd leaf stage) with 30-35% depletion, and (2) from 4th leaf stage to 5th leaf stage with 40-47% depletion. During the first peak, nutrients are mainly provided for the growth of roots and stems, and during the second peak, for nodule formation (Table 20).

Table 20. Dry weight of cotyledon and seed coat/plant after seedling emergence in two faba bean varieties.

	'Da Bai Pi'		'Xiao Qing Pi'	
Growth stage	Avg. dry weight (g)	% of plant dry wt.	Avg. dry weight (g)	% of plant dry wt.
Sowing	0.904	100.00	0.761	100.00
Emergence	0.643	71.13	0.532	68.82
4 leaf	0.575	63.61	0.461	60.57
5 leaf	0.217	24.01	0.101	13.27
6 leaf	0.169	21.68	0.072	9.46
7 leaf	0.183	20.24	0.064	8.41
8 leaf	0.177	19.58	0.058	7.62
9 leaf	0.156	17.26	0.046	6.05
10 leaf	0.132	14.60	0.024	3.13
11 leaf	0.125	13.83	0.011	1.45
12 leaf	0.084†	9.29	0	0

† All cotyledon nutrients depleted.

After seedling emergence, a leaflet (basal leaf) erupts on the 1st and 2nd nodes of the main stem. Compound leaves with two leaflets appear on the 3rd node and above. The number of leaflets of a compound leaf increases as the bean plant grows and develops. In general, the compound leaves bear two leaflets on the 3rd to 9th nodes, three leaflets on the 8th to 10th nodes, four leaflets on the 10th-13th nodes, six leaflets on the 14th-16th nodes, and seven leaflets on the 19th and above nodes. The same tendency exists for leaflet number on secondary branches of different nodes.

The number of leaflets is related to flowering. In general, flowers appear from the 9th node and above on the main stem, from the 4th node and above on the primary branch, and from the 2nd node and above on the secondary branch. On the branches, flower buds usually appear above the nodes with 3-leaflet compound leaves and develop into an inflorescence, indicating the transition from vegetative to reproductive growth. Under normal sowing, flowers that open after the appearance of 7-leaflet compound leaves on the main stem usually fail to produce pods.

Dynamics of Leaf Area

According to Jin and Zhuang (1986), the number of green leaves/plant was 9.75 during winter, 15.25 during early spring, 29.5 during flower bud emergence, 30 during blooming, 45.5 during late blooming, 47.75 during pod-setting, 80.5 during full pod stage and 49.25 during plump-seed stage. It is obvious that the leaf number is small during winter, but increases rapidly in spring, reaching the peak during the 20 days from pod-setting to full pod stage. It then decreases, resulting in a monopeak curve (Fig. 8). The development curves of leaf area index and leaf number are similar. Cultivation practices, especially planting date and fertilizer application, affect the development of leaf area. In the Shanghai region, by means of agronomic practices, the faba bean leaf area index is scheduled to peak during blooming and pod-setting, to maintain at the peak longer, and then to decline slowly. This procedure favors seed development and results in high yields.

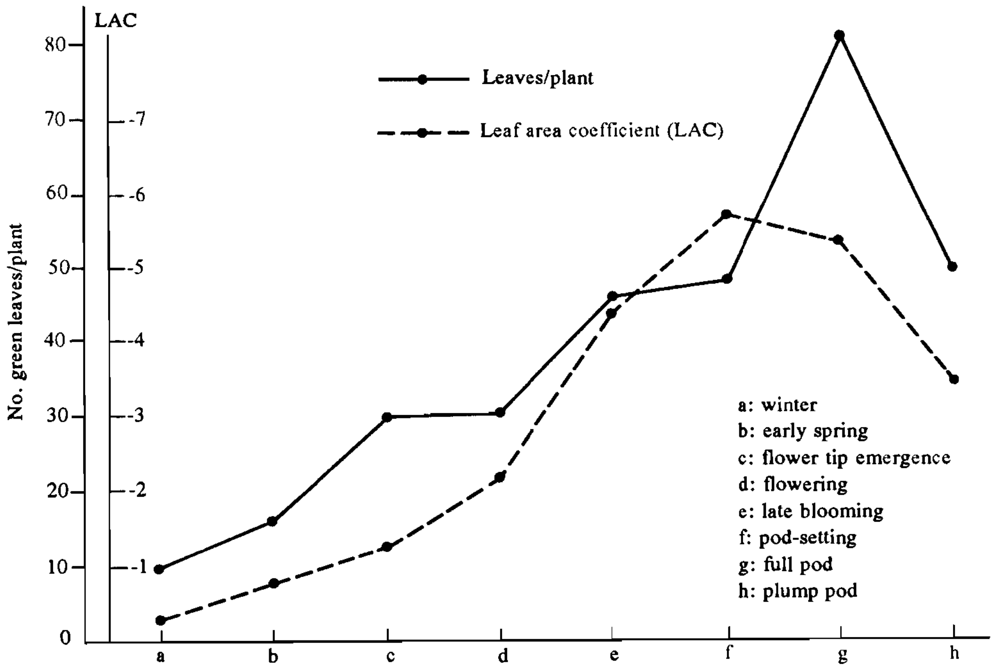

Fig. 8. The dynamics of faba bean leaf number and leaf area coefficient.

Chlorophyll Content and Photosynthetic Rate

There has been limited research on the relationship between chlorophyll content and photosynthesis in faba bean. Jin and Zhuang (1986) found that the change of chlorophyll contents from bud-emergence stage to plump-seed stage appeared as an "M" type curve (Fig. 9), with peaks occurring at both full-bud and full-pod stages. This pattern was similar to that of total nitrogen content in the plant, except that the total nitrogen content increased continuously during full pod stage, whereas the chlorophyll content decreased sharply as the leaves aged. Leaves at different positions on a plant contain 2-4 mg chlorophyll/dm^2, which can be expressed as a parabola fitted by the formula $y = 2.2217276 + 0.4948982x - 0.303349x^2$ (Fig. 10). The photosynthetic capacity of the 5th-11th leaves was the greatest.

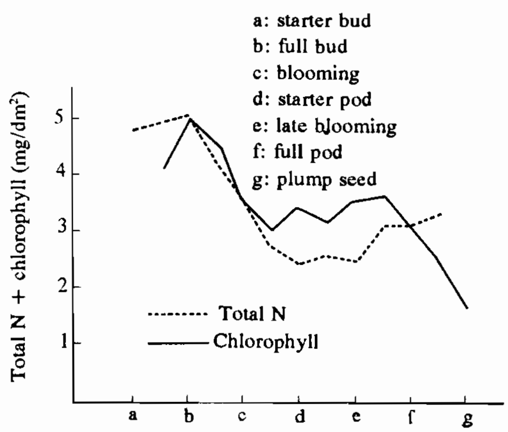

Fig. 9. Total nitrogen and chlorophyll contents during the middle and late growth stages of faba bean.

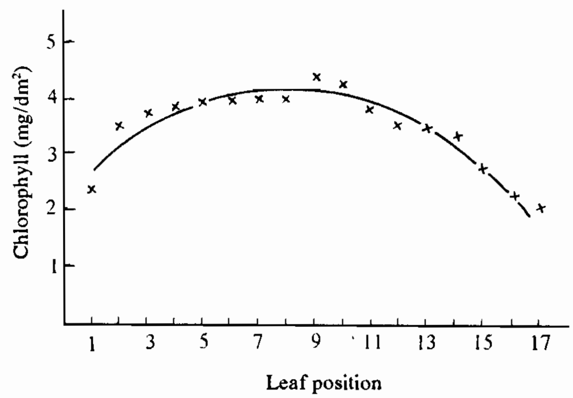

Fig. 10. Chlorophyll contents in faba bean leaves at different positions on one plant.

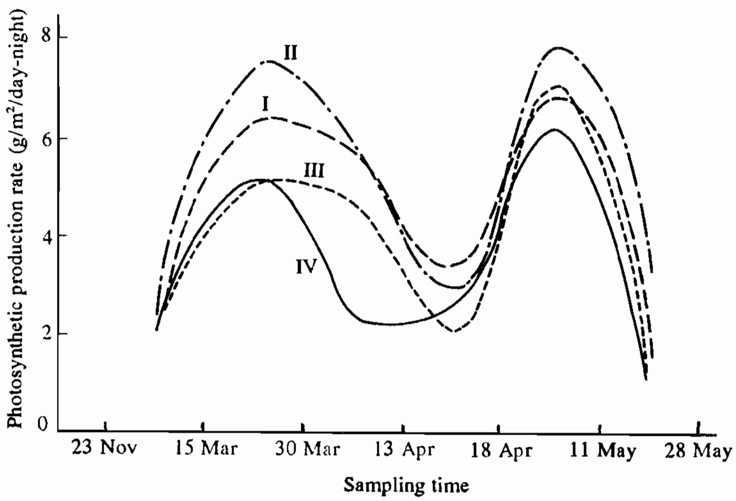

Fig. 11. The photosynthetic production rate of faba bean at different growth stages and under different cultivation conditions. I, fertilizer applied; II, fertilizer + irrigation; III, irrigation; IV, control.

From 23 February to 28 May, the rates of photosynthesis in faba bean leaves could be expressed as a double-peak curve. The first peak occurred during the inflorescence formation stage and the second peak occurred during plump-seed stage. Although the photosynthetic rates differed under different agronomic treatments, their patterns were similar (Fig. 11). Plants under fertilizer application and irrigation had higher photosynthetic rates and yields.

Flower and Pod Development

Characteristics of flowering and pod-setting

The inflorescence of faba bean is an axillary, short raceme with an indeterminate growth habit. The flowering stage lasts about 30 days. It is observed that for autumn-sown faba bean, flowering usually starts at the 5th-6th node up through to the 15th node. On the same blossom cluster, flowering starts from inside and progresses to the outside. The average flowering interval for different blossom clusters of the middle and lower parts of the plant is 1.7 days, and 0.8 days for different florets on the same cluster. For the upper part of the plant, the intervals are 2.5 and 1.3 days, respectively. The outmost floret of a lower blossom cluster opens on the same day that the inmost floret of the upper cluster opens. There are 30-40 florets on a branch, with a blossom period of about 20 days. The blossom period of a cluster is 2-3 days. A flower takes 4.3 days from blooming to fading and 10.7 days from fading to pod-setting. Pod-setting occurs earlier on the early blooming inflorescence. Thus, blooming and pod-setting of faba bean occur simultaneously. Pod-setting occurs on the lower parts of the plant at blooming stage and on the middle parts at late blooming stage. The early blooming inflorescence has a dominance for nutrition allocation and scores a higher pod production rate (Fig. 12).

During the day, the inflorescence starts to open at about 08:00 and ends at 18:00 hours. Most inflorescences open around noon (Table 21).

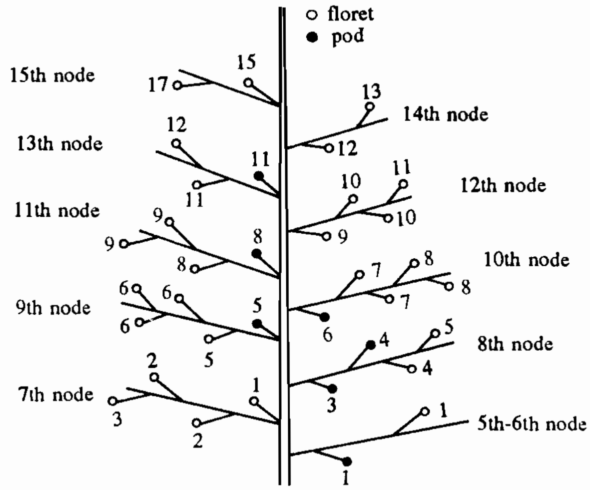

Fig. 12. Flowering model in faba bean.

Table 21. Blooming of faba bean during daytime at Yangzhou, Jiangsu (Yu and Zhang 1979).

	Blooming inflorescence	
Time	Number	%
04:30-06:30	0	0
06:30-08:30	3	6.4
08:30-10:30	6	12.8
10:30-12:30	10	21.3
12:30-14:30	15	31.9
14:30-16:30	11	23.4
16:30-18:30	2	4.2
18:30-20:30	0	0
Total	47	100

The pod-setting of faba bean mainly occurs on primary branches, on which 81.2% of the total number of pods/plant set. Only 13.6% and < 10% of the total number set on secondary branches and the main stem, respectively. The pod-setting rates of the primary and secondary branches are similar.

Pods develop quickly after pod-setting. The pod length reaches 3.5 cm in 10 days, 7.3 cm in 20 days and remains the same in 30-40 days. The fresh weight of the seeds in the pod reaches 0.13, 1.1 and 2.0-2.5 g in 10, 20 and 30-40 days, respectively.

The number of pods and pod-setting percentage of faba bean vary according to agronomic practices, such as genotype, weather condition, sowing date and fertilizer application. However, the general patterns are similar.

Dropping of blossom and pods

Blossom- and pod-drop in faba bean are very severe. It is estimated that the dropping rate of blossoms and pods reaches 92.5; 75.7% of blossoms and 16.8% of pods. Total pod-set is only 5-10% of the total number of flower buds and 10-30% of blooming flowers.

Blossom-drop starts at full blooming and reaches the peak at full pod-setting stage, while pod-drop starts at late blooming stage (Fig. 13). Florets are prone to drop 10-15 days after blooming. When a pod is going to be set or has just set at the base of a blossom cluster, the other florets of the same inflorescence are prone to produce an abscissa layer at their base and drop. The dropping of pods occurs 10-27 days after pod-setting.

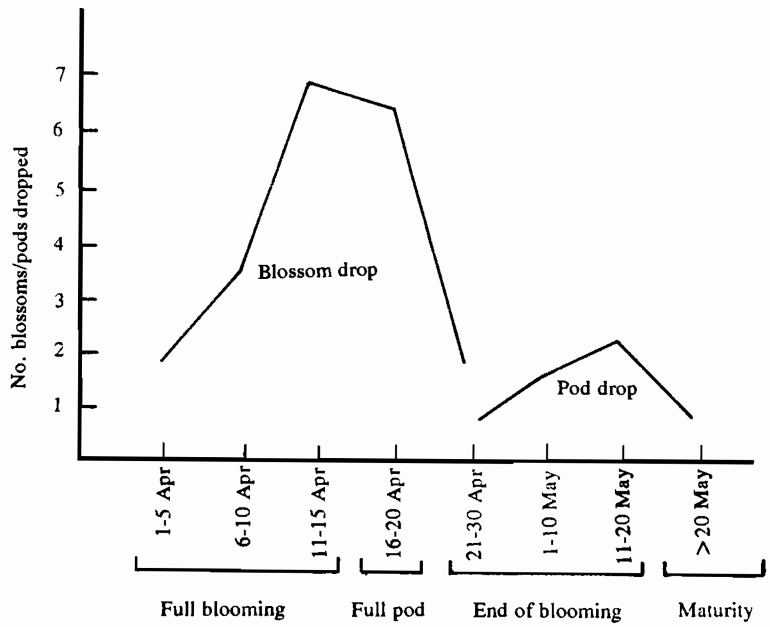

Fig. 13. Dropping of blossom and pod in faba bean.

Although some pods have developed for more than 20 days, they still remain 2-3 cm in length. They do not grow, and are prone to drop later. Pods at the upper part of plants usually drop 3-16 days after pod-setting. They take a shorter period to drop than pods in the middle and lower parts.

Florets at the upper part of the plant are more prone to drop than those at the middle and lower parts. The blossom-drop reaches 97.5% in the upper part, 94% in the middle part and 84.1% in the lower part. Blossom-drop in the outer periphery is very severe; the 1-2 flowers near the stem, especially the first flower at the lower part, are the most reliable for pod-setting. According to Zhou (1957) the pod-setting rate at the lower part of the plant is higher than that at the upper part of the same plant. Within the same inflorescence, the pod-setting rate of the first floret is the highest and that of the last floret is the lowest (Tables 22 and 23).

Table 22. Pod-setting of florets on different parts of a plant.

Nodes	Total no. florets	No. florets setting pod	Pod-setting rate (%)
5- 9	406	120	29.55
10-14	360	63	17.50
15-19	122	11	9.01

Table 23. Blossom-drop of different florets in the same inflorescence at the base of faba bean plants.

Floret	Total no. florets	No. dropped florets	Dropping rate (%)
First	155	15	9.7
Second	155	70	45.2
Third	150	140	93.4
Fourth	120	115	95.8
Fifth	15	15	100.0

Development of Pods and Seeds

Pods and seeds start to develop after flowering and fertilization. As the seeds grow, the size of pods increases and seeds become filled. This is usually called the plump-seed stage. In the beginning of this stage, the outer pod shell is green and covered with fine hairs with velvet-like down on the inner shell. When the seed volume increases to the maximum, the pods turn dark green and then black, and the water content decreases sharply. When the pods turn black, the seeds are completely mature.

On the same plant, pods and seeds reach maturity at different times. When pods turn black and seeds reach maturity at the lower part, pods are brown and seeds are plump in the middle part. While pods are green and seeds are formed at the upper part, pods are green and seeds are not yet formed at the top of the plant.

The fresh and dry weights of pods and seeds increase as the seeds develop and reach the maximum when mature. Conversely, the water content decreases continuously. According to Jin and Zhuang (1988b) the dry weight of the pods increased slowly after fertilization (5 April), but started to increase rapidly after mid-May. The increase up to maturity fitted an exponential growth. If the dry weight of seeds on the 17th day after fertilization was taken as the starting point, dry weight could be described with the formula: $y = 47.56\ e^{0.0819x}$ (Fig. 14). If the fresh weight of seeds on the 5th day after fertilization was taken as the starting point, fresh weight could be expressed as $y = 329.44\ e^{0.04055x}$ (Fig. 15). The correlation coefficient was about 0.95. The water content started to decrease when seeds reached the maximum size.

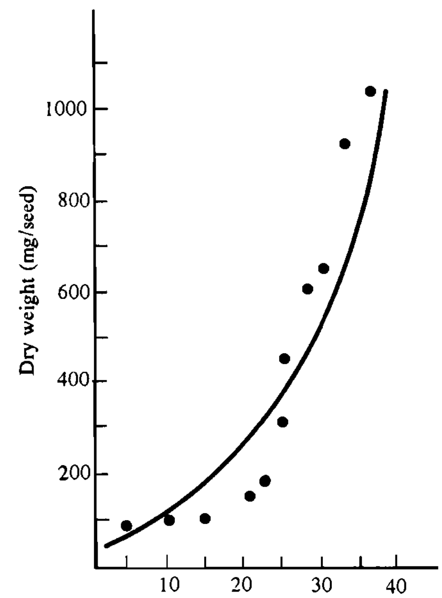

Fig. 14. The exponential growth trend of dry weight in seeds of faba bean.

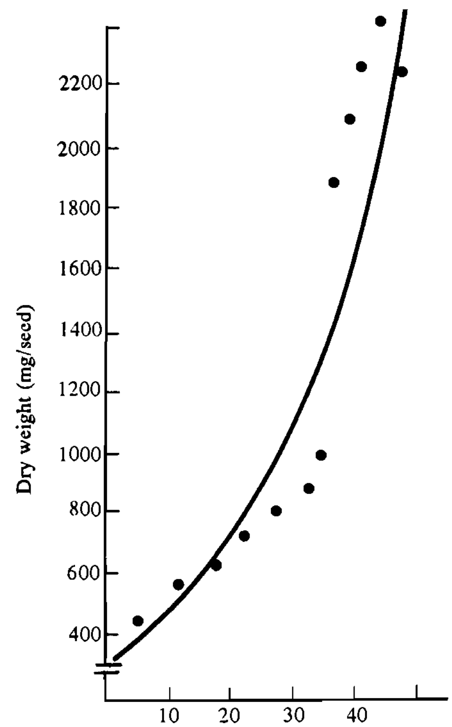

Fig. 15. The exponential growth trend of fresh weight in seeds of faba bean.

The plumpness of faba bean seeds is related to the pod-setting position. Seeds on the lower section of the plant are the plumpest, followed by the middle and the upper sections (Table 24). The plumpness of faba bean seeds also differs within a pod. Seeds located at the top of a pod are plumper, while there are more shrivelled seeds at the bottom. This is probably due to the nutritive dominance at the pod tip. Shrivelled seeds appear more often in pods containing many seeds. There are few shrivelled seeds in two-seed pods.

Table 24. Shrivelled seed percentage on different parts of a faba bean plant.

		Shrivelled seed	
Section	Total seeds	Number	%
Lower	32	2	6.2
Middle	33	6	18.2
Upper	27	12	44.2

Composition of Fatty Acids and Amino Acids

There are few reports on the composition of fatty acids and amino acids in faba bean seeds. Jin and Zhuang (1988a) investigated these components in three varieties: 'Qi Dou No. 2', 'Jia Din San Ban Dou' and 'Lun Xian No. 1' during 1986/87 (Table 25).

Table 25 shows that after fertilization the linoleic acid content increased rapidly, but the linolenic acid content decreased gradually. The content of the essential linoleic acid in the seeds was stable at about 50%, while the erucic acid content was low. During seed development, the correlation between the contents of linoleic acid and linolenic acid was significantly ($P < 0.05$) negative, $r = -0.8581$. It can be said that the fatty acid composition of faba bean is good, with high nutritive value.

Huang and Liu (1989) analyzed the amino acids in 15 Yunnan local faba bean varieties (Table 26). Comparison of faba bean seed protein with the standard protein (egg albumen) showed that the main limiting amino acid in faba bean seeds was methionine, which was only 25.2% of the standard, and was the lowest among grain legumes. However, the lysine content of faba bean seeds was 113.3% of the standard protein. The nutritive value of faba bean could be raised by proper balancing with different food in our daily diet.

Table 25. The composition of fatty acids in flowers, young pods and seeds of faba bean.

Sampling time	Fatty acid						
	Palmitic	Stearic	Oleic	Linoleic	Linolenic	Arachidonic	Erucic
Flower							
Days after fertilization							
5	14.66	3.10	5.41	33.45	35.71	1.84	5.61
10	13.21	2.50	2.56	47.80	32.35	0.61	0.79
Young pod							
Days after fertilization							
7	13.57	1.81	2.21	50.58	31.73	0.10	0
22	13.39	1.51	2.78	54.14	28.02	0.10	0.09
Seed							
Days before maturity							
30	13.17	1.34	4.52	59.05	20.81	0.71	0.40
25	16.04	0.85	8.84	54.81	19.02	0.32	0.12
11	14.47	1.62	11.67	64.82	6.68	0.40	0.34
8	14.47	2.38	18.29	58.61	5.68	0.39	0.08
5	11.70	2.15	25.19	54.93	5.57	0.25	0.02
3	12.87	1.79	24.25	55.20	5.41	0.40	0.07
Mature	11.87	2.20	22.20	54.91	5.53	0.43	0.05
2 days after maturity	12.11	2.08	26.77	53.74	4.77	0.29	0.25

Accumulation of Major Nutritive Substances during Grain Filling

Protein and fat

The absolute content of protein increases as seeds develop, especially in late May when it increases rapidly and reaches the maximum as a result of nitrogen retranslocation from different parts of the plant following the senescence of leaves. Then the content decreases as the dry weight of seeds decreases. The relative content of protein fluctuates during the grain-filling stage (Table 27).

The fat content increases during seed development, although it is not high. The maximum of absolute fat content appears after the dry matter, protein and starch contents have reached their peaks.

Table 26. Comparison of amino acid contents of faba bean, soybean and kidney bean.

Amino acid	Faba bean		Soybean		Kidney bean	
	Mean	SD	Mean	SD	Mean	SD
Aspartic acid	2.669	0.391	4.307	0.401	2.316	0.292
Threonine	0.878	0.114	1.405	0.114	0.855	0.059
Serine	1.166	0.135	0.916	0.165	1.143	0.123
Glutamic acid	4.124	0.341	7.518	0.738	3.268	0.442
Glycine	0.971	0.334	1.545	0.131	0.776	0.063
Alanine	1.024	0.151	1.552	0.129	0.781	0.060
Cystine	0.317	0.081	0.651	0.059		
Valine	1.015	0.171	1.703	0.143	1.085	1.153
Methionine	0.098	0.048	0.380	0.099	0.241	0.019
Isoleucine	0.899	0.106	1.633	0.185	0.952	0.113
Leucine	1.713	0.226	2.854	0.260	1.675	0.196
Tyrosine	0.795	0.105	1.344	0.109	0.650	0.060
Phenylalanine	1.051	0.109	1.911	0.163	1.113	0.129
Lysine	1.559	0.149	2.367	0.199	1.408	0.104
Histidine	0.579	0.075	0.923	0.086	0.536	0.070
Arginine	2.204	0.250	2.871	0.364	1.244	0.172
Proline	0.728	0.196	1.777	0.183	0.495	0.063
Total	21.955	2.128	36.733	3.296	18.719	1.971
Standard (egg albumen)	32.475	1.245	33.394	0.443	39.143	0.533
Sample number	15		17		24	

Changes in carbohydrate and nitrogen contents

Jin and Zhuang (1984) determined the soluble sugars and total nitrogen contents at the late productive stage using the variety 'Jia Din San Bei Dou' in Shanghai. Although there were some differences among treatments, the patterns of change were similar (Fig. 16). The content of soluble sugars decreased sharply after flower bud emergence, then increased gradually after the beginning of blooming. It decreased rapidly again at the end of pod-setting, which coincided with the accumulation and consumption of photosynthetic products.

The total nitrogen content stayed at a high level from flower bud emergence to the beginning of blooming, then decreased continuously before rising slightly as the seeds developed after blooming. The carbon/nitrogen ratio (C/N) dropped to the lowest at the beginning of blooming, and then rose to the highest at the end of pod-setting. The pattern of the C/N ratio curve was similar to that of soluble sugars (Fig. 16).

Table 27. The accumulation of protein and fat during the grain-filling stage.

Date	Protein		Fat	
	%	mg/seed	%	mg/seed
22 April	22.83	17.0	1.91	1.43
27 April	21.52	17.9	2.81	2.33
2 May	23.25	23.7	3.70	3.77
7 May	25.56	26.6	2.60	2.71
12 May	26.85	38.9	2.56	3.71
14 May	22.41	39.7	2.59	4.58
17 May	21.08	54.8	1.82	8.01
20 May	20.50	84.5	2.04	12.18
22 May	20.91	98.7	1.73	11.07
25 May	17.37	114.6	1.60	14.56
28 May	22.07	169.9	1.31	13.49
30 May	20.66	173.5	1.54	15.86
2 June	18.72	155.4	1.87	19.07
4 June	26.72	163.7	1.22	11.96

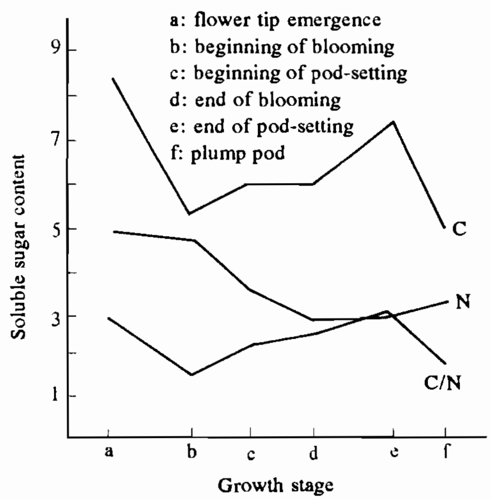

Fig. 16. The tendencies of sugar, total nitrogen and C/N ratio during middle and late growth stages of faba bean.

Dynamic Changes of Tannin Content in the Seed Coat

The high tannin content of faba bean limits wider use of the crop. It is known that 60-90% of the tannin is concentrated in the seed coat. Zhao (1987) studied the tannin contents of six varieties at different development stages. Tannin could be detected at the beginning of seed development, its concentration being already high in high-tannin varieties (Table 28). Then it decreased gradually as the dry weight of the seed coat increased rapidly, but the total amount increased continuously, reaching the maximum on 17 or 24 May (Fig. 17). There was no decrease in tannin synthesis in this stage of development, but during maturity, degradation of tannin occurred (Table 29).

Table 28. Tannin content (%) at different development stages of six faba bean varieties.

Date	'r82-1'	'San Bei Dou'	'C59-2'	'Chen Hu No. 10'	'Da Bei Can'	'Ri Ben Dou'
27 Apr	1.32	9.60	7.03	14.71	8.60	9.72
4 May	1.50	6.50	6.49	8.65	6.81	7.63
10 May	1.80	4.30	5.95	3.59	5.01	5.53
17 May	2.30	3.15	4.18	4.30	4.27	5.26
24 May	1.50	6.20	4.08	3.81	4.07	4.96
31 May	0.45	6.03	5.09	5.48	3.86	5.46
7 June	0.16	5.17	3.32	5.41	5.07	5.54

Table 29. The degradation of tannin in seed coat during the late development stage of six faba bean varieties.

	'r82-1'	'San Bei Dou'	'C59-2'	'Chen Hu No. 10'	'Da Bei Can'	'Ri Ben Dou'
a	4.94	11.28	8.03	7.11	10.44	9.88
b	0.18	7.25	4.39	5.54	6.58	9.20
c	3.76	4.03	3.64	1.57	3.86	0.68
c/a	95.43	35.73	45.33	22.08	36.97	6.88

a: The maximum tannin content during development (mg/seed).
b: Tannin content at maturity (mg/seed).
c: Degraded tannin (mg/seed).
c/a: Degradation (%).

The low-tannin variety 'r82-1' contrasted sharply with the high-tannin varieties (Fig. 17). Although tannin also was synthesized during the early and middle stages of development,

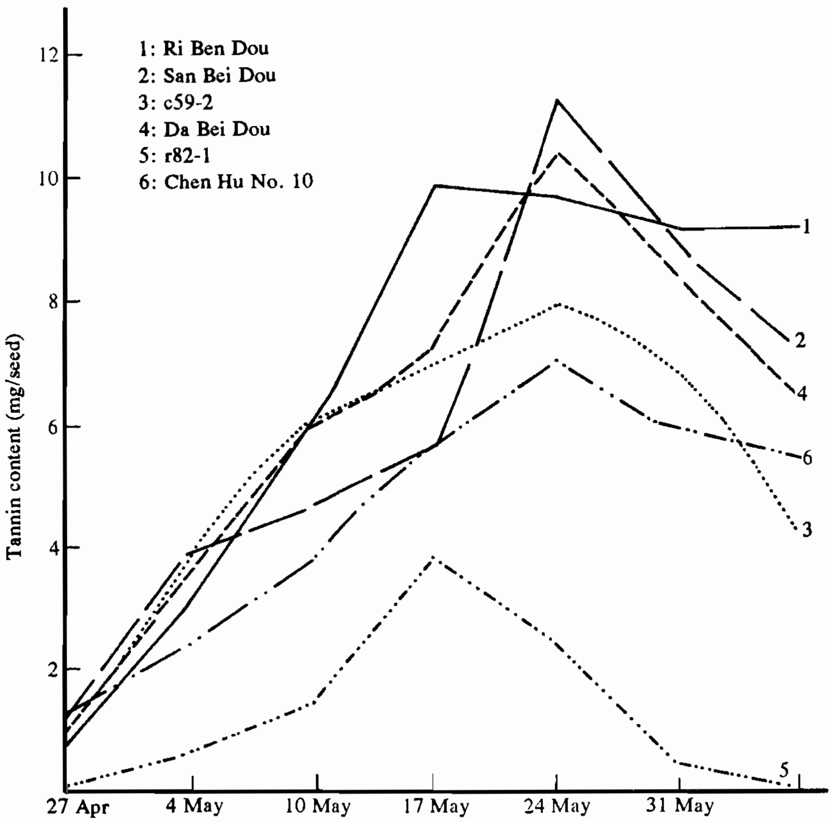

Fig. 17. The changes of tannin content in seed coat of faba bean.

in 'r82-1' the tannin content remained low. Its maximum tannin content was only 42% of the high-tannin varieties. At maturity, its tannin content was only 3% of the other varieties.

According to dry weight changes of the seed coat and the total tannin content, the seed development period could be divided into two periods: tannin-synthesizing and tannin-degrading. The synthesizing period lasted for 40-50 days from fertilization to early maturity. The dry weight of seed coat was light in varieties having a short synthesizing period. The degrading period lasted for 1-3 weeks from early maturity to harvest.

There were significant positive correlations between dry weight of seed coat and total tannin content during seed development. The correlation coefficients were: r = 0.73 in 'r82-1', 0.84 in 'San Bei Dou', 0.92 in 'c59-2', 0.94 in 'Chen Hu No. 10' and 0.97 in 'Da Bei Can' and 'Ri Ben Dou.' The seed coat in the low-tannin variety was thinner, and the 100-seed weight was less.

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Chapter 4. Study and Utilization of Faba Bean Germplasm Resources

General Situation

Germplasm resources are the foundation for selecting new varieties. The Chinese government has paid great attention to collection and research of faba bean germplasm. Collection has been conducted since 1956 in many provinces, municipalities and autonomous regions. Research on faba bean germplasm resources has been included in the national research program since 1978. In order to serve the breeding programs of faba bean better, the guiding ideology for research on germplasm resources has been nation-wide collection, safe preservation, in-depth research and creativity. The whole project included two stages: 1978 to 1985 was a stage of nation-wide collection, cataloging of the collected germplasm and evaluation of agronomic characters on some of the collected germplasm. From 1985 onwards, it has been a stage of identification and preservation, with further collection. About 2000 faba bean germplasm accessions had been collected by 1989 from 21 provinces, municipalities and autonomous regions of the country. However, because of the complication of different names for the same accession, or different accessions with the same name, the actual figure was about 1500 after proper identification. Germplasm resources have not yet been collected in five provinces, municipalities or autonomous regions. Collection also needs to be continued in remote areas in the rest of China (Lang 1988).

Owing to the long history of faba bean cultivation in China, varied climate, topography and soil types, and a long history of artificial and natural selection, many faba bean germplasm resources exist. According to surveys in 21 provinces, municipalities and autonomous regions, faba bean germplasm resources are more plentiful in Zhejiang, Yunnan, Sichuan, Hubei, Anhui, Hunan, Guizhou, Shanxi and Inner Mongolia than in Jiangsu, Jiangxi, Shaanxi, Fujian, Gansu and Tibet. The fewest resources exist in Qinghai, Henan, Hebei, Guangxi, Xinjiang and Ningxia (Zheng 1987).

Ecotypic Division of Faba Bean Germplasm

Faba bean in China can be divided into the autumn-sown and spring-sown ecotypes. The autumn-sown ecotype covers 80% of the total faba bean cultivated areas. It is grown from 20°N to 33°N and 98°E to 122°E. The spring-sown ecotype, which only covers 20% of the total area, is grown more widely than the autumn-sown ecotype, from 31°N to 46°N and 90°E to 122°E, and in Tibet, western Sichuan and northwestern Yunnan.

Average temperatures, rainfall, sunshine hours and means of 13 agronomic and yield

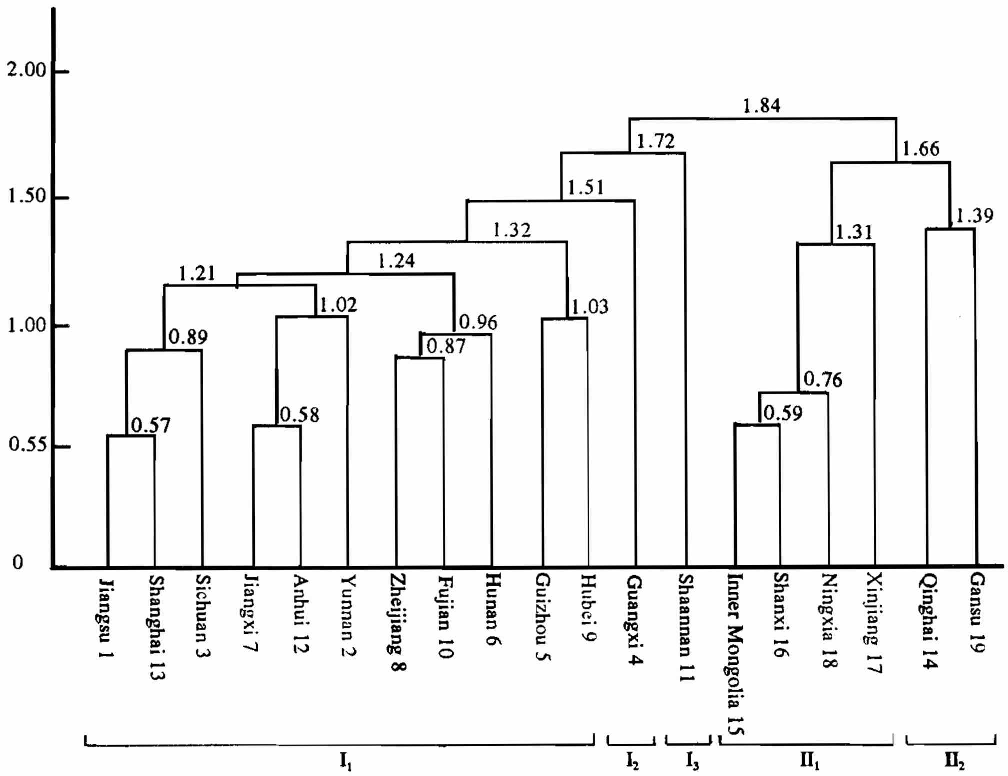

Fig. 18. Cluster analysis of China's faba bean germplasm resources.

characters of local faba bean varieties were obtained from the provinces, municipalities and autonomous regions where faba bean is grown to some extent. Ten years of data were collected and subjected to cluster analysis based on Euclidean distances (Zheng 1989). From the result, the 19 provinces, municipalities and autonomous regions could be divided into two groups (Fig. 18). These two groups accord with the areas where the autumn-sown and spring-sown ecotypes are grown (Fig. 19).

The Autumn-sown Ecotype

Subdivision of the autumn-sown ecotype

The differences in ecological and climatic conditions among the 11 provinces, municipalities and autonomous regions where the autumn-sown ecotype is grown are not obvious, except between Guangxi and southern Shaanxi. This ecotype can be divided into three different sub-ecotypes according to the results of the cluster analysis shown in Fig. 18.

Fig. 19. Ecotype division of China's faba bean germplasm resources.

1. Yangtze River Basin sub-ecotype: located in southeastern China along the coast and most of the hinterland provinces. It includes Zhejiang, Jiangxi, Shanghai, Fujian, Hunan, Guizhou, the central and southern parts of Jiangsu and Anhui, southern Henan, the eastern half of Sichuan and most of Yunnan (except the northwest). It forms a vast belt stretching from east to west.

2. South China sub-ecotype: includes Guangxi and Guangdong.

3. South Shaanxi sub-ecotype: includes southern Shaanxi south of Qinling Mountain and small parts of southeastern Gansu. Faba bean germplasm resources of Shaanxi concentrate in the southern part of the province south of Qinling Mountain.

Ecological conditions and germplasm characteristics

Yangtze River Basin sub-ecotype. Yunnan and Guizhou provinces are situated on a plateau. Except for the southwest of Yunnan, which has a tropical humid plateau climate, the majority of the Yangtze River Basin has a humid subtropical monsoon climate with mild winters but extremely hot summers. Jiangxi and Hunan are located to the south of the Yangtze River. Many mountains are found in the southern and western parts of these two provinces, but their central and northern parts are relatively flat. Jiangsu, Zhejiang and Shanghai are located on the eastern coast of China. The northern part of northern Jiangsu, where there are major irrigation canals, has a warm temperate semi-humid monsoon climate. Hubei, Henan and Anhui are located along the Yangtze River. There are many mountains in the western and southern parts of these three provinces, but the rest is flatland. Although areas south of the Huai River have a subtropical humid monsoon climate, those areas north of the Huai River have a warm temperate semi-humid monsoon climate. Eastern Sichuan, eastward from Yaan River and Xichang City, also has a subtropical humid monsoon climate. Thus it can be said that most areas where the Yangtze River Basin sub-ecotype is growing have a humid subtropical monsoon climate.

In the Yangtze River Basin, the cumulative temperature (> 0°C) for the faba bean growing period is 2300-3000°C. The amount of sunshine is enough for growing faba bean, except in eastern Sichuan which is rather foggy and has less sunshine. Sowing time is from early October to early November, and harvesting time is from mid-April to late May. The total growth period is 150-235 days, with an average of 205 days.

The plant height of this sub-ecotype is 30-150 cm (mostly 50-110 cm), and the average is 94.5 cm. The number of pod-bearing branches/plant is 2.5-4.8 (average 3.9). The number of pods/plant is 3-98 (mostly 12-24), and the average is 17.8. The pod length ranges from 3.5 to 9.0 cm, usually 6-8 cm. The number of seeds/pod is 1.0-3.8 (mostly 1.7-2.2), and the average is 1.9. The 100-seed weight ranges from 35 to 170 g, although most are 60-95 g, with an average of 76.8 g. Medium-size seeds are typical of this sub-ecotype.

South China sub-ecotype. This sub-ecotype is grown in the southernmost region in China where there is a subtropical humid monsoon climate. During the faba bean growing period, the weather is warm and almost frost free, with a cumulative temperature (> 0°C) of 2500-3000°C. Rainfall is enough for growing faba bean, but the number of sunshine hours is less than most of the provinces in the Yangtze River Basin. Sowing time is in late November, and harvesting time is from mid-March to mid-April. The total growth period is 96-160 days (mostly 110-140 days), with an average of 116 days.

The plant height of the South China sub-ecotype ranges from 30 to 60 cm, usually 40-46.8 cm, and the average is 41.2 cm. Short and small plants are the typical characteristics in this sub-ecotype. The number of pod-bearing branches/plant is mostly 1.0-2.5 (average 2.1). The number of pods/plant is 4-16, generally 6-10. The number of seeds/pod is 1-3 (mostly 2-2.2), and the average is 1.8. The 100-seed weight ranges from 42 to 80 g (mostly 45-70 g), with an average of 54.1 g. Most varieties (> 64%) are of the small-seed type, and this is another characteristics of this sub-ecotype.

South Shaanxi sub-ecotype. The area grown with this sub-ecotype is very small, mainly in southern Shaanxi province south of Qinling Mountain plus a small part of southeastern Gansu. The south of this area is Daibai Mountain, and the central part is the Hanshui Valley and Hanzhong Basin. The area has a humid subtropical monsoon climate. It is warm in winter, but the temperature is never high. It is thus suitable for growing faba bean. The cumulative temperature (> 0°C) within the faba bean growing period is over 2300°C. Sunshine is ample, but the rainfall is a bit too little.

There are four characteristics in this sub-ecotype: First, it is the earliest sown but the latest to mature in China. Sowing time is from late September to early October, and harvesting time is from late May to early June the next year. Second, it has the most pods/plant, from 23 to 94 with an average of 58.6. Plant height ranges from 65 to 130 pods/plant, from 23 to 94 with an average of 58.6. Plant height ranges from 65 to 130 cm (average 99.5 cm). Third, varieties having small seeds and lower 100-seed weight are dominant. There are 92% small-seed and 8% medium-seed varieties, with no large-seed types. The number of seeds/pod is 1.4-3.6, mostly between 1.7 and 2.2, and the average is 2.0. The 100-seed weight is 32-78 g, with an average of 53.8 g. Fourth, 88.9% of the varieties in this sub-ecotype have a green seed coat at maturity, the highest percentage in the autumn-sown region.

The Spring-sown Ecotype

Subdivision of spring-sown ecotype

The spring-sown faba bean ecotype can be divided into two sub-ecotypes according to the results of the cluster analysis shown in Fig. 18:

1. North China sub-ecotype: mainly grown in Xinjiang, Inner Mongolia, Ningxia, Shanxi, the northern parts of Hebei and Shaanxi, the central and northern parts of Gansu and the northern part of Beijing and Tianjin.

2. Qingzang sub-ecotype: mainly grown in Tibet, Qinghai, the southern part of Gansu, the western part of Sichuan and the northwestern part of Yunnan.

Ecological conditions and germplasm characteristics

North China sub-ecotype. The northern parts of Hebei and Shanxi are arctic-alpine areas; the central region is warmer, having a temperate to warm-temperate semi-arid continental monsoon climate. Inner Mongolia and Ningxia Autonomous Regions are situated on the Mongolian Plateau. There is a large longitudinal span from Inner

Mongolia to Ningxia, crossing four rainfall zones from the humid northeast to the arid southwest, but as a whole this area has a temperate continental climate. This sub-ecotype is also grown in the central and northern parts of Gansu.

The cumulative temperature (> 0°C) of the faba bean growing period in the above areas is generally 2400-2800°C. The total sunshine duration is about 1400 hours, but rainfall is less than 350 mm. Irrigation is necessary for growing faba bean. Sowing time is from early April to early May, and harvesting time is from early July to early August. Plant height of most of the germplasm is 50-90 cm, with an average of 68 cm. The number of pods/plant is 8-18, and the average is 9.6. The 100-seed weight is generally low, ranging from 31 to 130 g (mostly 62-70 g), and the average is 69 g. Small-seed type is dominant, and large-seed and medium-seed types are few.

Qingzang sub-ecotype. Most of this sub-ecotype is grown on the Qingzang Plateau and the Loess Plateau. The area is vast and the topography is rather complicated. There are different types of climate; Tibet has a plateau climate, while Qinghai has a continental plateau climate. In western Sichuan, where temperature is not high but sunshine is intense and rainfall is abundant, there are both temperate and subtropical plateau climates.

The southern part of Gansu has a humid to sub-humid temperate climate. In these areas, faba bean is mainly planted in small plains, valleys and hills at 800-2500 m above sea level, where it is cold in spring and cool in summer. The cumulative temperature (> 0°C) of the faba bean growing period is 2000-2400°C. The amount of sunshine is 1450-1500 hours, and the total rainfall is 250-350 mm. It is necessary to irrigate. Sowing time is from mid- to late March, and harvesting time is between mid- and late August. The total growing period ranges from 140 to 170 days (150-165 days for most varieties). Plant height is 50-180 cm (mostly 120-130 cm). The number of seeds/pod is 1.0-4.1 (mostly 1.6-3.0), and the average is 2.2. The 100-seed weight is 60-200 g (mostly 120-180 g), and the average is 244 g. This is the sub-ecotype having the highest 100-seed weight among the five sub-ecotypes in China. About 95% of the varieties in this sub-ecotype have a milky white seed coat, which changes from white to brown easily. There is no variety with a green seed coat in this sub-ecotype.

Types of Faba Bean Germplasm

Seed Types

Faba bean germplasm in China can be classified into three classes based on seed size: large, medium and small types (Table 30, Fig. 20). The three types are adapted to different ecoregions and various usages (Lang 1982).

Table 30. Agronomic characters of large-, medium- and small-seed faba bean germplasm in China.

Character	Large seed: Northern China	Large seed: Southern China	Medium seed	Small seed
Plant height (cm)	141.5 ± 20.5	132.8 ± 6.4	128.2 ± 13.4	123.0 ± 19.2
No. pods/plant	29.5 ± 17.7	25.6 ± 8.8	25.8 ± 6.2	28.7 ± 0.5
Pod length (cm)	8.8 ± 1.8	8.4 ± 0.5	8.4 ± 0.9	8.1 ± 2.0
Pod width (cm)	1.9 ± 0.6	1.9 ± 0.1	1.8 ± 0.2	1.6 ± 0.2
No. seeds/plant	44.3 ± 14.6	41.0 ± 15.1	49.1 ± 10.6	64.9 ± 14.8
Seed length (cm)	-	2.1 ± 0.6	1.7 ± 0.2	1.5 ± 0.2
Seed width (cm)	-	1.5 ± 0.1	1.3 ± 0.1	1.2 ± 0.2
100-seed weight (g)	148.5 ± 30.4	127.6 ± 5.8	86.5 ± 13.1	64.4 ± 17.2
Seed yield/plant (g)	64.8 ± 9.8	48.3 ± 13.9	42.4 ± 9.8	38.8 ± 11.0
Days from sowing to maturity	161.0 ± 9.9	212.0 ± 0.9	210.0 ± 3.1	207.0 ± 1.9

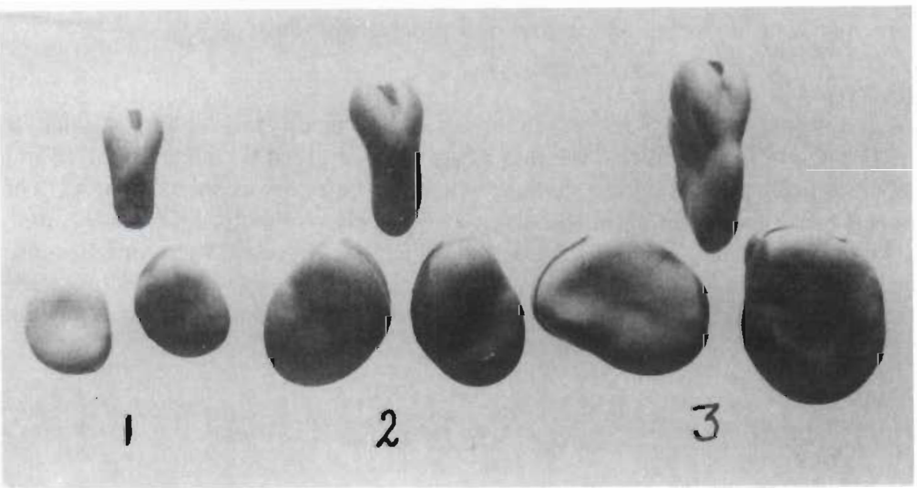

Fig. 20. Faba bean seed types: (1) small; (2) medium; (3) large.

Large-seed type

The 100-seed weight of this type exceeds 120 g. The seed shape usually is wide-thin or wide-thick. The color of the seed coat can be green, although the main color is milky white. Plant height is about 140 cm. This type occupies only 6.5% of China's total faba bean germplasm resources. Its main distribution is in Qinghai and Gansu, but it is also found in Zhejiang, Yunnan and Sichuan. Representative varieties are Zhejiang Cixi 'Dabaican', Qinghai Huangyang 'Maya', Gansu Linxia 'Maya' and Sichuan Xichang 'Dacandou'. These varieties need high fertilization for optimal yield. They cannot tolerate wet soils in paddy fields, and are only fit for growing on well-drained fields. However, the seeds produced are of good quality, delicious, large and attractive in color, and have high commercial value. They are suitable for use as a food crop and as a green vegetable. They are China's traditional faba bean export varieties.

Medium-seed type

The 100-seed weight of this type is between 70 and 120 g. The seed shape usually is medium-thin or medium-thick. The color of the seed coat is mainly green. This type is the most common, and has a wide distribution over the country, occupying 52% of China's total faba bean germplasm resources. It is found mainly in Zhejiang, Sichuan, Yunnan, Jiangsu, Guizhou, Xinjiang, Ningxia, Fujian and Shanghai. Representative varieties are Zhejiang Shangyu 'Tianjiqing', Sichuan 'Chenghu 10 Hao', Yunnan Kunming 'Beipidou' and Jiangsu 'Gidou 1 Hao'. Characteristics of these local varieties are wide adaptability, good tolerance to soil-wetness, tolerance to diseases and high yield. They are grown in paddy fields as well as on well-drained land. The seeds they produce are suitable for use as a food crop and in the food-processing industry.

Small-seed type

The 100-seed weight of this type is less than 70 g. Seed shape is mostly narrow-thick or globular. The color of the seed coat is either milky white or green. Plants are shorter and the number of pods/plant is higher than the other two types. It occupies about 42% of China's total faba bean germplasm resources. It is mainly distributed in Hubei, Anhui, Shanxi, Inner Mongolia, Hunan, Jiangxi and Shaanxi. Representative varieties are Zhejiang Pingyang 'Zaodouzi' and Shaanxi 'Xiaohudou.' These local varieties do not need high doses of fertilizers because they possess strong tolerance to soil infertility. They are usually used as animal feed and green manure.

Growth Types

In China, faba bean can be divided into two main types—spring and winter—according to growth habit (Zheng 1989). The spring type is planted in the spring-sown region. It can tolerate low temperatures of 3-5°C at the seedling stage. If it is planted in the autumn-sown region, it cannot tolerate the low winter temperatures and may not be able to survive. About 30% of China's total faba bean germplasm is the spring type, among which there are about 15, 50 and 35% of large-, medium- and small-seed types, respectively. The spring large-seed type occupies 70% of China's total large-seed faba bean germplasm resources.

The winter type is planted in the autumn-sown region. It can winter safely because of its tolerance to low temperatures of -1 to -5°C at the seedling stage. The main stem usually dies in winter, but its branches continue to grow in the following year. The winter-type germplasm occupies about 70% of China's total faba bean germplasm resources, among which there are about 3, 55 and 42% large-, medium- and small-seed types, respectively.

Plant Types

The plant height of faba bean is quantitatively inherited and is influenced by both genetic and environmental factors. Large differences in the amounts of rainfall and in soil fertility among regions create an obvious variation in plant height among the faba bean germplasm. In the spring-sown region where rainfall is less and soil fertility is poorer, accessions of short plant stature are more common, reaching 48.8% of the total. The shortest plant height is 30 cm. Accessions of medium and tall plant height occupy 17.5 and 33.7% of the total, respectively. In the autumn-sown region where rainfall is sufficient and soil fertility is better, short accessions are fewer (only 18.5% of the total). The shortest plant height is 38 cm. Accessions of medium and tall plant height occupy 63.4 and 18.1% of the total, respectively. In China's total faba bean germplasm resources, there are about 27.4% short types, 50% intermediate types and 22.6% tall types.

In addition, China's faba bean germplasm resources can be divided according to flower color into the white and purple (spotted) types. The white type is much less common.

According to usage, faba bean can also be divided into food or forage types. Large-seed and medium-seed types are used as food. Small-seed types are used as food and forage in the spring-sown region, but as green manure in the autumn-sown region.

Evaluation and Utilization of Faba Bean Germplasm

Collection, Evaluation, Cataloguing and Preservation

Since 1978, China has begun to study faba bean germplasm resources on a national basis (Zheng 1989). The first conference on germplasm research was held in 1981 in Zhejiang province. During the conference, standardization of descriptors for faba bean germplasm evaluation was achieved. The descriptors include phenological periods, morphologic characters and agronomic characters. Based on these standardized descriptors, each province, municipality and autonomous region evaluated the collected faba bean accessions. After 5 years of research, a great deal of experimental data were obtained. Using this information, Chinese scientists started to produce the "Catalogue of Faba Bean Germplasm Resources in China" in 1985. The catalogue includes 24 items, which are: collection number, name, origin, growth type (winter or spring type), time of sowing (month/day), 50% seedling stage (month/day), 50% flowering stage (month/day), time of 80% maturity (month/day), total growth period (days), plant height (cm), flower color, number of pod-bearing branches/plant, number of pods/plant, pod length (cm), pod width (cm), number of seeds/plant, number of seeds/pod, seed length (cm), seed width (cm), seed size, seed shape, seed color, 100-seed weight (g) and seed yield/plant (g).

Since 1985, accessions that had been evaluated and catalogued have gradually been put into the national gene bank for long-term storage at low temperature. The number of seeds is 1500-2000 per accession.

Through identification and evaluation of phenological, morphological and agronomic characters of faba bean germplasm, preliminary results have been obtained on three aspects.

Yield components

Yield/plant is determined by three main components: pods/plant, seeds/pod and seed weight. Statistics on Chinese national faba bean germplasm resources show that the lowest number of pods/plant is 2-3, and the highest is 93.7. Accessions with more than 20 pods/plant were collected mainly from Zhejiang, Shaanxi, Sichuan, Qinghai and Guizhou. Accessions having 15-20 pods/plant came mainly from Hubei, Gansu, Xinjiang and Shanghai, while accessions from the other provinces have fewer than 15 pods/plant. The number of seeds/pod varies from 1.7 to 2.9. Accessions with more than 2 seeds/pod originate mainly from Zhejiang, Gansu, Fujian, Shaanxi, Guizhou and Shanghai. The variability in seed yield/plant is also large. The lowest seed yield/plant is 2.6 g; the highest is 103.2 g. Accessions having more than 50 g of seed yield/plant originate mainly from Qinghai and Shaanxi. Accessions from Zhejiang and Gansu have seed yields > 35 g, while those from Shanghai and Sichuan have 32 g. Accessions of other provinces, municipalities and autonomous regions all have seed yields of < 30 g.

Pod length

Faba bean accessions with pod length longer than 10 cm have not been discovered in China yet. About 60% of China's faba bean germplasm has a pod length of 5.5-6.5 cm. Accessions with pod length of 6.6-7.5 cm comprise 16%, while those longer than 7.6 cm comprise 24% of the total. Accessions with longer pods were collected mainly in Zhejiang, Fujian, Gansu, Qinghai and Shanghai. Accessions with shorter pods came mainly from Shanxi, Inner Mongolia, Ningsia, Hunan and Shaanxi, while accessions from the other provinces, municipalities and autonomous regions are of medium pod length.

Seed color

China's faba bean germplasm resources can be divided into six groups based on seed-coat color. They are white or yellowish-white (about 46% of China's total faba bean germplasm resources), light green (27%), green (12%), dark green (4%), brown or red (5%) and other colors (6%). Studies indicate that the seed coat of faba bean is easily oxidized into brown because it contains tannin. This oxidative procedure is called browning. Seeds with green or dark green color can be preserved 1-2 years without browning, but seeds with milky-white color will turn brown 3-5 months after harvesting. Browning affects the commercial value of faba bean seeds and research is needed to solve this problem.

Evaluation of Specific Characters and Analysis of Major Nutrient Components

In order to allow wider utilization of the collected faba bean germplasm, 500 accessions were selected out of China's 1500 accessions for further evaluation, including analysis of the major nutrient components.

Resistance to diseases

Accessions with strong or partial resistance to chocolate spot (*Botrytis fabae*) and brown spot (*Ascochyta fabae*) diseases, based on the 1 to 5 scale of scoring, have not been discovered yet. Only 6% of the accessions have medium resistance to these two diseases. These accessions originate mainly in provinces along the middle and lower reaches of the Yangtze River. Most of the 500 accessions are moderately or highly susceptible to these two diseases.

Tolerance to soil wetness

Chinese autumn-sown faba bean is distributed mainly in provinces along the Yangtze River, and it is planted mostly in paddy-fields where the water-table level is high, much rainfall comes in spring and the soil is wet. Therefore, tolerance to soil wetness in faba bean is a very important character. Results of studies indicate that only 7-8% of the 500 faba bean accessions possess relatively strong tolerance to soil wetness. These accessions came mainly from Zhejiang and Hubei provinces. Some of them were collected in Sichuan and Yunnan provinces.

Tolerance to salinity

Identifying salinity tolerance aims at expanding the growing areas of faba bean along the coast and in the northwest of China, where there is a vast extent of alkali-saline soils. The study indicates that there are few accessions with strong tolerance to salinity. These accessions originate mainly from Zhejiang, Fujian, Gansu and Shaanxi provinces.

Analysis of the major nutrient components

The major nutrient components studied were total protein, amino acid, fat, total starch and amylose content in faba bean seeds. According to the analysis, there is no obvious difference in the major nutrient components among accessions collected from different provinces, municipalities and autonomous regions of China. The minimum and maximum seed protein content is 17.48 and 34.52%, respectively, although most of them are between 25.40 and 29.8% with an average of 27.08%. For the total of 17 amino acids, the minimum is 18.07%, the maximum is 32.85% (mostly 24.17-29.99%), and the average is 27.08%. The minimum fat content is 0.55% and the maximum is 2.61%. Most accessions are within the range of 1.18-1.82% fat content, with an average of 1.50%. For the total starch content, the minimum is 33.17% and the maximum is 53.36%, but most lie within 39.2-45.53% with an average of 42.40%. For the amylose content, the minimum, maximum and average is 6.00, 27.92 and 10.64%, respectively, although most accessions are between 8.84 and 12.44%.

Utilization of Faba Bean Germplasm Resources

The most important aim of collecting germplasm is utilization (Lang 1982). Germplasm accessions consist of local varieties that possess strong adaptability to local, natural and cultivated conditions (Zhao 1979). Some superior local varieties such as Zhejiang Cixi 'Dabaican', Qinghai Huangyuan 'Maya', Gansu Linxia 'Maya', Yunnan Kunming 'Beipidou' and Sichuan Xichang 'Dacandou' have been utilized in breeding up to the present.

Systematic selection is an effective and economic means of utilization. From the local varieties, new varieties that satisfy the breeding objectives can be selected. For example, new varieties such as 'Yundou 80-15' and 'Yundou 80-56', which possess higher yield, stronger tolerance to low temperatures and higher resistance to diseases, were selected from the local variety Yunnan Kunming 'Beipidou' by the Yunnan Academy of Agricultural Sciences. The new line 'Zhehang 119', which possesses early maturity, tolerance to late sowing and adaptability to a triple cropping system of faba bean/early rice/late rice, was selected from the local variety Zhejiang Pingyang 'Zaodouzi' by the Zhejiang Academy of Agricultural Sciences.

The evaluation of faba bean accessions aims at providing information for selecting parents for making crosses; thus it helps speed up the progress in breeding (Zhao 1979). Since 1985, five new faba bean varieties have been successfully developed by employing sexual hybridization with local varieties. These new varieties are 'Zhehang 41 Hao' in Zhejiang, 'Chenghu 11 Hao' in Sichuan, 'Lincan 2 Hao' in Gansu, 'Tongyan 1 Hao' in Jiangsu and 'Qinghai 4 Hao' in Qinghai. They have been released for large-scale seed multiplication and demonstration.

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Chapter 5. Faba Bean Breeding

General Conditions

Development and distribution of superior varieties are economic and effective measures to obtain stable and high yields in faba bean. Faba bean breeding in China started in the 1950s, later than other crops. After the 1960s, selection and breeding of new varieties were carried out gradually in various provinces of China. According to incomplete data, 61 superior local varieties were screened and identified, 22 varieties were developed by systematic selection, 13 by crossbreeding and 19 by foreign introduction. Altogether 115 varieties were identified or developed in 16 provinces, municipalities and autonomous regions all over China (Table 31).

Table 31. Number of faba bean varieties developed and introduced in different provinces of China.

Province	Superior local varieties	Introduced varieties	Systematically selected varieties	Cross-bred varieties
Zhejiang	17	2	4	1
Sichuan	3	2	4	2
Yunnan	13	2	4	1
Jiangsu	2	2	4	1
Hubei	2	2	3	0
Shanghai	2	2	0	1
Fujian	3	0	2	0
Guangdong	0	0	1	0
Guizhou	2	0	0	0
Jiangxi	1	0	0	0
Anhui	2	0	0	0
Gansu	4	4	1	2
Qinghai	5	3	3	4
Tibet	1	0	0	1
Shaanxi	2	0	0	0
Inner Mongolia	2	0	0	2
Total	61	19	26	15

During the 1950s, work was focused on the selection of superior local varieties. As a result, many local varieties with unique characteristics were selected. For example, many local superior varieties such as Zhejiang Cixi 'Dabaican', Zhejiang Shangyu 'Tianjiqing', Gansu Linxia 'Maya', Qinghai Huangyuan 'Maya', Sichuan 'Guanganhong', Yunnan Kunming 'Baipidou', Jiangsu Nantong 'Shanbaidou' and Hubei Xiangyang 'Dajiaoban' showed high yield potentials for many years. Among them, Zhejiang Cixi 'Dabaican', Gansu Linxia 'Maya' and Qinghai Huangyuan 'Maya' are still the best known and best varieties, with high and stable yields in China and abroad. After the 1960s, Chinese food legume breeders developed many superior varieties, mainly by systematic selection and crossbreeding, such as Zhejiang 'Zhehang 41 Hao', Jiangsu 'Gidou 1 Hao', Sichuan 'Chenghu 10 Hao', Gansu Linxia 'Dacandou' and 'Qinghai 3 Hao.' All played important roles in faba bean production. Although the area covered by faba bean in China is decreasing year after year, the total yield is increasing because of the rapid increase of yield per unit area due to the spread and cultivation of new varieties.

Breeding Goals

To determine the breeding goal is the prerequisite of faba bean breeding. The breeding goal should not only reflect the demand of the market, but also follow the laws of genetic inheritance, obtain the maximum photosynthesis production rate and coincide with the special production conditions. The main goals are to enhance stable and high yield potential and good quality.

In determining the goals of breeding in different regions, two basic characteristics of faba bean should be considered. First, faba bean is a crop with multiple usage: food, vegetable, fodder or green manure. When developing a variety for food, large seeds with high protein contents, optimal amino-acid content and high yield are required. When developing a variety for green manure, many branches with large amounts of fresh matter and nodules for nitrogen fixation are needed. Second, the limited ecological adaptability of faba bean requires that it be adapted to many natural environmental conditions and farming systems in order to develop varieties with wider adaptability.

On the whole, the breeding goals of autumn-sown faba bean in China are for high, stable yield (300-4500 kg/ha), disease resistance (rust, *Botrytis fabae*, *Ascochyta fabae*, etc.), strong humidity tolerance, good quality (more than 28% protein content, low tannin content) and early maturity, plus large-, medium- and small-seed varieties for various purposes.

Breeding goals of spring-sown faba bean are for stable high yield (3750-6000 kg/ha), disease and pest resistance (*A. fabae*, aphid, weevil, etc.), large, good seeds (100-seed weight > 150 g) with white seed coat and non-dehiscent pods. The varieties for fodder should be tall (plant height > 120 cm), with luxuriant vegetative growth and small seeds (100-seed weight < 70 g).

Main Breeding Systems

Collection, Identification and Purification of Local Varieties

China is a big country with complex natural environmental conditions and a long agricultural history. There are abundant local varieties of various crops obtained in the past through natural and artificial selection; faba bean is one of them. Local varieties are usually characterized by better adaptability, stronger stress tolerance and stable high yield. However, the physiological and ecological characters of these local varieties are manifold and the genotypes are complex. Some varieties are being mixed up. It is necessary to collect the local varieties widely, then by means of systematization, evaluation and identification, find superior varieties for production. Since the 1970s, collection, preservation, identification and utilization of local faba bean varieties have been carried out all over China and more than 2000 accessions were collected. The evaluation on pest resistance, drought, cold and salt tolerances and quality analysis were performed according to the national unified standard. Sixty-one superior local varieties were selected (Table 31). During the evaluation and identification process, selection was carried out carefully according to the genetic characteristics. The selected superior local varieties were tested and propagated before being introduced for wide production. Such varieties included Zhejiang Cixi 'Dabaican', Shangyu 'Tianjiqing', Qinghai Huangyuan 'Maya', Gansu Linxia 'Maya' and Yunnan Kunming 'Baipidou.' They are not only the commercial varieties for local production, but also the important sources for export which are well known in overseas markets.

Introduction and Evaluation

Introduction is a good way to improve faba bean varieties within a short period. According to recorded history, faba bean was introduced into China by Zhang Qian in the Han Dynasty when he was sent on a convoy to inspect the western regions. After the communist liberation (Lin 1984), the introduction of varieties developed rapidly. Varieties were not only introduced among provinces within China, but also from abroad. The number of varieties introduced successfully reached 19 according to the figures of 16 provinces, municipalities and autonomous regions (Table 31).

During the introduction process, blind introduction occurred, resulting in the failure of pod-setting. For example, farmers in the southern part of China liked the large-seed varieties that were grown in the north. The introduced spring-sown varieties from the north were planted in autumn. The vegetative growth was vigorous and the growth period was very long, but the economic traits were not good, resulting in late maturing and low yield due to the difference in ecological conditions between the north and the south. The late maturity also hampered the transplanting of early rice as a successive crop and affected production for the whole year.

To facilitate faba bean introduction, scientists from 11 provinces carried out the coordinated ecological tests during 1982 to 1985. The materials included outstanding superior varieties from the 11 provinces. Part of the results are shown in Table 32. It is obvious that the northern varieties that were introduced to the south usually showed prolonged growth period. There was a blooming stage but no pod-setting or only little pod-setting and failure to reach maturity. When the spring-sown faba bean varieties of

Table 32. The relationship of faba bean introduction and latitude.

Variety	Sowing	50% seedling emergence	50% blooming	50% pod-setting	Maturity
Zhejiang (30°N)					
Zhejiang Cixi 'Dabaican'	28 Oct	13 Nov	26 Mar	12 Apr	26 May
Yunnan Kunming 'Baipidou'	28 Oct	14 Nov	24 Mar	9 Apr	21 May
'Chenghu 10 Hao'	28 Oct	12 Nov	10 Mar	6 Apr	23 May
Hebei 'Dajiaoban'	28 Oct	11 Nov	4 Apr	19 Apr	31 May
Gansu Linxia 'Maya'	28 Oct	12 Nov	8 Apr	29 Apr	-
Yunnan (25°N)					
Zhejiang Cixi 'Dabaican'	12 Oct	24 Oct	9 Feb	10 May	25 Apr
Yunnan Kunming 'Baipidou'	12 Oct	24 Oct	5 Feb	7 Mar	25 Apr
'Chenghu 10 Hao'	12 Oct	24 Oct	21 Jan	2 Mar	25 Apr
Hubei 'Dajiaoban'	12 Oct	24 Oct	6 Feb	14 Mar	25 Apr
Gansu Linxia 'Maya'	12 Oct	24 Oct	11 Feb	-	-
Sichuan (32°N)					
Zhejiang Cixi 'Dabaican'	21 Oct	3 Nov	19 Mar	2 Apr	20 May
Yunnan Kunming 'Baipidou'	21 Oct	3 Nov	19 Mar	2 Apr	12 May
'Chenghu 10 Hao'	21 Oct	6 Nov	2 Mar	23 Mar	12 May
Hubei 'Dajiaoban'	21 Oct	4 Nov	19 Mar	2 Apr	20 May
Gansu Linxia 'Maya'	21 Oct	6 Nov	26 Mar	26 Apr	31 May
Hubei (32°N)					
Zhejiang Cixi 'Dabaican'	29 Oct	21 Nov	26 Mar	16 Apr	30 May
Yunnan Kunming 'Baipidou'	29 Oct	21 Nov	28 Mar	15 Apr	25 May
'Chenghu 10 Hao'	29 Oct	22 Nov	20 Mar	12 Apr	30 May
Hubei 'Dajiaoban'	29 Oct	21 Nov	29 Mar	20 Apr	31 May
Gansu Linxia 'Maya'	29 Oct	20 Nov	4 Apr	7 May	15 June
Gansu (40°N)					
Zhejiang Cixi 'Dabaican'	11 Mar	19 Apr	27 May	4 June	28 July
Yunnan Kunming 'Baipidou'	11 Mar	20 Apr	27 May	5 June	21 July
'Chenghu 10 Hao'	11 Mar	19 Apr	24 May	4 June	23 July
Hubei 'Dajiaoban'	11 Mar	19 Apr	27 May	5 June	30 July
Gansu Linxia 'Maya'	11 Mar	19 Apr	2 June	12 June	19 Aug

Gansu province situated at high latitude were introduced into Hubei and Sichuan, it was found that the growth period was 10 days longer. There was no pod-setting or pods failed to mature when grown in Yunnan and Zhejiang. The maturity stage would be more than 20 days earlier when the varieties of low latitude were introduced into regions of high latitude. It is suggested that introductions should be made in areas of similar latitudes and altitudes.

After the coordinated ecological tests, the blind introductions among provinces stopped. The scientific base was established for national introduction. The variety 'Xiangzhudou' was introduced from Zhejiang to Hubei, which now covers a large area and reaches an average yield of 3000 kg/ha and has become the main variety in Hubei province. Since 1963, the Sichuan Academy of Agricultural Sciences has introduced 96 local varieties from Zhejiang, Jiangsu, Hubei and other provinces.

Among these varieties, 'Pingyangqing', 'Shangzaozhao' and 'Fenghua 6 Hao' are all from Zhejiang and they are disease resistant. Two new varieties ('Chenghu 9 Hao' and 'Chenghu 10 Hao') were developed one after another from these three varieties through systematic selection and crossbreeding. 'Chenghu 9 Hao' and 'Chenghu 10 Hao' are disease resistant and show high yield potential. The cultivated area of these varieties reaches 4000-53 000 ha. 'Chenghu 9 Hao' and 'Chenghu 10 Hao' were awarded the Sichuan Provincial Scientific and Technical Achievement Prize and the Third-grade Scientific and Technical Advancement Prize in 1974 and 1986, respectively (Luo and Hu 1989).

Good results were obtained from international introduction; for example, in Gansu province, three vegetable type faba bean varieties ('174', '175' and '176') were introduced from England by the Qinghai Academy of Agricultural Sciences and are now widely grown in Gansu Province (Anonymous 1986). The average yield of these varieties is 3750-4875 kg/ha. The fodder type faba bean variety was first introduced to Xinjiang in 1962 and then introduced to Gansu by the Linxia Agricultural Research Institute. According to the data of the institute, the seed yield of this fodder type variety was 300-4500 kg/ha and the data of the Linxia Animal Husbandry Research Institute showed that the fresh fodder yield was 46 359 kg/ha, ranking first among the six varieties tested. It was 29.6% more than oat and 91.9% more than the fodder vetch (*Vicia sativa* L.). The adaptability of this variety is very wide as it can be grown in Qinghai, Inner Mongolia, Xinjiang and Gansu. Since the 1980s and the open-door policy in China, international cooperation of science and technology has been strengthened and the exchange of crop germplasm and breeding materials including faba bean developed. Varieties of determinate growth habit, long pod and large-seed type, and multiple flowers and pods type were introduced from ICARDA (International Center for Agricultural Research in the Dry Areas) in Syria in 1988 by Lang Lijuan of the Zhejiang Academy of Agricultural Sciences (Lang and Ying 1990; Lang *et al.* 1990). The varieties provided materials for development of new varieties in China.

Systematic Breeding

Systematic breeding is an individual selection procedure, which is called "single seed descendance" in China. This method is based on the high natural cross-pollination rate in faba bean, resulting in natural variation. An elite single plant is selected from the variants and is developed into a new variety through a series of selection and comparative tests. This procedure has an important practical significance in the beginning of breeding. According to statistics, in 16 provinces, municipalities and autonomous regions all over the country, 22 varieties had been developed through systematic breeding since the 1960s (Table 31). For example, four new disease-resistant and high-yield varieties ('Chenghu 3 Hao', 'Chenghu 4 Hao', 'Chenghu 6 Hao' and 'Chenghu 9 Hao') have been developed by the Sichuan Academy of Agricultural Sciences since 1963. The new variety 'Gidou 1 Hao' was developed from the local variety 'Jiajiasi' at the Agricultural Research Institute of Gidong county, Jiangsu province in 1977. This variety was introduced to grow in more than 10 provinces and municipalities. The spring-sown faba bean variety '204' was developed by selection among variants of the local variety 'Aba Dajiangbai 53 Hao' at the Linxia Agricultural Research Institute of Gansu province in 1972. The spring-sown varieties of 'Qinghai 2 Hao', 'Qinghai 3 Hao', 'Qinghai 4 Hao', 'Qinghai 5 Hao', 'Qinghai 6 Hao' and 'Nong 17 Hao' were developed at the Qinghai Academy of Agricultural Sciences by systematic breeding. Therefore, systematic breeding proves to be one of the most effective breeding procedures.

The basis of systematic breeding

The basis for better results of systematic breeding in faba bean lies in the high natural cross-pollination rate, which usually reaches 30%. Jiangsu 'Gidou 1 Hao' with green seed coat, Linxia 'Maya' with white seed coat and Linxia 'Red Broad Bean' with red seed coat were planted with row spacing of 40 cm for three successive years at the Linxia Agricultural Research Institute of Gansu province. The observations on seed coat color showed that the cross-pollination rates of 'Gidou 1 Hao', Linxia 'Maya' and Linxia 'Red Broad Bean' were 44.4, 1.4 and 5.3%, respectively, indicating a great difference in cross-pollination rates among varieties. The observation on emasculated florets with the addition of bees showed that 49% of the florets were pollinated and set pods, indicating that the high pollination rate is closely related to the presence of bees (Anonymous 1986). Different variations were produced by cross-pollination. The inheritance of these variants was relatively stable, thus providing an important basis for systematic breeding.

Another basis for systematic breeding is natural mutation. Like other crops, changes that occur on chromosomes or individual loci on the chromosome of faba bean under the influences of various factors in natural conditions lead to phenotypic variations. Thus, natural mutations are also the basis for systematic breeding.

Procedures of systematic breeding

A series of tests and evaluations are carried out from the individual selection to the development of a new variety (Fig. 21). Jiangsu 'Gidou 1 Hao' is a representative variety developed through systematic breeding. It is used as an example to illustrate the procedures of systematic breeding in China.

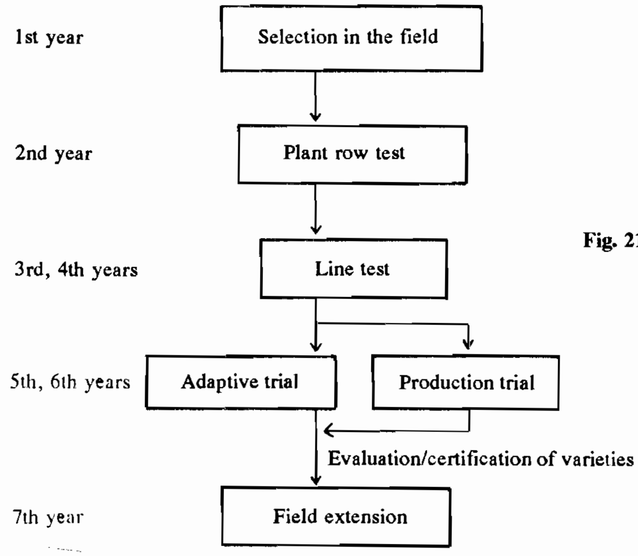

Fig. 21. Procedures of systematic breeding.

During the first year, individual plants were selected based on high yield and disease resistance. From the local variety 'Jiajiasi' 1160 single plants were selected in 1970. These plants were scored for the number of pods/plant, number of seeds/plant and seed weight, and finally 120 plants were selected.

The 120 selected single plants were planted in the autumn of the same year for comparison among rows. The distance between rows was wider than in field production. Checks were planted every eight rows. Field evaluation was made in the summer of 1971. Most lines were discarded and only seven lines, with stable and uniform yields, significantly better than the check, were selected.

Seeds of the seven selected lines were sown in plots in autumn with the same distance between rows as in the field. Alternative or random plots were used with 3-4 replications. The local commercial varieties were used as the check. Three elite lines ('Gidou 70-51', 'Gidou 70-59' and 'Gidou 70-111') were selected based on their disease resistance and yield performances in the summer of 1972.

These three lines were planted in autumn in larger plots, which were alternatively or randomly arranged with 3-5 replications. Strict evaluations on disease resistance and yield potential were carried out and the superiority of these three lines was confirmed, among which 'Gidou 70-51' showed the best performances in disease resistance, multiple pods and seeds and high yield. The yield of line '70-51' was 33.4% higher than the check 'Jiajiasi'. This line was named 'Gidou 1 Hao' in 1977 and was extended to more than 10 provinces and municipalities in China. Nevertheless, there is no fixed procedure for systematic breeding. Extra-superior lines can skip trials and be introduced for production as soon as possible.

Crossbreeding

The aim of crossbreeding is to develop elite varieties that meet production needs by means of gene recombination of the parents and occurrence of transgressive inheritance. From the incomplete data of 16 provinces, municipalities and autonomous regions, 16 superior varieties with distinguishing characteristics were developed through hybridization (Table 31). For example, the new faba bean variety 'Chenghu 10 Hao' with high disease resistance and yield potential was developed by the Sichuan Academy of Agricultural Sciences in 1977 (Luo and Hu 1989). The yield of 'Chenghu 10 Hao' is 56.8% more than the local varieties, and the cultivated area reaches more than 5300 ha. 'Qinghai 3 Hao' was developed by the Qinghai Academy of Agricultural Sciences in 1965 (Anonymous 1986). Its yield is 7500 kg/ha and 20% more than the local varieties. Its 100-seed weight reaches 153 g and it has become the main variety for exportation. Linxia 'Dacandou' was developed in 1981 by the Linxia Agricultural Research Institute of Gansu province (Anonymous 1986). Its 100-seed weight is more than 170 g. Its average yield is 6750 kg/ha and it also has become a main variety for exportation.

Further demands were put forward for faba bean breeding with the continuous development of production and gradual rise of living standards of the people. To develop new dwarf varieties suitable for the intercropping system, and new large-seed varieties that would meet the consumer's demands, parents with particular characters were required. However, these materials were not available in China. The author (Lang and Ying 1990; Lang *et al.* 1990) brought 26 local varieties of Zhejiang province to ICARDA in 1986 and carried out collaborative research on faba bean breeding with Drs M.C. Saxena and L.D. Robertson of the center for 2 years. They made eight combinations of determinate growth habit and 20 combinations of large-seed type faba bean with the Zhejiang local varieties as the female and germplasm of ICARDA as the male. F_2 generations were obtained in 1988 and brought back to China. The results are summarized in the following.

Determinate growth habit (determinate faba bean)

The characteristic of determinate growth habit type is the automatic cessation of upward growth of the apex when the plant growth and raceme elongation reach certain degrees, resulting in the formation of a terminal flower cluster and plant height of only about 50 cm. Determinate faba bean was produced by gamma ray treatment on the local commercial variety 'Primus' (indeterminate growth habit) by Swedish scientist Sjodin in 1971 (ICARDA 1985), which attracted the attention of many faba bean breeders in the world. The superiorities of the determinate growth habit are:

1. Short culm, which is helpful for lodging resistance and for an intercropping system.
2. Inhibition of the upward growth of the stem, thus reducing the competition among organs within the organism for assimilation products, and promoting the development of determinate pods and raising the harvest index.
3. Concentration and uniformity of pod-setting, which favors mechanical harvesting.

From the 1200 plants of F_2 populations of the eight combinations of determinate growth habit faba bean crosses (Table 33), 218 plants of determinate type were selected (Table 34). The number of indeterminate plants was 982 (Table 34). The ratio of determinate to indeterminate was 1:4.5. Among the combinations, the F_2 segregation of H94/FLIP84-241 FB was the most obvious and 42 plants of determinate type were obtained, which cover 26.3% of the total population. So it was suggested that the conservatism of the maternal parents in the combinations was less. From the 218 plants of determinate growth habit, the best nine F_2 single plants were selected (Table 35), the related economic traits of which were near the breeding goal. For example, N87023-10, N87023-20, N87024-1 and N87026-20 were ideal single plants of high yield. They become valuable

Table 33. Parental combinations.

Cross no.	Female (from China)	Male (from ICARDA)
N87019	H41	FLIP84-239FB
N87020	H44	FLIP84-239FB
N87021	H48	FLIP84-241FB
N87022	H94	FLIP84-241FB
N87023	H96	FLIP84-242FB
N87024	H189	FLIP84-242FB
N87025	H330	FLIP84-240FB
N87026	H593	FLIP84-240FB

Table 34. Segregation for determinate character in the F_2 generation.

Cross no.	Total F_2 plants	Determinate		Indeterminate		Det.:Indet.
		No. plants	%	No. plants	%	
N87019	160	22	13.8	138	86.2	1:6
N87020	160	26	16.3	134	83.7	1:5
N87021	80	22	27.5	58	72.5	1:3
N87022	160	42	26.3	118	73.7	1:3
N87023	160	26	16.3	134	83.7	1:5
N87024	160	25	15.6	135	84.4	1:5
N87025	160	27	16.9	133	83.1	1:5
N87026	160	28	17.5	132	82.5	1:5
Total	1200	218	18.2	982	81.8	1:4.5

Table 35. The economic traits of the nine best F_2 single plants of determinate growth habit.

	Plant			Seed		
Plant line	Height (cm)	No. pod-bearing branches	No. pods	No. seeds	100-seed wt. (g)	Yield /plant (g)
N87019-20	54.3	2	10	30	81.7	24.5
N87020-6	59.8	3	10	30	74.7	22.4
N87021-21	56.8	3	11	32	78.4	25.1
N87022-12	58.6	5	14	28	89.6	25.1
N87023-10	58.2	4	8	24	112.9	27.1
N87023-20	58.6	2	15	38	95.8	36.4
N87024-1	55.3	5	13	26	107.7	28.0
N87024-10	55.3	4	10	28	78.9	22.1
N87026-20	60.4	4	8	23	109.1	25.1

breeding materials or new lines for production. The determinate faba beans suit the intercropping system of Zhejiang, Jiangsu and other coastal provinces where faba bean/cotton interplanting prevails. The intercropping period of bean and cotton lasts more than 40 days. If the faba bean stem is tall, the growth of cotton seedlings would be affected because of shading. Farmers bundle up the bean branches to overcome the problem but the yield of bean is reduced severely. If the dwarf, determinate growth habit faba bean is interplanted with cotton, the above problem can be solved and the yield can be improved.

Large-seed type faba bean

According to the classifying standard of faba bean seed types in China, large-seed type refers to those with 100-seed weight > 120 g, medium-seed type 70-120 g and small-seed type < 70 g. Twenty cross combinations were made but five were lost because of pesticide poisoning.

The 100-seed weight of the 15 F_2 population of large-seed type was raised to different degrees in comparison with the maternal parent (Table 36). The increase ranged from 5.1 to 31.1 g, i.e., 6.5-43.3% increase. It was also obvious that the range of seed weight increase was greater in F_2 from maternal parents with lower seed weight, and vice versa. The segregation of seed weight in the 15 F_2 combinations is shown in Table 37. Of the total number of plants surveyed (750), the 100-seed weight of 238 (31.7%) was not higher than their respective maternal parent, the 100-seed weight of 405 (54%) was higher than their respective maternal parent but less than the standard of large-seed type. The 100-seed weights of 107 plants (14.3%) were more than 120 g, among which the best 21 F_2 large single plants (2.8%) were selected (Table 38) because of their good economic performances. The single plants with the seed weights more than both parents included N87033-14, N87034-49 and N87037-24. These elite plants will be developed into new large-seed type varieties that can be used directly in production.

Table 36. The 100-seed weight (g) of F_2 generation and parents of large-seed type and the increase in seed weight (%) over female parent.

		Average 100-seed weight (g)			% F_2 with 100-seed weight > female	
Cross no.	Parents	F_2†	Female‡	Male	±(g)	±(%)
N87007	H13 / 'Aquadulce'	83.0	73.0	160	10.0	13.7
N87008	H26 / 'Aquadulce'	89.6	94.4	160	-4.8	-5.1
N87018	H592 / 'Aquadulce'	76.5	70.4	160	6.1	8.7
N87035	H48 / 'Aquadulce'	99.3	77.0	160	22.3	29.0
N87036	H94 / 'Aquadulce'	107.7	107.0	160	0.7	0.7
N87009	H49 / 'New Mammoth'	89.7	85.2	180	5.4	5.3
N87010	H62 / 'New Mammoth'	102.7	71.4	180	31.3	43.8
N87033	H41 / 'New Mammoth'	104.3	74.4	180	29.9	40.2
N87034	H44 / 'New Mammoth'	94.4	100.1	180	-5.7	-5.7
N87011	H79 / 'New Mammoth'	94.8	97.0	180	-2.2	-2.3
N87012	H90 / 'Reina Blanca'	83.4	78.0	150	5.1	6.5
N87037	H145 / 'Reina Blanca'	111.9	95.0	150	16.9	17.8
N87038	H330 / 'Reina Blanca'	112.9	98.0	150	14.9	15.2
N87039	H110 / 'Reina Blanca'	98.7	71.7	150	27.0	37.7
N87040	H319 / 'Reina Blanca'	100.0	70.6	150	29.4	41.6

† 100-seed weights were data from traits in China.
‡ 100-seed weights of F_2 were the average of 50 randomly sampled single plants.

Table 37. The 100-seed weight (g) of 750 F_2 single plants from 15 parental combinations of large-seed type.

		Less than female parent		More than female parent but less than 120 g		More than 120 g	
Parents	No. of plants	No.	%	No.	%	No.	%
H13 / 'Aquadulce'	50	12	24	38	76	2	4
H26 / 'Aquadulce'	50	34	68	16	32	5	10
H592 / 'Aquadulce'	50	17	34	33	66	0	0
H48 / 'Aquadulce'	50	2	4	48	96	8	16
H94 / 'Aquadulce'	50	26	52	24	48	13	26
H49 / 'New Mammoth'	50	22	44	28	56	3	6
H62 / 'New Mammoth'	50	0	0	50	100	8	16
H41 / 'New Mammoth'	50	3	6	47	94	11	22
H44 / 'New Mammoth'	50	32	64	18	36	3	6
H79 / 'Reina Blanca'	50	29	58	21	42	5	10
H90 / 'Reina Blanca'	50	24	48	26	52	1	2
H145 / 'Reina Blanca'	50	14	28	36	72	20	40
H33 / 'Reina Blanca'	50	14	28	36	72	16	32
H110 / 'Reina Blanca'	50	5	10	45	90	5	10
H319 / 'Reina Blanca'	50	4	8	46	92	7	14
Total	750	238	31.7	405	54.0	107	14.3

Table 38. Yield and yield components of the best 21 F_2 single plants selected from crosses of large-seed types.

Line	No. pod-bearing branches/plant	No. pods /plant	No. seeds /plant	100-seed weight (g)	Seed yield (g)/plant
N87007-6	2	9	27	121.5	32.1
N87009-19	3	12	31	124.8	38.7
N87010-11	2	7	21	155.2	32.6
N87010-36	2	8	23	134.3	30.9
N87033-3	3	7	26	126.9	33.0
N87033-4	3	7	29	142.1	41.2
N87033-14	2	8	18	188.9†	34.0
N87033-23	3	8	31	129.7	40.2
N87033-26	4	8	34	135.9	46.2
N87033-27	3	8	23	170.0	39.1
N87033-29	3	6	26	130.0	33.8
N87033-49	3	7	20	180.5†	36.1
N87035-14	2	7	27	130.0	35.1
N87035-22	4	7	27	127.0	34.4
N87037-11	3	12	25	132.4	33.1
N87037-24	3	10	22	153.6†	33.8
N87038-1	3	11	23	134.8	31.0
N87039-1	3	8	25	144.4	36.1
N87040-6	3	10	27	127.8	34.5
N87040-12	4	10	25	121.6	30.4
N87040-37	5	15	28	122.5	34.3

† More than both parents.

The results obtained from crossbreeding for large-seed type faba bean indicate that even though the seed weight and the number of seeds seem to be contradictory, the probability exists for selection of single plants with more pods setting and 100-seed weights more than 120 g. Seven single plants (N87033-3, 4, 14, 23, 26, 27, 29) with more than 120 g of 100-seed weight and more than 30 g of plant yield were selected in the combinations N87033 (H41/'New Mammoth'). This may be due to the great difference of the seed weights between the parents (100-seed weight of the female was only 70 g, while the male was about 180 g). So, if the breeding goal is high yield with large seeds, the females should be medium- or small-seed type varieties with good pod-setting, while the male should be large-seed type with seeds significantly heavier than the female. It is also obvious that in crossbreeding the selection of parents is the key point, which directly affects the occurrence of ideal variations among hybrid progenies and the success of developing new lines.

Based on experiences in different regions, the following principles apply when selecting the parents for crossing:

1. Select parents with well-integrated traits. The advantages and disadvantages of the parents should be mutually complemented, for example, the parents of Linxia 'Dacandou' of Gansu province are 'Britain 175' and Linxia 'Maya'. The plant of Linxia 'Maya' is tall, but the number of pods and seeds is small. The seeds are plump but the protein and lysine contents are low. 'Britain 175' has optimal plant height and more pods and seeds but the seeds are not plump. The mutual complementation is achieved by hybridization of these two parents.
2. One of the parents should be the local commercial elite variety. The other parent is chosen in accordance with the disadvantages of the former. The varieties thus developed will have greater adaptability. Of course, alien varieties that are adaptable to the local conditions should not be excluded absolutely.
3. The varieties with better combining ability should be selected as the parents. Practice has already demonstrated that the performance of superior varieties is not always in accordance with the performance of their progenies derived from hybridization, so not all superior varieties are superior parents for hybridization. Only superior varieties with strong genetic transmission ability are promising parents. A good parent must possess better combining ability. The superior characteristics tend to be expressed among hybridization-derived progenies when varieties with better combining ability are used as parents.
4. Materials with bigger differences in ecological types and of distant relatives should be selected as the parents. The genetic backgrounds, advantages and disadvantages of varieties with different ecological types, different geographical origins and different affinity relationship are quite different. Their progenies derived from hybridization will have richer genetic bases. More variation of types, including transgressive segregation of favorable traits, will occur due to gene recombination. New varieties with better adaptability will be selected because of the different ecological conditions under which both the parents are produced.
5. Parents also should be selected according to the genetic distances of quantitative traits. Genetic distances were recently analyzed by the Qinghai Academy of Agricultural Sciences. No direct relationship was found between geographical distribution and genetic distance; for example, the origins of Qinghai 'Maya' and Qunong 'Beibicandou' are the same, but the genetic distance between them is great.

Recurrent Selection Breeding

Under natural conditions, seed bearing of faba bean can be achieved by both self- and cross-pollination. So the breeding systems of both self- and cross-pollination can be used, although the perfect breeding systems for faba bean should be unique and suit its biological features. Recurrent selection of one or more cycles is suggested by the practical experience of the Shanghai Agricultural College. Two or more superior varieties are self-pollinated and then segregation occurs among progenies. Progenies with inferior traits are discarded. Useful genes are accumulated and the vitality of the population is raised by means of free pollination and a higher natural cross-pollination rate. Superior single plants are selected periodically from the population, according to breeding goal, and are self-pollinated. Plant lines are then evaluated under isolation. After screening, superior plant lines with similar characteristics are mixed to form a population. Free pollination is promoted to enrich the superior genes in the population. The faba bean variety 'Lunxian 1 Hao' was developed after 8 years of recurrent selection by the Shanghai Agricultural College. It has the advantages of strong stress tolerance, good quality, early maturity and high pod-setting rates (Gong 1989).

Tissue Culture

Huang *et al.* (1985) of the Shanghai Agricultural College carried out faba bean tissue culture research in the 1980s. Callus formation and green plantlet regeneration were achieved, which passed the technical identification of Professor Wang Kaiji from the Biology Department of the Fudan University in Shanghai on 1 July 1984.

The materials used were explants of the varieties Jiangsu Nantong 'Shanbaidou' and Zhejiang Shangyu 'Tianjiqing', which included hypocotyl, cotyledon and embryo without cotyledon. The induction of callus and green plantlets from hypocotyl is described here.

Dry seeds that had been stored for about 1 year were rinsed with distilled water and then submerged in 70% ethyl twice (5 minutes each time), followed by rinsing with sterile water three times. They were then submerged in sterile water at 25°C for 36 hours. The seed coat was removed on the laminar flow work station and the hypocotyls were transferred to the flasks with induction medium. There were 10 flasks with five hypocotyls in each. After calli were induced from hypocotyls, the callus derived from one hypocotyl was divided into two pieces and transferred onto redifferentiation medium. Forty flasks were transferred with one piece of callus in each. The callus introduction medium was modified N6 medium (Table 39) supplemented with 2 mg/L of 2.4-D and 300 mg/L of LH. Calli were induced under 25°C and diffused light (500 lux). Redifferentiation medium was modified MS medium supplemented with different hormones (Table 40: refer to footnote). Redifferentiation was at 25°C with 10 hours of light (3000 lux)/day. The pH value of both callus induction and redifferentiation media was 5.8. The media contained 0.6% of agar and were autoclaved before use.

After incubation for 1 week, the hypocotyls began to enlarge. White and loose calli appeared on the surface of the enlarged parts after about 10 days. One week after the removal of white and loose calli, light yellow and compact calli appeared on the enlarged parts. All 50 hypocotyls produced calli, so calli induction frequency was 100%. When these calli were transferred to Nos. 3, 13 and 17 of the redifferentiation media, green spots occurred after 24 days and gradually grew into green shoots. Finally 11 green

Table 39. Modified N6 medium.

Constituents	Amount (mg/L)	Constituents	Amount (mg/L)
$(NH_4)_2SO_4$	232	Na-EDTA	37.25
KNO_3	2830	$FeSO_4 \cdot 7H_2O$	27.85
$CaCl_2 \cdot 2H_2O$	83	VB_6	1.0
KH_2PO_4	400	VB_1	1.0
$MgSO_4 \cdot 7H_2O$	185		
$ZnSO_4 \cdot 7H_2O$	1.5	Glycine	2.0
$MnSO_4 \cdot 4H_2O$	4.4	Nicotinic acid	0.5
H_3BO_3	1.6	Sucrose	30 g

Table 40. Modified MS medium†.

Constituents	Amount (mg/L)	Constituents	Amount (mg/L)
$CaCl_2 \cdot H_2O$	220	$CoCl_2 \cdot 6H_2O$	0.025
KNO_3	1900	Myoinositol	300
$MgSO_4 \cdot 7H_2O$	370	Na-EDTA	37.25
NH_4NO_3	830	$FeSO_4 \cdot 7H_2O$	27.85
KH_2PO_4	170	Glycine	2.0
$MnSO_4 \cdot 4H_2O$	22.3		
$ZnSO_4 \cdot H_2O$	8.6	VB_1	0.5
H_3BO_3	6.2	VB_6	0.5
$NaMoO_2 \cdot 2H_2O$	0.25	Nicotinic acid	0.5
$CuSO_4 \cdot 5H_2O$	0.025	Sucrose	30 g

† No. 3 = Modified MS + KT_2 + NAA 0.5 + IBA 0.5 + LH 300.
No. 13 = Modified MS + KT_3 + NAA 0.5 + IBA 0.5 + LH 300.
No. 17 = Modified MS + $6BA_4$ + NAA 0.2 + IBA 0.2 + LH 300.

shoots were obtained. Of the three media, No. 13 was the best. Because the green shoots first appeared on this medium, the green shoot formation frequency was 40%, and the green shoot grew faster than on Nos. 3 and 7. After 2 months, the green shoots on the No. 13 medium reached 10 mm and roots were differentiated.

Conclusions obtained by Huang *et al.* (1985) included:

1. Modified N_6 medium supplemented with 2 mg/L 2,4-D was the best for callus induction from different explants of faba bean.

2. Under the same redifferentiation conditions, the green shoot formation frequencies of hypocotyl-derived calli were higher than cotyledon-derived callus, suggesting that redifferentiation frequency was dependent on explants.
3. Calli with the same texture reacted differently on different redifferentiation media. For example, the green shoot formation frequency was as high as 40%, which was highest among 10 redifferentiation media. Of course, further investigation for redifferentiation is needed because of the limited number of calli tested.
4. Induction and redifferentiation were consistent between the varieties 'Shanbaidou' and 'Tianjiqing', suggesting that the relationship between the success of tissue culture and the genotype in faba bean is not as close as expected.

Main Faba Bean Varieties

Zhejiang Cixi 'Dabaican'

The origin of this variety is Cixi county of Zhejiang province. The growing area usually occupies 20 000 ha (bean/cotton interplanting area). The average yield is more than 3000 kg/ha (based on actual growing area). A maximum average yield of 4500 kg/ha was recorded in 1974. It is a high-yielding variety and its seeds are the largest among local varieties of Zhejiang province. The 100-seed weight reaches 120-135 g. The seeds look bright and clean with a white seed coat. The protein content of dry seeds is 29.5% and the lysine content is 2.7%. The seeds taste delicious and commercial value is high. It is popular in the international market and has ready markets in Japan and other countries of Southeast Asia. The humidity stress tolerance of this variety is low and it suits interplanting with cotton in the coastal cotton belt and dryland. The yield potential on dryland is higher than in a paddy-field. This conclusion was obtained in 1982 by the Zhejiang Academy of Agricultural Sciences (Lang 1988). The results indicate that economic traits are much better when this variety is grown in dryland than in a paddy-field (Table 41).

'Dabaican' is a late-maturing variety. It is generally sown in autumn (20-25 October) and harvested in early summer (25-30 May). Its total growth period is 210-215 days. The production rate is 112-150 kg/ha.

Zhejiang Shangyu 'Tianjiqing'

The origin of this variety is Shangyu county of Zhejiang province. The growing area usually occupies 1667-2000 ha. The average yield is 2250 kg/ha, and reached 3600 kg/ha in 1974. The seed coat is green and 100-seed weight is about 90 g, belonging to the medium-seed type. The protein content is 31.5% and is the best among local varieties of this province.

Table 41. Comparison of Cixi 'Dabaican' grown in dryland and paddy-field.

	Plant			Seed		
Treatment	Height (cm)	No. pod-bearing branches	No. pods	No./plant	100-seed wt. (g)	Yield /plant (g)
Dryland	130.8	5.8	30.2	48.4	135.0	53.6
Paddy field	110.0	4.0	22.0	28.2	120.5	34.9

Table 42. Comparison of Shangyu 'Tianjiqing' grown in dryland and in paddy-field.

	Plant			Seed		
Treatment	Height (cm)	No. pod-bearing branches	No. pods	No./plant	100-seed wt. (g)	Yield /plant (g)
Dryland	125.3	4.0	17.0	51.3	67.0	32.6
Paddy field	93.4	3.8	17.2	49.6	64.0	30.2

This variety can tolerate high humidity and late planting and is disease resistant (especially to chocolate spot). It suits the paddy-field on plains. To evaluate its high humidity tolerance, it was grown in both dryland and paddy-field in 1982 (Lang 1988). The results are shown in Table 42. It is obvious that the economic traits are similar in both dryland and paddy-field, indicating the strong adaptability of this variety.

Shangyu 'Tianjiqing' is an early maturing variety. It is usually sown in late October and harvested between 21 and 25 of May the next year. The total growth period lasts 205-209 days.

Sichuan 'Chenghu 10 Hao'

This variety was developed by the Crop Research Institute of Sichuan Academy of Agricultural Sciences in 1977. The hybridization was made in 1969 from Zhejiang 'Jiande-qingpi' (female) and Zhejiang 'Pingyang-qing' (male). The growing area of this variety has reached 5300 ha in Sichuan province. The average yield is 2230 kg/ha. It is a light green, medium-seed type with 100-seed weight of 80-90 g. It is disease resistant and has stable high yields. It grows well in soil of medium or high fertility. It is a good food and fodder variety.

Yunnan Kunming 'Baipidou'

This is a local and elite variety in Kunming of Yunnan province, where it occupies a large growing area. The average yield is 2550-3000 kg/ha. The seeds are medium size with 100-seed weight of about 100 g and the seed coat is white. The seed protein content is 27.92% and the lysine content is 1.847%. The total growth period is 190-195 days. It grows well in soil of good fertility.

Jiangsu 'Gidou 1 Hao'

This variety was developed from the local variety 'Jiajiasi' through systematic breeding by the Agricultural Elite Breeding Station of Gidong county, Jiangsu province in 1977. Extension of this variety was started in 1985. The average yield ranges between 3000 and 3750 kg/ha. The seeds are green and of medium size with 100-seed weight of about 90 g. The seed protein content is 31.4%, and the lysine content is 2.226%. It is highly resistant to rust and tolerant to chocolate spot. It covers a large growing area in Jiangsu, Shanghai and other places. The total growth period is about 220 days.

Gansu Linxia 'Maya'

This good variety was selected during the screening and identification of local varieties in the 1950s by the Linxia Agricultural Research Institute of Gansu province. It is a spring-sown variety. The name was given because of its origin (Linxia district) and its large seed with a horse tooth-like shape.

'Maya' varieties have been cultivated for a long time. They possess high adaptability and stable high yield. The average yield is 5250 kg/ha and the maximum yield reaches 7500 kg. The seed coat is milky white and 100-seed weight is 170 g. The seed protein content is 25.6% and the lysine content is 1.56%. It is a late-maturing variety. The total growth period is 155-170 days. It grows well in soils of high fertility and is an important variety for exportation.

Gansu Linxia 'Dacandou'

This spring-sown variety was developed by the crossbreeding of 'Britain 175' as the female and Linxia 'Maya' as the male by the Linxia Agricultural Research Institute of Gansu province. The extension started in 1981 in the same province. The average yield is between 3750 and 4500 kg/ha. The seed coat is milky white and 100-seed weight is about 160 g. The seed protein content is 27.9% and the lysine content is 1.74%.

'Dacandou' grows well in soil of abundant water supply and high fertility. It has high adaptability to hilly areas of 1770-2600 m above sea level.

Qinghai Huangyuan 'Maya'

This elite variety was selected through screening and identification of local varieties by the Crop Research Institute of Qinghai Academy of Agricultural Sciences in the 1950s. The seeds are large with 100-seed weight of about 160 g and the seed coat is milky white. The seed protein content is 28.1% and the lysine content is 1.59%.

It has a long history of cultivation. It bears the advantages of high adaptability and stable high yield. It is distributed in areas of 1800-3000 m above sea level. The average yield in a paddy-field is 3750-5250 kg/ha, and in dryland 2250-3000 kg/ha. It is also an important variety for exportation.

'Qinghai 3 Hao'

This spring-sown variety was developed by crossbreeding of Tibet 'Lasa 1 Hao' as the female and 'Huzhudong-candou' as the male by the Qinghai Academy of Agricultural Science in 1965. The seeds are large with 100-seed weight of more than 160 g and the seed coat is milky white. The seed protein content is 24.3% and the fat content is 1.2%.

This variety has been released and widely cultivated in Qinghai province. The average yield is 3750-7500 kg. It grows well in soil of high fertility and where the climate is warm and abundant irrigation is available.

Purification of Existing Varieties

Biological mixture tends to occur in faba bean due to a high rate of natural cross-pollination. Mechanical mixture also tends to occur during harvesting, transportation, processing and storage. All these mixtures will reduce the purity of seeds. Therefore, besides the avoidance of mechanical mixture, two important measures should be taken during the process of elite breeding.

Establishing a Commercial Production Base for Faba Bean

Protection measures for certain precious faba bean varieties are adapted by the agricultural department of the government, which makes specific plans for production and purchase. For example, Zhejiang Cixi 'Dabaican' is a precious variety with a cultivation history of more than 400 years; however, the good quality and its traits are maintained by the following measures:

1. Maintaining single variety plantation: the Agricultural Development Department of the government strictly prohibits the introduction of alien varieties, especially th

small-seed type varieties, to the district where 'Dabaican' grows to prevent them from mixing.

2. Carrying out purification and rejuvenation: screening at plant, pod and seed levels becomes the routine procedure for farmers to ensure the purity. Before sowing, the chosen seeds are screened again for large and plump seeds with light green seed coat, black hilum and no disease lesions. They are exposed to sunlight for 2-3 days successively to raise the germination and seedling emergence rates.
3. Interplanting with cotton: to promote the seed development by applying phosphorus and potassium and by controlling diseases and pests.

Establishing an Elite Breeding Base for New Varieties

After adaptive trials and production demonstration, seeds of newly developed varieties should be produced rapidly for extension and utilization. To avoid mixture and deterioration, and extend the period for usage, elite breeding bases for new varieties have been established by the agricultural departments in various districts. These bases are well isolated. The primary elite breeding base should be isolated from other varieties for more than 500 m and the secondary base should be isolated from other varieties for more than 300 m.

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Chapter 6. Faba Bean Cultural Techniques

Planting Patterns of Faba Bean

As a result of the vastness of the faba bean growing areas in China and the differences in climate, soil, topography and economic development, faba bean planting patterns occur in great variety.

Crop Rotation

As shown by years of practice, experiments and research on faba bean cultural techniques in China, the suitable planting pattern for faba bean is not continuous cropping, but rotational cropping. According to the investigation done by Xu (1981), faba bean that had gone through years of continuous cropping was easily affected by the disease *Fusarium solani* Mart, and its number of branches and podding rate were all reduced, which eventually resulted in lower yield (Table 43).

Table 43. The effects of continuous cropping on agronomic characters of faba bean.

Year	Plant height (cm)	No. pod-bearing branches /plant	No. pods /plant	No. seeds /pod	100-seed wt. (g)	Yield	
						kg/ha	%
1	135	5.8	19.0	1.8	90.5	1400	100
2	115	3.7	11.7	1.7	87.0	1134	78
6	110	2.4	8.7	1.7	74.8	618	43

Faba bean yield decreased after numerous years of continuous cropping because faba bean keeps consuming the same nutrients in the soil, and some of these nutrients cannot be restored and regulated promptly. Phosphorus and potassium also are sharply reduced, which is unfavorable for faba bean growth. The acidity of soil rises while root nodules decrease in number, and the nitrogen-fixing ability of rhizobia declines as well. The root system cannot grow well, and the reproduction of rhizosphere microorganisms is simultaneously affected. Insect pests and plant diseases such as root rot, basal stem rot and chocolate spot are more serious in a continuous cropping system than in a rotational cropping system. Therefore, rotational cropping of faba bean is very important. Through years of cultural practice, the Chinese farmers have created various types of rotational cropping systems, which can be summed up as follows.

Rotational cropping patterns in triple-cropping areas

In the vast rice-growing provinces south of the Yangtze River, the natural conditions are favorable for farming. Population density is high and land is limited. The multiple-cropping index is high and cultivation is meticulous. It is characterized mainly by continuous double cropping of rice. The winter crops are barley, wheat, rape, green manure and faba bean, etc. The growing area of faba bean is not large. As continuous cropping is not suitable for faba bean planting, the crop rotation is mainly between faba bean, barley, wheat, rape and green manure in this area:

1. Faba bean (or green manure such as Chinese vetch)/early rice/late rice.
2. Wheat (barley)/early rice/late rice.
3. Rape/early rice/late rice.
4. Green manure/early rice/late rice.

These four patterns keep going in cycles. In the provinces of Zhejiang and Fujian, because the per capita farm land available is limited, the multiple cropping index keeps rising and rotational cropping of manure/rice/rice is no longer the dominant planting method.

Another rotational cropping pattern in the triple-cropping areas, such as Guangdong and Fujian provinces, is the alternate rotation between double-cropping of rice and one crop of rice/dryland crops:

Year 1: faba bean (or rape)/early rice/late rice
Year 2: wheat/early rice (or soybean)/soybean (or late rice).

These areas are short of labor, and therefore rotation between dryland crop and paddy rice is adopted to mitigate the constraints of manure, water and labor resources.

Rotational cropping patterns in double-cropping areas
In the vast areas of the middle and lower Yangtze River Basin and in southwest China, besides the double-cropping of rice, single-cropping of rice also covers a large area. Some of these areas adopt one cropping of middle rice and some adopt one cropping of late rice, with barley, wheat, rape, faba bean and pea planted in winter. These constitute the double-cropping system, of which the rotational cropping patterns are as follows:

Year 1: wheat/rice
Year 2: faba bean (or green manure)/rice
Year 3: wheat (or rape)/rice.

However, in areas like Fujian, Sichuan and Yunnan provinces, besides following the above rotational cropping system, in order to increase the economic income, one cropping of cash crops in alternate years is also adopted in the paddy areas, which constitutes the cropping pattern of summer-autumn paddy rotation:

Year 1: faba bean (or wheat)/rice
Year 2: tobacco/rape (or a fallow field in winter).

In Jiangxi and Fujian provinces, there are also main sugar cane growing areas. Therefore, they have the following rotational cropping patterns:

Year 1: winter faba bean
Year 2: sugar cane
Year 3: sugar cane (stubble cane).

Some areas that adopt this pattern do not keep stubble cane in the second year, so they plant wheat in winter instead. Thus, the pattern of the third year becomes wheat/rice.

Rotational cropping patterns in one crop/annum areas
In the northwest, cold highland areas such as Qinghai and Ningxia provinces, there is only one crop per annum of spring-sown faba bean or wheat, etc., so the rotational cropping pattern is characterized by the alternate growing of faba bean and another crop. In general, every year has one round of rotation, mainly faba bean/oat/wheat or faba bean/wheat/corn/wheat. In general, faba bean is grown only once every 2 or 3 years.

Mixed-cropping, Intercropping and Undercrop-sowing

In order to raise the crop yield, farmers have to make better use of sunlight, water resources, nutrient contents and land. They also have to control the growth of weeds and reduce pests and plant diseases. The methods of mixed-cropping, intercropping and undercrop-sowing have been adopted in China.

Mixed-cropping
This is quite an old planting method. At present, this method is still adopted on fairly large areas in Yunnan, Qinghai and Ningxia provinces, where faba bean is grown together with rape, barley and green manure. In the central part of Yunnan province, the yield/ha of mixed cropping of barley with faba bean is 20% higher than that of just growing wheat or faba bean only. By mixed-cropping, one can have a triple harvest of grain, oil and manure. For mixed-cropping, it is important to select crops that are basically similar to faba bean in sowing time. Also, it is better to select crops or varieties that grow slowly in their early growing stage but quickly after the blooming and podding stages of faba bean, to avoid competition for soil nutrients and fertilizer utilization. To obtain a high yield of faba bean, faba bean should cover the largest portion of land under the mixed-cropping system. However, in reality, it is not easy to control the proportion of different crops in mixed planting, and so the yield is not stable. As a result of mixed cropping, the wide-narrow row intercropping is gradually being developed in which rape, wheat, etc. are planted in the middle of wide rows, and the acreage of mixed-cropping is decreasing.

Intercropping and undercrop-sowing
Intercropping and undercrop-sowing is another pattern of multi-cropping rotation. It

Table 44. **Consequences of intercropping wheat and faba bean (Ningbo, Zhejiang).**

Crop (wheat:faba bean)	Yield (kg/ha) Wheat	Faba bean	Total	Yield increase (%)
1:0	2653	0	2653	100
4:1	2481	787	3268	123
3:1	2289	898	3187	120
2:2	1848	1675	3525	133

makes full use of the land, sunlight, nutrients and water. It is more advanced than mixed-cropping in that it is more convenient to manage and can increase the yield/unit area. According to the experiments done in Zhejiang and Sichuan provinces, intercropping of faba bean and wheat can increase yield by about 20% more than that of wheat cultivation alone (Table 44). In some spring-sown faba bean areas, such as Gansu and Qinghai, mixed-cropping of faba bean with rape has always been adopted. However, in recent years, the method of planting faba bean with wide row spacing has been adopted with rape planted in between, which has brought high yields of both faba bean and rape.

Intercropping and undercrop-sowing of faba bean and a following season crop is getting more popular. It has various patterns, which are mainly faba bean/cotton, faba bean/corn and faba bean/potato. In the cotton production areas along the southeast coastal district such as Jiangsu and Zhejiang, the undercrop-sowing of cotton after faba bean is quite common. Faba bean is sown from late October to early November. In general, the ridge width is 120-150 cm. Faba bean is planted on either side of the ridge and the space between two rows is 80-100 cm. The space between two plants is 15-20 cm (Fig. 22). In early April of the next year, cotton is sown between the rows of faba bean (Fig. 22). Their symbiotic growing period is about 50-60 days, i.e., from the emergence

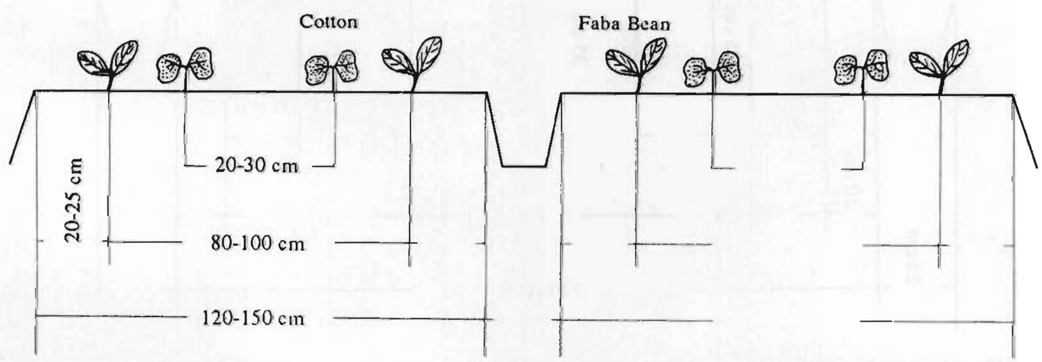

Fig. 22. Faba bean/cotton undercropping system.

of cotton seedlings to the harvesting of faba bean. If cotton is transplanted from a nutrient trough, the symbiotic period can be shortened. Intercrop sowing of faba bean and cotton is favorable to cotton's resistance to cold weather during its seedling stage. Therefore, this method has been widely adopted in coastal cotton production areas of Zhejiang province. Intercrop sowing of faba bean and corn has been widely adopted in the Yangtze River Basin and in the southern provinces. In general, the ridge width is 170-200 cm, with one or two rows of faba bean planted in the middle of ridge. Between the wide spacing rows, corn will be planted the following April. The symbiotic period of the two is 50-60 days. After faba bean is harvested, sweet potato can be planted in its place (Figs. 23 to 25).

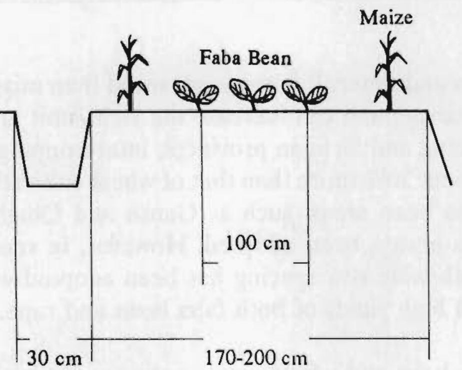

Fig. 23. Faba bean/maize undercropping system.

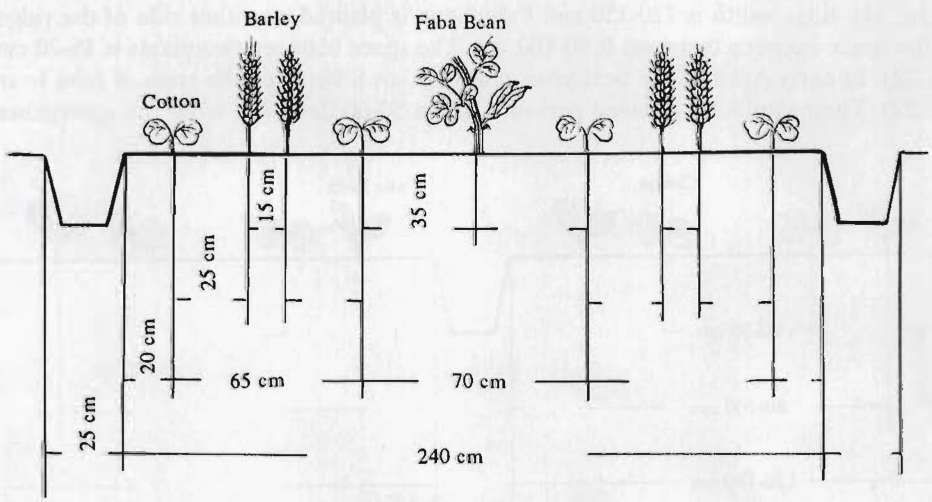

Fig. 24. Faba bean/cotton/barley intercropping system.

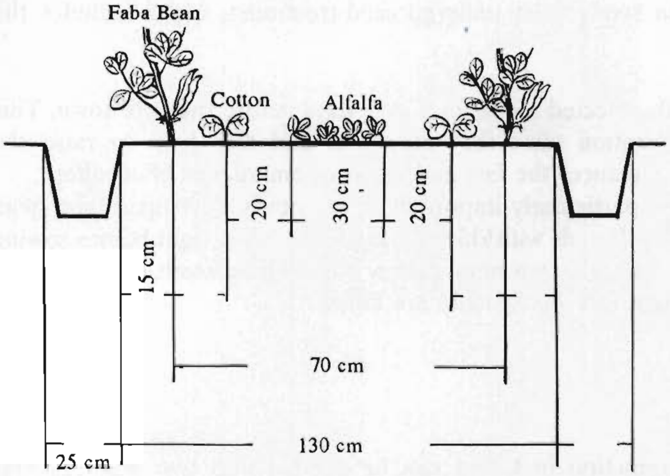

Fig. 25. Faba bean/cotton/alfalfa intercropping system.

Main Cultural Techniques

Selection of Recommended Varieties

The adaptability of faba bean to different climates and soils is low, so selection and introduction are done carefully according to the local soil and climatic conditions (Lang and Sheng 1988).

For the dry spring-sown area of northern China, cultivars adaptable to dry soils, e.g., Qinghai Huangyuan 'Maya', Gansu Linxia 'Maya', Linxia 'Dacandou' and Inner Mongolia 'Dabanya', are needed. In the eastern coastal cotton-growing region, cultivars adaptable to the alkaline soil, e.g., Zhejiang Cixi 'Dabaican' and Jiangsu 'Gidou I Hao', are needed. For the southern rice-growing area, cultivars need to tolerate high humidity. Representative cultivars include Zhejiang Shangyu 'Tianjiqing', Shanghai 'Shanbaidou', Hubei Xiangyang 'Dajiaoban', Sichuan 'Chenghu 10 Hao', Yunnan Kunming 'Baipidou', Guangdong 'Guangpu 3 Hao' and Fujian 'Todouzi.' The hilly regions in the southwest require cultivars like the Shaanxi Hangshong 'Xiaohudou' and Zhejiang Jinhua 'Xiaolizhong' which are adaptable to poor acid soils.

Attention must be paid to latitude and elevation when introducing cultivars. Faba bean is a crop requiring a lot of sunlight, so the introduction of the northern cultivars to the south will result in pod-bearing failure.

Besides selecting good cultivars, it is essential to have good-quality seeds. Seeds must be fully mature, plump and disease free in order to score a high germination percentage.

Before planting, the chosen seeds must undergo seed-treatment, which includes the following.

1. Insulation of the carefully selected seeds for 1 or 2 days before they are sown. This can promote water absorption after they are sown and also help to raise the germination rate, which enhances the fast and vigorous emergence of seedlings.
2. Inoculation of rhizobia is particularly important in the newly developed faba bean growing areas. Treatment of seeds with rhizobia should be done right before sowing so that the treated seeds can be sown immediately after. These seeds should not be exposed directly to sunlight lest the rhizobia are killed.

Timely Sowing

The area of faba bean production in China can be divided into two main regions according to the sowing and harvesting seasons: the spring-sown area in the north and autumn-sown area in the south (Fig. 2).

Spring-sown and autumn-sown faba bean have different temperature optima (Lang and Sheng 1988). For example, spring-sown faba bean is susceptible to low temperature whereas autumn-sown varieties cannot resist cold conditions. Research shows that suitable mean temperatures are 9-12°C for seedling emergence, 14-16°C for vegetative growth, 16-20°C for flowering and 16-22°C for podding.

Table 45 shows that in the north of China, winters can be severe with temperatures always below 0°C. Here, the period with temperatures suitable for sowing and growing of faba bean is from March (2.7°C) to August (17.6°C). Thus, the crop is sown between March and April and harvested in August (a growth duration of about 160 days). In contrast, winters in the south and east are mild (mean temperature in October is between 14.8 and 18.1°C) and are fit for autumn-sown faba bean. After winter, the temperature rises gradually to between 9.6 and 11.9°C in March and 18.9-20.4°C in May. In general, faba bean in this region is sown in October or the beginning of November and harvested between April and early June (a growth duration of about 200 days) (Table 46).

Whether the sowing of faba bean is timely or not has much to do with the loss of flower buds, flowers and pods later in the season. According to the results of a trial carried out (autumn-sown faba bean) in Yangzhou (Jiangsu province) by Yu and Zhang (1979) (Fig. 26), timely sowing has large effects on podding. For example, if faba bean is planted on 5 October then podding is successful for about 20% of the total number of flowers. However, if the crop is planted on 15 November then podding is reduced to only about 10% of the total number of flowers.

In the rice-growing area of the southern lowland region, three crops are produced each year. The late rice is harvested in mid-November, which delays the sowing of the faba

Table 45. Climatic data of different parts of China (all figures are means of 10 years of data).

Zone	Climate variable	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Northern	Rainfall (mm)	2	5	11	27	56	52	104	117	76	39	11	1
China	Max. temp. (°C)	1.0	3.7	9.3	16.9	20.1	23.1	24.8	24.1	18.9	14.3	7.7	2.6
(Gansu)	Min. temp. (°C)	-12.5	-9.2	-2.3	2.7	6.8	9.3	11.9	12.2	8.4	2.4	-4.0	-10.6
	Mean temp. (°C)	-6.7	-3.7	2.7	9.2	13.1	15.8	17.8	17.6	12.9	7.4	0.7	-5.2
Mid-	Rainfall (mm)	7	9	21	50	98	90	264	174	127	42	22	5
China	Max. temp. (°C)	9.1	11.5	16.5	21.9	25.1	27.9	29.5	30.0	24.9	20.6	15.1	10.8
(Sichuan)	Min. temp. (°C)	2.5	4.6	8.4	12.5	16.9	20.3	21.9	21.7	15.4	14.4	9.2	4.5
	Mean temp. (°C)	4.8	7.4	11.9	16.7	20.4	23.6	25.2	25.1	20.9	16.9	11.7	7.1
Southern	Rainfall (mm)	13	11	16	27	95	178	221	212	117	91	41	14
China	Max. temp. (°C)	15.3	17.2	20.8	24.0	24.9	23.8	24.0	23.9	22.6	20.1	17.5	15.2
(Yunnan)	Min. temp. (°C)	1.4	2.9	5.7	9.2	13.8	16.1	16.8	15.9	14.1	11.3	6.6	2.6
	Mean temp. (°C)	7.5	9.3	12.7	16.1	18.9	19.4	19.7	18.9	17.4	14.8	11.0	8.0
Eastern	Rainfall (mm)	63.2	97.5	118	132	164	210	129	154	178	97	42	71
China	Max. temp. (°C)	7.7	9.2	13.6	20.5	24.5	28.6	33.0	32.3	26.8	22.4	16.3	10.9
(Zhejiang)	Min. temp. (°C)	1.4	2.5	6.6	12.2	16.4	21.2	24.9	24.5	20.0	14.8	8.6	3.8
	Mean temp. (°C)	4.1	5.4	9.6	15.8	19.9	24.3	28.4	27.8	22.8	18.1	12.5	7.1

Table 46. Date of sowing to emergence, branching, budding, flowering, pod-setting and maturity for faba bean in different areas of China.

Province	Sowing	50% seed emergence	50% branching	50% budding	50% flowering	50% pod-setting	90% maturing	Total growth period (days)
Gansu (northern China)	14 Mar	16 Apr	29 Apr	17 May	2 June	12 June	19 Aug	157
Qinghi (northern China)	1 Apr	26 May	30 May	5 June	15 June	20 June	30 Aug	152
Sichuan (mid-China)	20 Oct	6 Nov	24 Nov	2 Feb	18 Feb	27 Mar	11 May	198
Yunnan (southern China)	12 Oct	24 Oct	-	24 Dec	5 Feb	7 Mar	25 Apr	195
Zhejiang (eastern China)	28 Oct	17 Nov	1 Dec	16 Feb	16 Mar	4 Apr	28 May	212

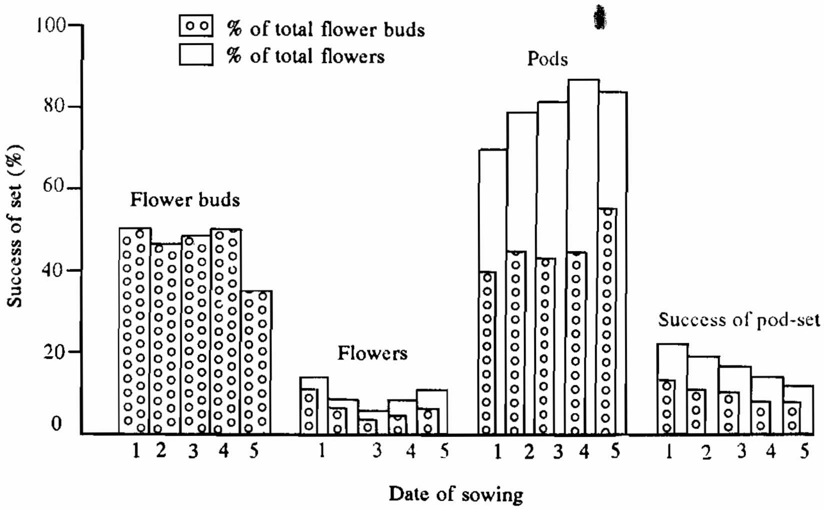

Fig. 26. Proportional losses (%) of flower buds, flowers and pods, and success of pod-set (%) in faba bean sown on different dates in Jiangsu, China, 1979. Sowing dates: 1 - 5 Oct, 2 - 15 Oct, 3 - 25 Oct, 4 - 5 Nov and 5 - 15 Nov.

bean. To resolve this problem, the Shaoxing Institute of Agricultural Sciences in Zhejiang province devised a system of faba bean undercropping with late rice. The system is as follows: 10 days before the harvest of late rice, faba bean seeds are planted between the rows of rice, at a row distance of every 50 cm and with 15 cm between each seed (the rice is spaced every 16.5 cm). The cultivars of faba bean used are early maturing and tolerant of wetness. The average amount of seeds sown is about 188 kg/ha. In general, the average yield exceeds 2250 kg/ha. This practice is popularly adopted by the farmers.

In the spring-sown faba bean growing area, the sowing time should be when the temperature starts rising again. That is, early sowing should be started by all means. In the experiment done by the Linxia Institute of Agricultural Science, Gansu province (Table 47), seeds were sown when the temperature was still relatively low. Consequently,

Table 47. Seed yield and yield components of faba bean under different sowing times.

Sowing date	Days to seedling emer-gence	Plant height (cm)	Pod height (cm)	No. pods /plant	No. seeds /plant	100-seed weight (g)	No. pod-bearing branches	Seed yield kg/ha	Seed yield %
7 Mar	44	156	25	15.5	25.8	150.9	1.9	4447	117
20 Mar	34	165	29	10.3	18.6	145.6	1.1	4410	116
2 Apr	26	162	31	12.1	20.2	137.9	1.2	3787	100

the main stem grew slowly while the basal lateral branches began to sprout. After the emergence of seedlings, the main stem and its branches grew synchronously. The growth of internodes at the basal part will be shortened, restricted by the factors of nutrient content and temperature. The podding position will be lowered as well. If seeds are sown late, after sprouting, the temperature is relatively high. The main stem grows faster, which results in longer elongation of internodes. This is unfavorable to its growth at later stages. Therefore, in spring-sown faba bean growing areas, early sowing at the optimum time should be adopted.

Throughout China, the sowing rate of faba bean is calculated according to seed size. When the 100-seed weight exceeds 170 g, the average sowing rate is between 300 and 375 kg/ha. For cultivars with a 100-seed weight of 120 g, the average rate is about 187 kg/ha. Those with a 100-seed weight between 70 and 120 g are seeded at about 150 kg/ha. The small-seed cultivars (100-seed weight less than 70 g) are sown at about 112 kg/ha.

Proper Sowing Density

Proper sowing density can help to achieve full utilization of sunlight, air, water and fertilizer, to obtain high yield. Faba bean is a branchy crop. Its yield consists of four factors: number of branches/unit area, number of pods/branch, number of seeds/pod and seed weight. Therefore, the coordination of the relations among these four factors is the main basis for proper planting density. If the planting density is too sparse and the population density is too low, yield cannot be high; if planting is too close, the leaves will overlap each other, which will result in inadequate exposure to light and affect the growth of individual plants. The number of pods and the number of seeds will decrease, as will yield. According to the analysis of the experiment done by Xie Renxing during 1981 to 1989, the path coefficients between faba bean yield and the number of pod-bearing branches, number of pods/branch, number of seeds/pod and 100-seed weight are respectively 0.99428, 0.30742, 0.45621 and 0.4898. This indicates that faba bean yield can be raised by increasing the number of pod-bearing branches/unit area, but the other three yield components will be reduced when the number of pod-bearing branches increases. Nevertheless, in the experiment done by Xie Renxing (Table 48), the yield of 530 000-600 000 pod-bearing branches/ha is still higher than that of 450 000 pod-bearing branches/ha. This agrees with the result of the experiment done by Shi Hanming in Qidong county of Jiangsu province, in which yield was highest when the number of pod-bearing branches was 530 000-680 000/ha (Table 49). Although the podding rate, number of seeds/pod and 100-seed weight will increase when the number of pod-bearing branches/ha decreases, 380 000 pod-bearing branches/ha will result in a sharp decrease in yield because of inadequate population. Therefore, maintaining the optimum number of pod-bearing branches/unit area can help to obtain high yield.

It is necessary to fix the optimum planting density according to the local conditions and coordinate the relations between plant, branch, pod and seed. The planting density of

Table 48. Effect of number of pod-bearing branches on agronomic characters of 'Cuiwan Baibidou' faba bean, Zhejiang province.

No. pod-bearing branches/ha	No. pods /branch	No. seeds /pod	100-seed weight (g)	Seed yield (kg/ha)
380 000	4.6	2.28	73.0	2474
450 000	4.4	2.25	73.9	2658
530 000	4.0	2.24	72.9	2783
600 000	3.6	2.16	70.0	2762

faba bean varies with different varieties. The large-seed type varieties have taller plants and broad leaves and they are generally distributed in areas of better water and manure conditions. The planting density is relatively lower. For example, 'Jiepo Candou' in the Mang county of Yunnan province has a 100-seed weight of 140 g, and its plant height is about 110 cm in general. According to experiments, the yield will be the highest when the sowing rate is 300 kg seeds/ha in 112 500 double-plant/pit. Most of the medium-seed types are of medium plant height and leaf size, so their planting density is generally higher than that of large-seed types. According to the experiment carried out by Xie Renxing in the Shaoxing county of Zhejiang province, the variety 'Cuiwan Baipidou', for example, when sown with 188 kg seeds/ha in 127 500-150 000 pits with two seeds/pit, has the highest yield. As for the small-seed type, based on the experiment done at the Dali county in Yunnan province, the optimum density is 380 000-510 000 seedlings/ha.

The planting density of faba bean must also be adapted to the local conditions of soil fertility and moisture. In general, for those areas of good conditions, the density should be thinner. In the medium- or low-yield field, density can be appropriately raised. These measures have proved to be quite effective. According to experiments done by the Institute of Agricultural Science of Kunming City in Yunnan, when each hectare was planted with 150 000-225 000 seeds and a high amount (60 000 kg) of farm manure was applied, the number of pod-bearing branches reached 680 000-750 000 and the yield reached 3750-5250 kg/ha. If the number of seeds sown/ha is < 380 000 on medium- or low-yield soil (2-3.25% organic matter, 0.1135-0.1975% total nitrogen, 0.0776-0.1135% total phosphorus) the yield can be increased by increasing planting density. The yield of 3000 kg/ha is derived from about 225 000-380 000 basic seedlings. The number of pod-bearing branches is 600 000-705 000. Investigations done in Fujian and Zhejiang provinces have shown the same tendency. The planting densities discussed above are all based on the prerequisite of optimum sowing time. If sowing is delayed, then the density must be appropriately raised to make up for the loss. In general, proper planting density should be fixed according to the variety sown, soil fertility and climatic factors in order to obtain high and stable yield.

Table 49. Effect of number of pod-bearing branches on agronomic characters of faba bean, Jiangsu province.

No. pod-bearing branches/ha	No. flowers dropped	No. flowers and pods	Effective pods		No. pods /plant	No. seeds /plant	100-seed weight (g)	Seed yield (kg/ha)
			No.	%				
300 000	517	389	128	24.8	4.98	9.22	87.8	6051
380 000	595	468	127	21.3	5.30	10.00	80.5	6768
450 000	503	400	103	20.5	4.57	8.64	80.4	6471
530 000	510	436	74	17.1	3.91	7.49	81.0	6840
600 000	459	379	80	17.3	3.52	6.32	80.2	6750
680 000	443	364	79	17.8	3.50	6.52	77.7	5987
750 000	434	365	69	15.3	2.87	4.35	78.2	6261
830 000	345	304	41	11.9	2.32	4.18	78.6	6147
900 000	312	273	39	12.4	2.26	4.36	76.6	6059

Techniques of Fertilization

Requirements of Faba Bean for Nutritional Elements

Faba bean is capable of azotification of rhizobia. Fertilizer was rarely applied in the past, but sometimes ash fertilizer was used. There is a saying among the farmers "if ash fertilizer is applied on faba bean, pods will be piled up mountain-high". In fact, this is a serious mistake. Faba bean is a crop requiring quite a lot of fertilizer (6.7-7.8 kg nitrogen, 2-3.4 kg phosphorus, 5-8.8 kg potassium, 3.9 kg calcium and some trace elements) to produce 100 kg seeds and their corresponding biological body. The contents of phosphorus, potassium and calcium in the faba bean seeds and stems are all higher than those in cereal crops, e.g., 117% higher than that in wheat and 78.8% higher than that in corn (Table 50).

Table 50. A comparison of phosphorus, potassium, and calcium contents (%) of faba bean, corn and wheat.

	Seed			Stem			
Crops	P_2O_5	K_2O	CaO	P_2O_5	K_2O	CaO	Total
Faba bean	1.21	1.29	0.15	0.29	1.94	1.20	6.08
Wheat	0.85	0.50	0.07	0.20	0.90	0.28	2.80
Corn	0.57	0.37	0.03	0.30	1.64	0.49	3.40

From Sun Qu (1981).

The amount of nutritional elements absorbed by faba bean varies at different periods of growth. During the blooming stage it requires more nutritional elements than in any other stage, taking up about 50% of the total. During the period from the end of the blooming stage to ripening, it absorbs relatively more nitrogen and phosphorus, while at the seedling stage it absorbs more potassium and calcium (Table 51). Therefore, to determine the rational fertilizing techniques, it is necessary to understand the regularity of faba bean's requirements for nutritional elements.

Nitrogen requirement

Nitrogen is a major component for building up cell protein, chlorophyll and vitamins. Although faba bean itself is capable of fixing nitrogen from the air, the amount of nitrogen is not adequate to meet the required amount for its own growth. In general, it can only supply 1/3-1/2 of the total amount required. Moreover, it is not until the 4-5 leaf stage that the rhizobia will invade the roots and gradually begin azotification. The optimum temperature for the functioning of the root nodules is 15-25°C. At the early

Table 51. Uptake of nitrogen, phosphorus, potassium and calcium by faba bean during different growth periods.

Nutrient	Growth period		
	Seeding to 10% flowering	Blooming	End of blooming to maturity
N	20	48	32
P_2O_5	10	60	30
K_2O	37	46	17
CaO	25	59	16

From Zhang Zhanlin (1961).

stage of rhizobia's invasion into the root system, it needs to rely on the supply of nitrogen from faba bean to build up its own body. Therefore, at the seedling stage, both spring- and autumn-sown faba bean will lack the ability to fix adequate nitrogen even under favorable temperatures. To obtain strong seedlings, deep roots and abundant branches, it is necessary to add appropriate amounts of nitrogen fertilizer at the sowing and seedling stages. The azotification ability of rhizobia is strongest during the blooming stage, and relatively weak at the seedling and the post-podding stages. In the whole process of faba bean growth, quite a lot of nitrogen is required at the seedling, blooming and podding stages.

At certain stages, the intensity of azotification of faba bean rhizobia meets the requirement for nitrogen, but there are stages at which they do not coincide with each other. For example, at the blooming stage, the azotification of rhizobia is still not producing adequate nitrogen to meet the requirement. Therefore, to attain high faba bean yield, it is necessary to apply appropriate amounts of nitrogen fertilizer at the seedling and the blooming stages, as well as at later stages. According to the research done by the Ninghai Science and Technology Committee in Zhejiang province (Anonymous 1984), by adding nitrogen and sulfate of ammonia at 75 kg/ha at the seedling and the blooming-podding stages, or by soaking seeds in ammonium molybdenum of 0.1% concentration for 24 hours, the azotification ability can be enhanced, which will promote plant growth and bring about sharp increases in yield (Table 52). By applying calcium superphosphate at 300 kg/ha and additional applications of sulfate of ammonia at 75 kg/ha at the seedling and the blooming-podding stages, yield can be increased by 8.6 and 13.9%, respectively.

Phosphorus requirement

Faba bean is very sensitive to phosphorus, which is an indispensable element for metabolism, photosynthesis and rhizobia azotification. The phosphorus content differs

Table 52. The effects of nitrogen application on agronomic characters and yield of faba bean.

Treatment†	No. seedlings /ha	No. pod-bearing branches /ha	No. pods /ha	No. seeds /pod	100-seed weight (g)	Seed yield kg/ha	Seed yield %
A	85 050	337 500	703 500	1.69	113.60	1144.35	173.45
B	85 290	360 000	765 000	1.63	112.10	1155.90	174.19
C	85 290	391 500	930 000	1.76	111.52	1255.50	189.12
D	85 080	382 500	946 500	1.74	111.75	1316.55	198.40
E	85 290	388 500	795 000	1.68	111.50	1245.00	187.60
Control	85 290	276 000	634 500	1.63	106.94	663.60	100

† A = calcium superphosphate 150 kg/ha before sowing and at blooming to pod-setting; B = calcium superphosphate 300 kg/ha before sowing; C = same as B + sulfate of ammonia 75 kg/ha at seedling stage; D = same as B + sulfate of ammonia 75 kg/ha at blooming to pod-setting stage; E = same as B + seed soaked in 0.1% ammonium molybdate for 24 hours.

at certain growing stages. At the budding stage, the phosphorus content is in the following order: meristem > reproductive organ > vegetative organ; at the podding stage, the order will be reversed. The phosphorus content in the meristem decreases with the growth of the plant. The percentages at the budding, blooming and podding stages are respectively 37.7, 24.6 and 12.3%. This shows that phosphorus is conveyed from the vegetative organ to the reproductive organ to supply the need of seed growth. Therefore, both at the seedling and podding stages, faba bean requires a lot of phosphorus for root development, formation of root nodules and plumping up of seeds.

In general, phosphorus fertilizer is used as a basal fertilizer or as a late foliar top-dressing. According to the experiment done at the Cixi county of Zhejiang province, on the basis of 1500 kg of farm manure/ha, additional application of calcium superphosphate in different amounts (37.5, 75.0, 150 and 187.5 kg/ha) can increase the number of pod-bearing branches and raise the yield by 50.8-74.6% (Table 53). Research was conducted by Yu *et al.* (1985) in cotton fields given calcium superphosphate at 300 kg/ha. When the field was divided into two halves for applying manure at planting and for top-dressing at planting and post-Spring Festival, respectively, the budding of faba bean for the latter one was earlier and stronger than the first half where fertilizer was applied solely at planting. The senescence stage was delayed for the latter treatment. The economic character was improved and yield was increased by 14.9% (Table 54). Huang and Huang (1986) did top-dressing experiments and demonstrative production by applying KH_2PO_4 at 0.3% concentration to different soils and different varieties in different years. The results show that with spray application of KH_2PO_4, the average yield is 1890.6 kg/ha, which is 11.97% (4.7-19.7%) higher than the average yield of 1688.6 kg/ha for the one without application of KH_2PO_4 (with just water for comparison). The reason for the higher yield is that photosynthesis and the accumulation of carbohydrate are thereby enhanced so that the senescence process is slowed down while the number of pods, number of seeds and the seed weight increases (Table 55).

Table 53. The effects of different rates of phosphorus fertilizer (calcium superphospate) as base manure on yield of faba bean.

Fertilizer (kg/ha)	No. pod-bearing branches /plant	No. pods /plant	Seed yield	
			kg/ha	%
187.5	4.6	21.0	1650	174.6
150	4.6	20.3	1635	173.0
75	4.2	17.9	1425	150.8
37	4.2	17.9	1425	150.8
0	3.5	15.0	945	100

Table 54. The effects of different timing of application of calcium superphosphate at 300 kg/ha on agronomic characters and yield of faba bean.

Application	Plant height (cm)	Thickness of branch stem (cm)	No. pod-bearing branches /ha	No. pods /branch	No. seeds /pod	100-seed weight (g)	Seed yield (kg/ha)
All at seeding	96.5	0.91	2 179 500	4.08	1.57	142	1893
Half at seeding; half by top-dressing	77.0	0.89	2 206 000	4.06	1.60	153	2175

Table 55. The effects of spraying KH_2PO_4 on agronomic characters and yield of faba bean.

Treatment	No. pods /plant	No. seeds /pod	100-seed weight (g)	Seed yield	
				kg/ha	%
Spray KH_2PO_4†	15.75	1.89	108.83	1890.6	119.7
Control	13.04	1.79	105.22	1688.6	100

† The concentration of KH_2PO_4 = 0.3%, sprayed once both at 80% blooming and pod-setting stages; mean values of a 7-year experiment.

Through experiments of different application times and fertilizer concentration of top-dressing, it can be seen that spray application at both the blooming and podding stages will bring about the highest increase. Varied concentrations such as 0.3, 0.6 and 0.9% make no significant difference.

Potassium requirement

Potassium can enhance the intensity of photosynthesis, promote metabolism and synthesis of carbohydrate and help in the formation of amino acids and synthesis of protein. Potassium can enhance the plant's ability to resist cold, drought and diseases. Furthermore, it can increase the number of root nodules, enhance azotification and improve storage quality of faba bean, which prevents deterioration during storage. Farmers in China have a habit of applying only plant ash on faba bean. This is, of course, merely an old fertilizing method at a low production level.

The effects of potassium application on faba bean differ with the levels of potassium in the soil. When the effective content of potassium in the plowed layer is below 375 kg/ha, the effect of the application of potassium on yield increase is great. When the effective content is at the level of 375-600 kg/ha, the application of potassium will still be of certain effect. The research done by Liu Qiongfang (1984) shows that the application of 2700 kg plant ash/ha in varied ways at the seedling stage will increase yield by 17.96-24.95%. The foliar-spray method provides the best result. The faba bean plant fertilized with ash will have larger leaf area and heavier leaf weight. The number of blossoms and pods as well as the seed weight will also increase. Thus, the yield is raised as a result (Table 56).

Table 56. The effect of applying plant ash on faba bean growth.

Treatment	Leaf Area (cm^2)	Leaf Fresh wt. (g)	Leaf Dry wt. (g)	% increase Blossoms	% increase Pods	Plant ht. (cm)	100-seed wt. (g)	Seed yield kg/ha	Seed yield %
Foliar application	26.40	10.81	1.56	16.6	10.49	77.13	51.36	2817	124.92
Applied near root	25.55	9.87	1.55	11.29	5.32	76.82	51.16	2768	122.75
Blanket application	24.96	9.72	1.51	1.41	6.74	76.55	46.93	2660	117.96
Control	20.24	7.72	1.37	0	0	66.43	49.95	2255	100

Note: the sample leaves were the compound leaves that emerged 20 days after application of ash and had two small leaves on the top.

Foliar application of phosphorus and potassium fertilizers at the blooming stage can satisfy the needs of vegetative and reproductive growth and will reduce blossom- and pod-drop. In 1962, the Grain Crop Research Institute of Jiaxin county of Zhejiang province conducted experiments with the foliar application of phosphorus (calcium superphosphate, 1%) and potassium (potassium sulfate, 0.5%) at the early blooming stage. Results show that phosphorus and potassium can help to increase the number of blossoms and pods, as well as reduce blossom- and pod-drop. Potassium shows even greater effect than phosphorus (Table 57). The application of plant ash at the blooming stage can achieve the same effect. During the blooming stage of faba bean, the application of 5250 kg burned mud and soil ash or 1500 kg plant ash in the morning of a fine day can increase the number of pods, seeds and seed weight and the average yield/ha can reach 1950 kg, which is 20.9% higher than the yield (1612.5 kg/ha) of the field without this fertilizer application.

Yang Shaocong (1989) conducted research on the relations between potassium deficiency and the content of nitrogen and potassium in the soil and faba bean plant. Potassium deficiency becomes more serious with the decrease in content of rapidly available potassium in the soil. According to the data collected at the rice fields of Yuxi, Jiangchuan, Chengjiang, and Tonghai counties in Yunnan province, when the content of the rapidly available potassium is 60 ppm in sandy soil and 83 ppm in loamy soil, there will be no potassium deficiency. The seriousness of potassium deficiency increases with the decrease in potassium content in plant. The potassium content in a normal plant (grade 0) is more than double the content in a diseased plant. Among different levels of diseased plants (grades 1-4), there is no distinct difference in potassium content. In general, if the potassium content in the plant is not below 0.92% at the budding stage, nor below 0.60% at the blooming stage or 0.84% at the pod-setting stage, there will not be a potassium deficiency.

The seriousness of potassium deficiency also tends to increase with the rise of the nitrogen/potassium (N/K) ratio. The N/K ratio of a normal plant is 3.38-4.15 lower than that of a diseased plant (grade 1). If the N/K ratio is not higher than 3.39 at the budding stage, nor higher than 5.00 at the blooming stage or 3.40 at the podding stage, there will not be a potassium deficiency.

Trace element requirement

High amounts of trace elements such as molybdenum, boron, iron and copper are not required by faba bean, but they are indispensable, especially molybdenum and boron, for its regular biophysical activities. Molybdenum can promote enzyme activity, enhance azotification, improve metabolism of nitrogen and promote synthesis of protein. It can also increase the chlorophyll content of faba bean, promote absorption, distribution and transformation of phosphorus in the plant, increase the intensity of absorption by seeds and enhance the vigor of seed germination. Through the research carried out by the Shaoxin Institute of Agricultural Science in Zhejiang province, it has been found that the application of molybdenum on faba bean is a convenient, cheap and yet effective measure

Table 57. The effect of foliar fertilization at the early blooming stage upon faba bean yield.

	Buds			Blossoms			Pods			Seed yield	
Fertilizer	No. emerged	No. dropped	% dropped	No./plant	No. dropped	% dropped	% dropped	No. /plant	No. seeds /pod	kg/ha	%
Calcium super phosphate (0.1%)	147.5	64.5	43.7	103.0	78.0	75.7	61.0	8.3	2.12	2698.5	119.3
Potassium sulfate (0.5%)	168.5	43.0	25.5	125.5	78.5	62.5	70.5	6.3	2.12	2851.5	128.9
Control	107.5	39.5	36.7	68.0	55.0	60.9	25.0	7.0	1.96	2212.5	100

to achieve yield increase. From 1981 to 1983, at nine units of three districts, when seeds were presoaked in an ammonium molybdate solution of 0.1% concentration, the average yield reached 3787.5 kg/ha. With spray application of 750 kg/ha ammonium molybdate solution of 0.1% concentration at the budding stage, the average yield was 2230.5 kg/ha. These two methods helped to increase yield by 9.75 and 7.02%, respectively, compared with the control. According to the experiment done by Yang Hongfei (1982) on the variety 'Niutabian', foliar spray of ammonium molybdenum (0.05%) brought about the greatest increase in yield. If the concentration was higher than 0.05%, the amount of increase dropped instead (Table 58).

Seed dressed with ammonium molybdenum can also help to bring about yield increase. An experiment was carried out with every kilogram of seed dressed respectively with 2 and 4 g of ammonium molybdenum in comparison with the undressed seeds (Table 59). The ammonium molybdenum must be dissolved completely before it is used for dressing the seeds, and the dressed seeds must be sown immediately so that their germination will not be affected. Care should be taken that molybdenum fertilizer is not mixed with acid or be in contact with any metal objects.

Boron is also an indispensable trace element for faba bean growth. When faba bean suffers from boron deficiency, the fibers of the fibrovascular bundle which stretch into the nodules cannot grow properly, and the connection between the plant and rhizobia is cut. As a result, rhizobia on the roots do not have an adequate supply of carbohydrate and are very weak in azotification. Boron also participates in the transport of carbohydrate in the plant. It can adjust the absorption of ions effectively by enhancing the absorption of positive ions while diminishing the absorption of negative ions. It can help to increase the podding rate and the seed weight.

According to the research done by Dai Zhongxin (1984) of the Central China Agricultural College, the spraying of 10 ppm of naphthylacetic acid plus 1000 ppm of boric acid at both the blooming and podding stages can greatly reduce pod-drop and raise podding rate. In general, the applications can help to increase yield by more than 10% and shorten the ripening time by 5-7 days. Such applications are convenient, economical and effective. Before naphthylacetic acid is used, it should be dissolved with alcohol. The best time for spraying is on a sunny day or a cloudy evening. Spraying on the back of the leaves will bring about the optimum effect. Huang Zhongai (1989) carried out experiments of spraying different concentrations of boron on faba bean at the blooming stage. The result shows that spraying boron can help to raise the chlorophyll content of leaves and increase the number of pods. The result is better if it is a mixture of 4-CPA (4-chlorophenoxyacetic acid) in concentration of 4-CPA 50 ppm + Boron 500 ppm. Yang Wenyu (1989) of the Sichuan Agricultural University conducted research on the spraying of B_9 4000 ppm solution at the 5-leaf, 15-leaf (blooming stage) and 25-leaf (post-blooming stage) stages on the top of the plant until the solution started dripping down from the top. The result shows that all treatments can greatly shorten the plant height without affecting the number of nodes, and can increase the number of pods, raise

Table 58. The effects of foliar spraying of ammonium molybdenum upon faba bean yield and yield components.

Ammonium molybdenum		Plant height	No. pod-bearing branches	No. pods	No. seeds	100-seed	Seed yield	
Concentration	Frequency†	(cm)	/plant/	plant	/pod	weight (g)	(kg/ha)	%
0.05%	0	106.2	7.5	31.2	1.89	102.0	2446.5	100
	1	113.2	8.0	37.3	1.98	102.5	3207.0	131.0
	2	116.8	6.7	34.4	1.95	103.0	3282.0	134.1
	3	112.7	8.0	39.7	1.84	103.5	3342.0	136.6
0.1%	0	108.2	7.1	30.5	1.98	101.5	2589.0	100
	1	112.2	7.7	34.3	1.99	103.0	3045.0	117.6
	2	113.2	7.1	39.3	2.01	105.5	2910.0	112.4
	3	115.7	7.4	34.3	1.88	106.5	2821.5	109.0
0.2%	0	108.2	6.5	30.1	1.88	102.5	2476.5	100
	1	117.0	7.5	31.8	1.88	104.0	2679.0	108.1
	2	116.0	7.8	39.5	1.90	105.0	2719.5	109.8
	3	115.2	6.8	34.5	1.85	105.5	2743.5	110.7

† 1st spray on 5 Dec. (seedling stage); 2nd spray on 7 Feb. (10% blooming stage); 3rd spray on 29 March (10% pod-setting stage).

Table 59. The effects of seed dressing with ammonium molybdenum on faba bean yield and yield components.

Ammonium molybdenum (g/kg)	Plant height (cm)	No. pod-bearing branches /plant	No. pods /plant	No. seeds /pod	100-seed weight (g)	Seed yield	
						kg/ha	%
1	118.0	8.25	41	1.95	104.0	3064.5	115
2	113.0	8.26	38.8	1.99	104.5	2937.0	110.3
0	101.8	8.0	33.0	1.97	104.0	2662.5	100

the percentage of seeds to pods and the harvest index without affecting the number of seeds and seed weight. Therefore, during the pod-setting stage, spraying with a plant-growth regulator can control vegetative growth and promote the growth of pods.

Principles and Methods of Fertilization on Faba Bean

According to the regularity of faba bean growth and requirements for nutritional elements at different growing stages, the main principle of fertilization is that for application of basal fertilizer, organic manure should be dominant along with phosphorus and potassium fertilizers. The amount of fertilizer applied for the seedling stage should be appropriately adjusted according to the actual state of seedling growth. Fertilizer application at the blooming-podding and later stages and foliar top-dressing is also necessary.

For basal fertilizer, organic manure should be dominant, plus phosphorus and potassium. Organic manure has the advantage of slow release, which maintains a longer effective duration. It can strengthen seedling growth, accelerate the formation of rhizobia and increase vegetative growth, all of which lays a good foundation for high yield. In order to define clearly its effects on yield, Wang (1984) carried out experiments on the individual application and the combined application of nitrogen, phosphorus and potassium as the basal fertilizer. The result shows that except for the case of individual application of 75 kg nitrogen and potassium/ha, the others all show a sharp increase in yield. The application of phosphorus and potassium can bring about a greater effect than that of nitrogen (Table 60). The optimum amounts applied are: for individual application, nitrogen 75 kg/ha; calcium superphosphate 225-375 kg/ha; potassium chloride 112.5-187.5 kg/ha; and for combined application, nitrogen 37.5-75 kg/ha; calcium superphosphate 225-372 kg/ha; potassium chloride 37.5-187.5 kg/ha.

Seedling fertilizer

In case of inadequate application of basal fertilizer, or late sowing, or weak and puny seedling, or drought, it is necessary to apply an appropriate amount of nitrogen fertilizer.

Table 60. The effects of application of nitrogen, phosphorus and potassium fertilizers on faba bean yield.

Treatment (kg/ha)	No. pod-bearing branches /plant	No. seed-bearing pods /plant	No. well-grown seeds /pod	100-seed weight (g)	Seed yield	
					kg/ha	%
N75	3.36	4.48	1.94	44.6	1561.5	100.53
N150	3.74	5.08	1.81	44.7	2218.5	142.85
N225	4.14	4.05	1.79	44.4	1747.5	112.56
P450	4.54	4.94	4.94	44.4	2052	132.13
P750	4.35	5.54	1.77	44.9	2205	142.03
P1050	4.35	4.61	1.80	44.6	1912.5	123.19
K75	3.77	4.81	1.65	45.4	1639.5	105.46
K225	4.27	4.82	1.86	47.1	2109	135.85
K375	4.16	5.02	1.67	46.6	1980	127.54
N75 + P450 + K375	4.70	6.96	1.75	48.9	2092.5	134.78
N150 + P750 + K225	4.75	5.63	1.92	48.6	2413.5	155.46
N225 + P1050 + K375	4.90	4.63	1.82	48.6	2728.5	187.87
Control	2.75	5.75	1.72	41.4	1552.5	100

If the phosphorus and potassium basal fertilizers for the seedling stage are not applied, the nitrogen fertilizer should be applied as early as possible.

Blooming and podding fertilizer

In the whole process of the growth of faba bean, the highest contents of nitrogen and chlorophyll in the plant are during the budding to early blooming stages. This is also the period in which faba bean has the greatest need for fertilizer. Therefore, application of fertilizer at this stage can meet the needs of the great demand and consumption of nutrients for vegetative and reproductive growth. This will raise the podding rate and bring about an increase in seed weight. The amount of fertilizer applied in this period is almost half of the total requirement. Nitrogen can never be excessively applied and must be applied appropriately according to the specific state of seedlings and soil. Otherwise, it will have the opposite effect. The economical and effective foliar top-dressing can be applied during the blooming-podding stage, during which phosphorus, potassium and some trace elements are dominant, combined with an appropriate proportion of nitrogen fertilizer.

Field Management of Faba Bean

Irrigation and Drainage

Faba bean can be easily damaged by drought or by waterlogging. According to the experiment on the water requirement of faba bean done by the Meteorological Department of Yunnan province, the water consumption of its whole growing period is 221.8 m^3. The peak period is the blooming stage, which requires 45.6 m^3 water. At this stage, the soil moisture content must be kept at 30-40%. For example, when the soil moisture is 22.2% at 0-30 cm of soil depth, and the water-storing capacity is 57.3 m^3/ha, faba bean is already in serious shortage of water and is withering. The optimum moisture contents in soil at different growing stages are: 18% at the sowing stage, 18-19% at the seedling stage, 19-20% at the budding stage, 20-21% at the blooming stage and 19-20% at the podding stage. In the autumn-sown faba bean areas in the south, drought often occurs in winter and spring. Zhejiang province suffered from continuous drought from December 1962 to 4 March 1963 and the total amount of precipitation from 1964 to 1965 was only 18.7 mm. There was again a continuous drought for three more months, in which the total amount of precipitation was only 22.7 mm. However, those areas that had started prompt irrigation all got better yields. According to the extensive survey carried out by the Zhejiang Academy of Agricultural Science in the winter (1964) and spring (1965), the average yield in the area with irrigation was 1714.5 kg/ha which was more than 60% higher than the average yield of 1069.5 kg/ha in the area without irrigation. The faba bean plants receiving prompt irrigation grow better and stronger before winter. They have more branches, bigger root nodules and larger leaf area after winter, which has laid a good foundation for producing more pods and seeds and an increase in seed weight (Table 61). In case of continuous drought, the earlier the irrigation is started, the better the results it will bring.

Table 61. The effect of irrigation on faba bean growth.

Character	Irrigated	Nonirrigated
Plant height (cm)	73.7	49.1
Stem thickness (cm)	0.68	0.50
No. branches/plant	2.8	1.8
No. root nodules/plant	54.0	18.3
Fresh wt. of root nodules (g/plant)	1.17	0.32
Fresh wt. of root (g/plant)	5.7	2.5
Leaf area/plant (cm^3)	665.2	313.0
Leaf area coefficient	0.86	0.40

Table 62. The effects of different timing of irrigation upon faba bean yield.

Irrigation time	No. pods /plant	No. seeds /plant	100-seed weight (g)	Seed yield /plant (g)	Seed yield	
					kg/ha	%
22 April (seedling stage)	8.3	18.0	167.0	28.9	2869.6	100
9 May (early budding stage)	8.5	19.2	168.5	32.6	4105.5	143
11 May (late budding stage)	8.5	20.0	167.5	33.9	4311.0	150
21 May (early blooming stage)	7.3	16.9	160.5	24.1	3600.0	126.5

The critical period for water requirement of faba bean is from the budding stage to the early blooming stage. During this period, those areas of water deficit must be irrigated promptly. According to research by the Linxia Institute of Agricultural Science in Gansu province (Table 62), irrigation at the budding stage has a great effect on the increase of the number as well as weight of pods and seeds and eventually in yield as well.

There is a common saying in China: "dry blossoms, wet pods." That means that fine weather during the blooming stage can give faba bean adequate sunshine which is good for blooming and fertilization and will reduce blossom- and bud-drop. The saying does not mean that water is not required during the blooming stage. On the contrary, this is the critical period of water requirement in the whole growing process of faba bean. In dry areas, irrigation must be carried out promptly to meet the needs of faba bean for its pod-setting stage. There is always a long dry period in winter and spring at Yunnan province. Faba bean is very sensitive to irrigation. From the seedling stage to early blooming stage, instead of irrigation, farmers reduce the evaporation of water by inter-row cultivation. At the blooming and podding stages, irrigation is done to meet the needs of vegetative and reproductive growth. At pod-setting stage, irrigation is needed to ensure the plumping up of seeds. To avoid soaking and flooding, ditch irrigation should be adopted.

Although faba bean growth requires quite a lot of water, waterlogging should be avoided. In the winter faba bean growing areas, especially the rice-growing areas of the middle and lower Yangtze River Basin, the underground water level is high. Therefore, in areas that are rainy in spring, it is important to dike and drain away excessive water to ensure regular growth of faba bean. If there is waterlogging at the seedling stage for 3 days, the leaves will turn yellow, and after 5 days, the roots will rot; if this continues for more than 7 days, the seedlings will die. If there is waterlogging at the blooming and podding stages, the stem base will turn black and rot. Therefore, in Jiangsu and Zhejiang provinces, farmers usually adopt the method of "deep-ditch and high-ridge"; the higher the underground water level, the deeper the ditches are dug. In winter and early spring, the ditches must be promptly cleared to drain away excess water and prevent waterlogging.

Tip-pruning and Top-removing

The main reasons for blossom- and pod-drop are nutrient deficiency and unbalanced distribution of nutrients. As shown by many researchers, prompt tip-pruning and top-removing can promote vegetative and reproductive growth, adjust the distribution of nutrient and modify the regularities of blossom- and pod-drop. The podding rate is accelerated, which can help increase the number of pods and seeds, as well as their weight and yield eventually. Research was carried out by the Institute of Agricultural Science at Jiaxin district of Zhejiang province in 1964 (Anonymous 1964). Under different years and different climates, tip-pruning and top-removing of the faba bean variety 'Xiangzhudou' show their effectiveness on yield increase (Table 63).

The 2-year experiment (Table 63) shows that tip-pruning and top-removing done in mid- and late April increase yield. The optimum times for tip-pruning are prior to the

Table 63. The effects of tip-pruning and top-removing at different times on faba bean yield.

	Yield		
Treatment date	With tip-pruning (kg/ha)	Control (kg/ha)	As % of control
1962			
11 April	2538.0	2610	97.3
16 April	2935.5	2610	112.4
20 April	2715.0	2610	114.3
26 April	2997.0	2610	114.8
4 May	2184.0	2610	83.7
1963			
3 March	1044.0	1061.3	98.4
7 April	1368.8	1256.3	108.8
14 April	1314.8	1106.3	118.8
21 April	1311.0	1105.5	117.0
28 April	1235.3	1053.0	'117.3
6 May	907.5	1129.5	80.4

emergence of the compound leaves (composed of 7 leaflets) on the first branch and prior to the emergence of the compound leaves (composed of 6 leaflets) on the second and third branches. Tip-pruning and top-removing should be done in fine weather after dew drops have evaporated to prevent water from getting into the cut. Otherwise, the cut will turn rotten. If the faba bean plants are not growing well or the crop density is not high or the soil fertility is low, tip-pruning and top-removing should not be done.

Harvest and Seed Reservation

Optimum Harvesting Time

The optimum time for harvesting faba bean can ensure highest yield and quality without affecting the optimum time for sowing and transplanting of the following crops. This can ensure high yield for all crops in the whole year. Qiu and He (1985) from the Zhejiang Agricultural University carried out experiments in 1982 and 1983 to find out the effects of different harvesting dates on faba bean yield and quality. The harvesting dates were 13, 17, 21 and 25 May. The result shows that the best harvesting time is when 2/3 of the pods of the whole plant have turned brown, the water content in the plant is 77.4% and the water content in the pod is 61.8%, that is, the time of late "milky-maturity" stage. The best time for these experiments is 21 May, when the nutrient content in the pods has already been basically transferred into the seeds. The plumping up of seeds has stopped and dry matter has stopped increasing. The content of protein in seeds and the development rate of seeds are high and so they are of better quality (Table 64).

Table 64. Effects of different harvesting dates on faba bean† yield and quality.

Harvest date	Germination (%)	Germination vigor	Seed protein (%)	100-seed weight (g)	Seed yield	
					kg/ha	%
13 May	79.5	76.5	31.8	51.16	1387	100
17 May	77.0	60.5	31.2	59.23	1563	112
21 May	73.0	63.0	30.5	65.90	1969	141
25 May	62.5	42.5	30.5	67.28	1999	143

† Cultivated variety = Shaoxin 'Xiangzhudou'. Whole plant harvested. Germination and vigor based on experiment initiated on 2 June using 50 seeds replicated four times. Germination vigor investigated on 7 June and germination percentage on 10 June.

From the speed of seed plumping, we can see that pod and seed development are compatible. By 4 March (34 days after blooming) the seed capacity has reached the highest point. Before 28 April, the plumping up of seeds proceeds very slowly, but after this date, its speed increases sharply. By 17 May the fresh weight has reached the highest point. After this, the weight will drop rapidly. By 23 May the plumping up of seeds has stopped, both the fresh and dry weights are relatively stable and the volume no longer changes (Fig. 27).

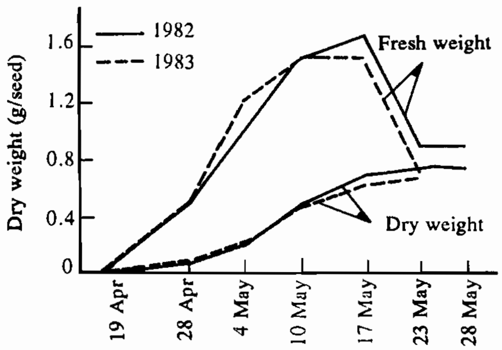

Fig. 27. The rate of filling-up of seed.

Seed Selection and Seed Reservation

For reservation of seeds, it is necessary to select before harvesting in the fields those plants which are sturdy and have low pod positions. There should be abundant pods, short internodes and plants should be free of insect pests and diseases. They are then marked and after harvesting, the pods from the middle of the plants are taken for reservation. The grains will be selected again before sowing in order to pick out those that have more pods and seeds and bigger seeds. The Seed Culture Teaching Group of the Zhejiang Agricultural University (Anonymous 1961) carried out experiments on three different harvesting days of four varieties to define the effects of different harvesting time on 100-seed weight, yield and the yield in the following year as well. Harvesting 1 or 2 weeks before the optimum harvesting time will affect the yield and 100-seed weight of the first year. It also has greater effects on the seeds of the upper part of the plant. However, early harvesting affects slightly the yield and economic character of the crop in the following year. Therefore, the plant for reservation can be harvested 1 or 2 weeks ahead of the regular harvesting date to ensure the optimum time for sowing in the following cropping season. The pods on the upper part of the plants harvested earlier should be removed and those on the lower part left to ripen naturally until they are shelled for reservation.

Research on Comprehensive High-yielding Cultural Techniques for Faba Bean

Standardized Cultural Techniques for Spring-sown Faba Bean

From 1984 to 1987, the Academy of Agricultural Science of Qinghai province organized all the research, teaching, and production institutions within the province to conduct research on standardized cultural techniques of spring-sown faba bean in Xining city and the main faba bean growing areas (Anonymous 1987). Using the experience of the farmers, they conducted many comprehensive experiments. After analyzing data obtained from many years of multilocation experiments, they established a mathematical model. Then they worked out programs of standardized faba bean cultural techniques for different areas according to local conditions. These programs were subjected constantly to revision for improvement.

The goal of this research program was to attain faba bean yield above 3759 kg/ha on irrigated fields and above 1875 kg/ha on dryland and to reduce the production cost. The end goal was to achieve high yields and low cost.

Through a great deal of analyses of climate and experimental data and through determination of the growth vigor, the growth feature and yield on thousands of faba bean plots in main production areas, more than 4000 data were obtained. After systematic environmental and regional designation based on factors such as soil, elevation, temperature and precipitation, research was carried out at the key units which were set up after the regional division and classification. The focus was on those primary factors that have greater effects on yield, such as growth density, fertilizer, row spacing, variety, sowing date and irrigation. Minor factors such as weeding, foliar dressing and tip-pruning were maintained at the minimum level by cultural measures. For random factors such as frost, disease, pests and weeds, countermeasures were adopted according to the actual situation. Sometimes a certain item among the primary factors under research was fixed at a certain allowable level for production. For example, only the permitted varieties such as 'Qinghai 3 Hao' and 'Maya' were used, and irrigation was carried out in the conventional way. Thus, although there were not so many factors that were directly studied, the research could reflect the comprehensive effects of environmental and cultural measures on the varieties.

In 1985, research on systematic technical development was conducted. Under the guidance of the specialists, experiments were conducted to compose and design comprehensive cultural techniques concerning the five factors (growth density, application of nitrogen and phosphorus fertilizer, sowing date, row spacing and sowing depth) by means of quintuple quadratic orthogonal regression (rotation compose design). Through experiments at 26 points in both irrigated and dry areas, more than 10 compatible models of agricultural technical measures were established for varieties such as 'Qinghai

3 Hao' and 'Maya'. With these models, and through simulation experiments with the computer, the bases for the programs of standardized cultural technique were obtained.

In 1986, the programs were subjected to verification. Four sets of optimum programs and one set of zero-level standard program as the control were subjected to verification at 24 points. The results showed high significance in both irrigated and dryland areas. At 12 points in the irrigated fields, 33 programs brought about yield increase, which covered 68.8% of all the optimum programs. The yield/unit area was raised by 8.7% in comparison with the control. In the dry areas, 25 programs showed yield increase, covering 52% of the programs. The average yield increase was 2.2%. There were altogether 15 programs in which the yield exceeded both the control and the designed objective by more than 10%.

During the verification period, eight sets of demonstration programs were also carried out at 284 farming households in four different counties. These programs covered 46.31 ha in which irrigated land constituted 23.28 ha and dryland 23.03 ha. The average yield in the irrigated land was 4777.5 kg/ha, which was 18.9% higher than the yield of the check (measures decided by farmers themselves); average yield in the dryland was 3598.5 kg/ha, 41.6% higher than the check.

In 1987, on the basis of the previous year's experiments, 13 sets of standardized cultural programs for both irrigated and dry areas at four main faba bean growing counties were launched. Thus, "The Table of Comprehensive Cultural Techniques of Faba Bean" was published and distributed. In all, 40 053 demonstration households were organized and 6135.4 ha of irrigated and dry demonstration fields were planted. The average yield was 3993 kg/ha. The area of the irrigated demonstration fields was 3730.94 ha and its average yield was 4237.5 kg/ha, which was 23.79% higher than the check. The area of the dry fields was 2404.5 ha and its average yield was 3615 kg/ha, 22.21% higher than the check. According to the analyses of yield from the monitored fields in 1987, eight sets of programs proved to be the best. The average yield for the four irrigated land programs was 4717.2 kg/ha and the average yield for the four dryland programs was 3804.6 kg/ha. The control yields were 3551.4 and 2979.3 kg/ha, respectively. Therefore the increases were 32.8 and 27.7% higher than the check. To analyze the reason for the yield increase in the programs of comprehensive cultural techniques (Table 65), we present as an example the mathematical model of the high-yield variety 'Qinghai 3 Hao' faba bean. Its yield model is:

$$Y = 294.58 + 2.9248x_1 + 16.08x_2 - 9.4328x_3 + 5.2225x_4 + 8.71x_5 + 0.8307x_1x_2 - 3.248x_1x_3 + 16.7312x_1x_4 + 13.87x_1x_5 + 16.978x_2x_3 - 0.1713x_2x_4 - 0.6656x_2x_5 - 10.7587x_3x_4 - 2.4369x_3x_5 + 10.8138x_4x_5 - 0.924x_1^2 - 4.934x_2^2 + 4.0734x_3^2$$

In the linear items, it can be seen that the effects of the five agronomic measures are in the following order: X_2 (fertilization)) > X_3 (sowing time) > X_5 (sowing depth) > X_4

Table 65. Comparison of faba bean yield ('Qinghai 3 Hao') and yield components between high-yield demonstration fields and the control.

County	Township	Treatment	No. pods /plant	No. seeds /plant	100-seed weight (g)	Seed yield	
						kg/ha	%
Huzu	Shuangshu	Demonstration	8.7	17.6	186.5	4699	127.0
		Control	4.5	9.3	173.0	3700	100
Huzu	Weiyuan	Demonstration	10.92	21.6	145.7	4455	122.2
		Control	6.5	12.2	142.3	3646	100
Huangzhong	Zongzai	Demonstration	12.8	23.7	168	5895	142.9
		Control	5.9	11.2	145	4125	100
Datong	Xinzhuang	Demonstration	6.04	12.1	159	4983	128.6
		Control	5.60	9.8	156	3876	100

(row spacing) > X_1 (density). In the quadratic items, it can be seen that the fertilization level and sowing time have greater effects on yield. The effects of the comprehensive agronomic measures are interactive. Besides the effects of the primary factors, there are also correlated effects between factors. Take, for example, the relation between sowing time and row spacing. For early sowing, the row spacing should be wide, whereas for late sowing it should be narrow. The combination of high density with wide row spacing can raise the yield. However, the combination of high density with narrow row spacing or low density with wide row spacing will cause a drop in the yield. The comprehensive cultural techniques can provide optimum combinations of different effective measures to achieve the maximum comprehensive effects and coordinate the utilization of time and space. Thereby, the yield would be raised.

Cultural Techniques for High-yielding Autumn-sown Faba Bean

Some institutions such as the Shanghai Agricultural College (Anonymous 1986), the Institute of Agricultural Science of Nantong in Jiangsu and the one at Dali City in Yunnan conducted research on high-yield techniques for large areas and summarized the experience. For the 5.42 ha of verified experimental fields in Shanghai, the average yield was 3394.05 kg/ha, which was 20-60% higher than that of the conventionally cultured fields. The average yield of the 60 000-ha fields in Nantong of Jiangsu province was 2797.5 kg/ha in 1978 and 2962.5 kg/ha in 1979. The yields of the high-yield fields even reached 5085 kg/ha and 4624.5 kg/ha in the 2 years. From 1984 to 1986, the average yield of the 6000-ha faba bean fields in Dali city of Yunnan province was 3223.5 kg/ha. The average yield was 3270 kg/ha in 1987, being 61.48% higher than the average yield (2032.5 kg/ha) of the 36 years before the 1980s. In the 0.29-ha demonstration field grown with the improved high-yield variety 'Fengdou 1 Hao' the average yield was 7005 kg/ha. The highest yield reached 7710 kg/ha. Through this research, the following causes for high yield were determined.

Optimum sowing time

The experiments with sowing carried out at different times showed that in Shanghai district, faba bean sown within the period from August until the following March could all bloom and pod. However, the yield was highest when faba bean was sown in mid- to late October. The average yield of faba bean sown within this period was 4198.5 kg/ha and the average diurnal temperature was 15-17°C. In the experiment done at Dali city of Yunnan province, the yield of faba bean sown in mid-October was the highest, averaging 5409 kg/ha. The period from the day of "Cold Dew" to "Frost Fall" was the optimum sowing time in this area. The temperature often goes below -5°C in winter in the autumn-sown faba bean area, especially in the middle and lower Yangtze River Valley. If faba bean is sown too early, the growth of seedlings will be too fast before the Spring Festival (5 February) and early branching will result in weaker resistance to cold weather so that the plant cannot survive the winter safely. If faba bean is sown too late, the seedlings will still be small before the Spring Festival, branches will not be able to develop fully and the ideal yield cannot be attained. Therefore, the sowing time in different areas must be decided according to the varieties' characteristics and local climate. This is an essential prerequisite for high yield.

Determination of rational planting density

First, the suitable basic seedlings and sowing methods should be decided according to the factors of variety, soil and cropping system to attain high yield. The research done by the Shanghai Agricultural College at its three experimental sites shows that the optimum number of basic seedlings for pure growing of faba bean is 120 000-150 000 plants/ha while the optimum number for intercropping is 105 000 plants. The best sowing method is by drilling. The illumination condition is better with wide row plus narrow interplant spacing. According to determinations made 10 days after closure of rows, the intensities of illumination at the heights of 5, 25 and 45 cm are 9.41, 16.77 and 32.15 Lux (10^3), respectively, higher than those in equal-spacing rows by 171.18, 62.05 and 12.35%, respectively. The optimum row spacing for pure faba bean cultivation is 6-70 cm and 90-105 cm for undercrop-sowing. In Dali City of Yunnan province, in the fields of medium soil fertility, the number of basic seedlings for faba bean yield above 3750 kg/ha should be 300 000-375 000 and the number of pod-bearing branches should be 675 000-750 000. According to the Shaoxin Institute of Agricultural Science in Zhejiang province, faba bean in the high-yield fields should have 525 000-600 000 pod-bearing branches.

Therefore, the best density must be decided through experiments according to the local conditions.

Table 66. The effect of molding upon faba bean yield and yield components.

Treatment	No. plants /ha	Plant height (cm)	No. pod-bearing branches/plant	No. pods /branch	No. seeds /pod	100-seed weight (g)	Seed yield	
							kg/ha	%
Molding	121 000	102.3	5	4.2	2.9	81.5	4560	116.9
Control	121 000	97.4	4.8	3.9	2.8	79.0	3900	100

Ditching, molding and dyking against the cold weather

In the autumn-sown faba bean area, especially in the middle and lower Yangtze River Valley, severe cold weather (below -5°C) often occurs in winter. Sometimes it lasts quite long, which is likely to cause cold injury to faba bean. Pre-winter ditching and molding can be quite effective in providing resistance to cold weather. Post-spring molding can also help drainage, and thus raise the podding rate, seed weight and eventually the yield of faba bean (Table 66).

Improvement of fertilizing techniques

To attain high yield of faba bean, the conventional practice of "applying only ash manure" must be changed. The Shanghai Agricultural College has summed up the fertilizing techniques of "application of basal fertilizer, top-dressing at the seedling stage, fertilizing at the blooming-podding stage and at the later stage, and then the top foliar dressing." For basal fertilizer, nitrogen and phosphorus are applied in combination and they are mainly applied by hole application. The amount of calcium superphosphate applied is 150-300 kg/ha. If drought occurs, manure and water should be applied to attain good germination. At the seedling stage, nitrogen fertilizer can be applied appropriately to accelerate seedling growth before winter comes. This strengthens them to survive the winter and increases the number of pod-bearing branches. The blooming stage is the peak growing stage during which vegetative growth is transferred to reproductive growth, so fertilization shows its greatest effect at this stage.

The Shanghai Agricultural College carried out experiments with the application of nitrogen fertilizer at different times. The results show that both basal fertilizer and fertilizer applied at the blooming stage have the greatest effects on yield increase. The yields/unit area were 2466 and 2451 kg/ha, being 39.35 and 38.35%, respectively, higher than the check. According to the analysis, from the time of budding to seed plumping, there are two peak periods of nitrogen and chlorophyll contents in the plant: the first one is at the early blooming stage, and the second is at the post-podding stage. Thus, the application of fertilizer at the blooming stage can satisfy the need for nutrients during these two peak periods. In applying fertilizer for the blooming stage, nitrogen, phosphorus, molybdenum, boron, etc. can be applied in the way of foliar top-dressing, which is both convenient and economical.

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Chapter 7. Diseases and Insect Pests of Faba Bean

A total of 102 faba bean diseases caused by fungi, bacteria or virus were recorded according to Yu Dafu (1979), an outstanding Chinese plant pathologist. The fungal diseases, mainly rust (*Uromyces fabae*), chocolate spot (*Botrytis fabae*), ascochyta blight (*Ascochyta fabae*), zonate spot (*Cercospora zonata* Wint.) and root rot (*Fusarium solari* Mart.), are most common in faba bean growing areas in China. The major insect pests are faba bean beetles, aphids and root nodule weevils.

Diseases

Rust [*Uromyces fabae* (Pers.) de Bary]

Rust is widely distributed in both autumn-sown and spring-sown areas, particularly in the Yangtze River Basin, with varying severity in different years. The fungus has a wide host range besides faba bean, such as pea, vetch, bush vetch, fivevein vetch (*Vicia sativa* L.) and some weeds. During 1933/34, Professor Yu noted that there was a severe rust epidemic around the lower course of the Yangtze River, causing 70-80% production loss in severely infected fields. In 1988, there was a rust epidemic in Yunnan province causing yield reduction of 14.5% compared with the production of the previous year.

Symptoms
The disease mainly infects leaves and stems. In the early stage of infection, light yellowish spots appear on the leaves. They then develop into rust-brown, small, bulging spots about 1 mm in diameter. These are young uredinia, which will later burst open to disperse rust-colored, powder-like urediospores. In the late stage of infection, teleutosoris, which are black, elliptical, intumescent spots larger than the uredinia, are formed on leaves, particularly on petioles. The centers of the teleutosori later also burst open to discharge black powder-like teleutospores. Symptoms on stems are similar to those on leaves. Uredinia and teleutosoris, especially the latter, are also produced on the stems. Plants die early if the infection is serious (Fig. 28).

Pathogen
The disease is caused by the organism *U. fabae*, an uredinale, which can form five types of spores in a life cycle: basidiospore, pycnidiospore, aecidiospore, urediospore and teleutospore, on the host plant. Urediospores and teleutospores are more commonly found.

The urediospore is spherical to oval in shape, 28-31 x 16-27 μ in size, light yellowish-brown in color with micro-echinulate and 3-5 germ pores on its surface. Some large

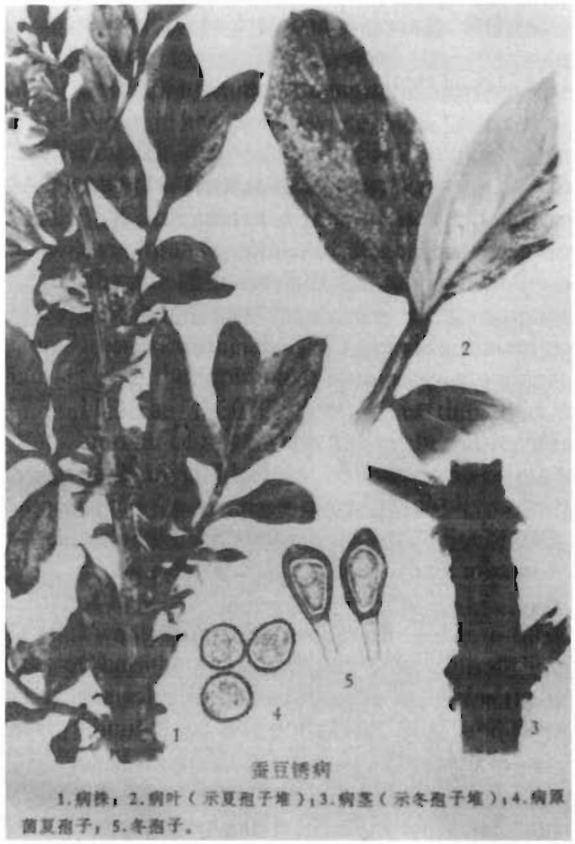

Fig. 28. Faba bean rust (*Uromyces fabae*).

spores can be 28 x 35 μ in size. The wall of the spore is 1.5-2.5 μ thick. The optimum temperature for urediospore germination is 16-20°C, with 1-2°C as the minimum and 31°C as the maximum temperatures. Spores begin to germinate within 1 hour at 20-22°C. Thermal death point (TDP) of the spore is 5 minutes at 46°C, 10 minutes at 42-44°C, 20 minutes at 40°C and 30 minutes at 38°C. The urediospores need high relative humidity (RH) to germinate. At 20-25°C, when RH is higher than 95%, the germination rate is 70% in 24 hours, whereas at 80-90% RH, the germination rate is less than 30%. Little or no germination occurs if RH is below 80%. Spores can survive more than 100 days if RH is around 50% and temperature is kept at 1°C.

The teleutospore is a single cell of spherical to oval shape, mammillate and with a dark brown, smooth surface. It is 22-40 x 17-29 μ in size, with light brown halva 90 μ or longer. Germination of teleutospore does not need a dormant period or low temperature treatment. The mature spore germinates under 95-100% RH and 16-20°C to produce a germ tuber (basidium) and basidiospore. However, if spores are dipped into drops of water, they can produce a long basidium and do not form a basidiospore.

Epidemiology

The pathogen survives winter by forming teleutospores and urediospores on crop debris. Urediospores germinate to infect faba bean directly in the next spring. Teleutospores germinate to form basidia and basidiospores. The basidiospores produce germ tubes to infect faba bean, from which the pycnidiospores and aecidiospores are formed and dispersed by wind and rain to infect stems and leaves of nearby faba bean plants. Afterwards, urediniospores are formed to infect crops in the field repeatedly and finally form teleutospores on diseased plants.

During April to May, the abundant rainfall with high RH and optimal temperature as well as the wet southeast monsoon reaching the Yangtze River Basin are favorable for the spreading of faba bean rust. The disease is usually less severe in a drier and higher temperature season. The high humidity in the main autumn-sown faba bean growing area in China usually favors the infection and development of the disease. Temperature determines the time for the outbreak of the disease. The optimal temperature for the formation of a uredinium is 14-24°C but the maximum amount forms at 18-24°C. Normally, infection is more severe in lower parts of the field than on dry, sunny slopes. Humidity plays an important role in causing this epidemic disease.

Chocolate Spot (*Botrytis fabae* Sardina)

Chocolate spot is a common disease in both autumn- and spring-sown areas in China, particularly in the Yangtze River Basin and almost all provinces in the south of the river except Yunnan province. The amount of infection differs every year because of the variation of climatic condition each year. As early as in 1924 and 1925, the disease was reported to be caused by *Botrytis* species, which would infect faba bean particularly although it might also slightly infect *Vicia sativa.*

Symptoms

The pathogen infects the leaves, stems, flowers and sometimes young pods of faba bean. Although the disease usually occurs in early spring, the infection can already be seen on the lower foliage of the plants in November and December. From late February to early March, small reddish-brown spots are formed initially on foliage at the early stage of infection. Then they enlarge to become spherical or elliptical lesions, slightly concave with brown centers and dark brown margins (Fig. 29). The lesions are small, not exceeding 1-3 mm in diameter and remain the same size in most cases during the growing season of crop. However, the size of lesions is associated with the number of lesions on foliage, i.e., the fewer the lesions, the larger the size, sometimes reaching 4 to 5 mm in diameter. The initial symptoms on stems and petioles are similar to those on foliage with small brown spots, then spread vertically to form streak lesions with brown margins and finally break to form necrotic areas with brown margins in different lengths. Symptoms on flowers are brown spots, which are well distributed; in severe cases, the corolla withers. Serious infection of the plant results in darkening, drying and grey mold

Fig. 29. Faba bean chocolate spot (*Botrytis fabae* Sardina).

covering the whole plant. These are conidiophores and conidiospores. Dark sclerotia attached to the hollow dead stem are visible when the stem is cut open.

Pathogen

Chocolate spot is mainly caused by *B. fabae*, but *Botrytis cinerea* Pers. is another minor agent. The conidiophore is light brown and from it the conidia-bearing apparatus forms. Each apparatus is swollen at the end and bears a cluster of conidia. The conidiospore is a single cell, spherical or elliptical, and is light green or light grayish-green. The sclerotium is brownish-black and elliptical with a rough surface.

Epidemiology

The pathogen, as sclerotia, survives summers and winters on debris of diseased plants in soil. Under favorable environmental conditions, the sclerotium germinates to form a conidiophore that causes primary infection. Afterwards, numerous conidia are formed on diseased plants continuously and dispersed by wind and rain to infect other plants in the field. Yu (1979) found that the optimal temperature for spore germination and disease infection is below 20°C, but infection may occur at a temperature as high as 30°C. Temperatures of 15-25°C usually last a long time during the faba bean growing period in both autumn- and spring-sown areas. Although temperature may be considered as one of the important environmental factors for disease infection, the most important cause is humidity. The disease becomes epidemic or causes serious damage when relative humidity is 80% or higher. Yu (1979) analyzed meteorological data from Kunmin, Yunnan province and Nanjing of Jiangsu province for the effect of RH on the development of chocolate spot disease. He found that during the last 2 months of faba bean growth, it was so dry in Kunmin that little disease was found but almost all plants were infected in Nanjing because of the high humidity and rainfall. The average rainfall in March was 38 mm with 60.5% RH and in April 47 mm with 61.8% RH from 1928 to 1933. In Kunmin, average monthly rainfall in March and April from 1951 to 1980 was 15.2 and 21.1 mm respectively, and RH in April was only 58% which was unfavorable for disease infection. However, in Nanjing in 1933, rainfall in April and May was 114.1 mm with 83.2% RH and 116.4 mm with 85.2% RH, respectively. From 1951 to 1980, the average rainfall in March and April was 72.7 and 93.7 mm and RH in April was 75%, which was favorable for the development of chocolate spot. In the Yangtze River Basin, a long, continuous rainy period from March to May every year is a major predisposition for the infection and outbreak of chocolate spot.

Ascochyta Blight (*Ascochyta fabae* Speg.)

Although *A. fabae* is observed in different parts of China, it is not as widely distributed as chocolate spot. However, during an outbreak, damage is more severe than chocolate spot, with 50% or more yield loss in severely infected fields. Normally, more infection occurs in moist fields and less infection is found in drier fields. Yu (1979) suggested that Ascochyta on faba bean in China is a special kind of pathogen infection.

Symptoms

The pathogen mainly infects leaves, stems and pods. Lesions on foliage initially are small brown spots, then enlarge into spherical or long elliptical shapes of 2-22 x 2-16 mm in diameter or into irregular shapes, which have dark brown or chocolate-brown margins with light gray centers and numerous black pycnidia. The lesions usually have concentric rings on their surfaces and often break to form necrotic areas. The change of color in the center of the lesion is associated with the climatic environment; for instance, in Yunnan, where the climate is always dry, the center of the lesion is white, whereas in places of higher humidity, it is grayish-white. The color of lesions on leaves is lighter and they are bigger than those on stems, which are round or oval. The center of the lesion on the stem is gray with chocolate margins, usually sunken deeply into the host tissue. The lengths of lesions vary, with the longest about 25 cm. Numerous pycnidia form on

Fig. 30. Left: faba bean Ascochyta blight (*Ascochyta fabae* Speg.); Right: faba bean zonate spot caused by *Cercospora zonata* Wint.

the surface of the infected tissue. On pods, lesions are circular or oval, deep brown with black margins and often sunken deeply into the host. On diseased seeds, brown to black lesions are formed on the surface of grains and often produce pycnidia; such seeds normally do not germinate well (Fig. 30).

Pathogen

The disease is caused by deuteromycetes. The pycnidium is heart-shaped, dark brown with ostioles, and 172 x 178 μ (95-270 x 111-301 μ) in size. The pycnidiospore is 17.9 x 5.9 μ (1.4-30 x 3.8-7.9 μ) in size.

Epidemiology

Pycnidia and pycnidiospores on diseased stems and pods of faba bean debris can survive winter or summer. In the next spring when weather is getting warm with high humidity in the air, numerous pycnidiospores are released from the pycnidia through ostioles to infect lower leaves and the disease gradually spreads to the whole plant. During April and May, when there is much rainfall, the peak of infection may occur. Pycnidiospores are dispersed by rain and wind. Diseased seeds used for planting are a main cause of large-scale field infection.

Faba Bean Zonate Spot (*Cercospora zonata* Wint.)

Faba bean zonate spot is a common disease in China, particularly in the area along the Yangtze River. This disease always break out in overplanted faba bean fields where humidity is high. Conversely, less infection may occur in highland and dry fields. Faba bean is the major host of the pathogen which may also infect *V. sativa* in some cases.

Symptoms

Cercospora zonata mainly infects leaves, but may also infect stems and pods of faba bean. Lesions are small reddish-brown spots, 1 mm in diameter. They are formed on the lower leaves at the initial stage, and then rapidly enlarge to become circular or irregular zonate lesions of 5-7 mm, sometimes up to 14 mm in diameter with a gray center and reddish-brown margins if the climatic condition is favorable. Under moist conditions, gray mold is found on zonate lesions, which are conidiophores and conidia. Lesions on stems are dark gray and elliptical (Fig. 30).

Pathogen

The disease is caused by *C. zonata*, a specie of Deuteromycetes. From 3 to 5 conidiophores protrude from the stoma; they are brown in color, swelling at the base, curving at the tip-bearing conidia, which are hyaline strips with 6-12 septa.

Epidemiology

The pathogen survives winters in soil with diseased debris and produces conidia to cause primary infection the following year and it is dispersed by wind and rain to cause re-infection, especially during a long period of wet climatic conditions with temperatures between 18 and 26°C.

Faba Bean Root Rot (*Fusarium solani* Mart.)

Faba bean root rot is caused by a *Fusarium* species which is a strong parasite on faba bean. Although the disease is not common in China, it usually occurs in the spring-sown area, and in the autumn-sown area it is found only in Yunnan. The poorly growing plants in dry poor soil or frost-injured plants are easily infected by *Fusarium* species.

Fig. 31. Faba bean root rot caused by *Fusarium solani.*

Symptoms

Initially, at the flowering stage, faba bean plants are infected by *F. solani* on rootlets and fibrous roots, then gradually spread to the main root and the base of stem. Small parts of the diseased root and stem base turn black and rotten. Then most of the root system becomes moribund and dry. The leaves of infected plants are pale green or yellowish-green. The disease is characterized by black necrotic areas in various sizes around the margin of the lower (oldest) leaf, which then enlarge gradually to cover the whole leaf and became black. Later, both the infected leaf and stem turn black, shrink and die. All epidermal and cortical cells of roots and stem base can be infected and turn brown. Under humid conditions, a layer of light red mold can be found on the surface of the stem base; these are the conidiospores of the pathogen (Fig. 31).

Pathogen
The disease is induced by *Fusarium* species which produce two types of conidia, of which the macroconidia are covered by spindles with 0-12 septa and the microconidia are oval or kidney shaped, single or double cell(s), but rarely formed or detected.

Epidemiology
The major source of primary inoculum is from the diseased debris of crops left in the field. Seeds can also carry the pathogen but it is not as serious. According to the work of Yu (1979), the pathogen can survive in the soil for at least 2 years and infect the root system of faba bean directly as the soil conditions become favorable. Temperatures between 16 and 18°C and dry soil or a badly drained field can easily induce the infection. Ruan (1986), from the Plant Protection Department of the Yunnan Agricultural University, investigated the epidemiology of faba bean root rot at the seedling stage in Yunnan, and the results are as follows.

A close relationship exists between soil moisture content and disease occurrence rate. An investigation was carried out in central, western and eastern Yunnan with 10 survey sites for each area and the result showed that the average disease occurrence rates were 11.45 ± 6.07, 16.75 ± 13.75 and 45.21 ± 24.07, corresponding to relative soil moisture contents of 45.2-72.1, 73.9-91.5 and 7.92%, respectively. Soil moisture content, in particular, seriously affects root rot disease of faba bean after seedling emergence until the 3-5 leaf stage. Therefore, attention should be paid to having a good drainage system with a high ridge to avoid flooding of the field.

Soil pH does not affect the existence of faba bean root rot disease. A disease incidence of 28.79, 31.27, 34.44 and 34.09% was found in different fields with soil pH of 6.0, 6.5, 7.0 and 7.5, respectively, showing no significant difference.

Disease incidence is noticeably reduced by crop rotation. Investigations carried out in Chuxiong, Dayao, Dongchuan and Qiujing counties of Yunnan province found that disease incidence was obviously reduced to 5.69% after only one year's crop rotation, and that of continuous cropping was 38.10%.

Faba Bean Galls (*Olpidium viciae* Kusano)

Faba bean galls is one of the major diseases on spring-sown faba bean in highland areas, including Songpan, Xiaojin and Maekang areas of northwestern Sichuan at an elevation of 2500-3400 m. It has been getting serious since the 1970s and so far over 4000 ha of crop have been affected with a yield loss of 20%. It is also affecting Gansu, Tibet and Shanxi provinces.

Symptoms
Symptoms mainly appear on leaves and stems. At the initial stage of infection, on the

back (or sometimes front) side of leaves, chlorotic galls are formed, then progressively enlarge to become light brown, circular or elliptical rough spots. Thus, the small tumor-like galls are formed, 3-5 mm in diameter and 1-3 mm high. There are 10 to 30, with a maximum of more than 50 small galls on one small leaf and 20-30 galls often coalesce adjacently to form huge galls, resulting in rolling up and abnormal growth of leaves. At the later stage, the galls turn black or brown, the tissues decay and a few galls break to form necrotic areas. Leaves with more galls usually die earlier. Similar galls can form on the middle or lower parts of the stems. Seriously infected plants are often stunted with few pods, or even fail to yield.

Pathogen

Xing (1984) first identified the pathogen of the disease as *O. viciae* by means of microscopic examination, inoculation, symptom and host range determinations. It was reported as a new specie in 1912 in Japan. In 1936, S. Kusano confirmed that the small galls in Japan were caused by the same pathogen which had a wide host range, including faba bean and pea. Xing (1984) found that by artificial inoculation the pathogen can also infect rapeseed, cabbage, cucumber, spinach and buckwheat but not soybean, kidney bean and other legume crops.

Epidemiology

The pathogen survives winter as cysts on debris of diseased plants in the soil. The cysts 3.5 cm deep in soil have the highest infection rate and those deeper or nearer the surface cause less infection to the plants. This indicates the association of the soil condition with the germination of cysts. The cysts can survive 1-2 years in the soil. The primary inoculum source is cysts from debris of the last infected crop in the field. The cysts germinate and discharge the single flagellum zoospores in the next spring. They penetrate the roots of the young seedlings of faba bean and form thin-walled zoosporangia in host cells to cause disease. Mature zoosporangia release zoospores to penetrate deeper layers of cells or to infect other healthy plants. Disease symptoms on plants usually appear 13-18 days after infection. In the late stage of crop growth, sporogenic (cystigerous) plasmodia and cysts are formed to complete the disease cycle.

Integrated Control of Faba Bean Diseases

Control of faba bean diseases in China is by agricultural control measures and with the help of chemical treatment to reduce loss of yields.

1. Reduce and eliminate the inocula by rotation of legumes with cereals and rape for winter crops, and in spring-sown areas, the rotation of faba bean with cereals/cereals (or potato); intercropping of legume with cereals (or potato) is also recommended.
2. Reduce water level of the soil by deepening drainage ditches. Improvement of microclimatic conditions unfavorable for the disease infection and outbreak is needed.

3. Select disease-resistant cultivars and disease-free seeds by selecting healthy, disinfected seeds.
4. Chemical control: treat seeds with fungicides. Carbendazim, thiram, at a dosage of 0.6-1.0 kg/100 kg of seed, 25% Bayleton or 15% Baytan, at a rate of 0.3% to seed weight, are effective in controlling galls. The control effect is 86.5 and 94.9%, but seedling emergence rate is reduced by 4.4 and 6.7%, respectively. For foliar sprays in fields, Bordeaux mixture, canbendazim and thiophanate are all effective in controlling the fungal diseases including chocolate spot, Ascochyta spot and rust of faba bean. The dosage, time and number of applications should be adjusted according to the climatic conditions, disease incidence and kinds of chemicals.

Insect Pests

Faba Bean Beetle (*Bruchus rufimanus* Boheman)

Faba bean beetle is one of the major pests of faba bean seeds. It is also called bean weevil or bean borer. The historical record states that faba bean beetles came from Japan. They are now widely distributed, causing great damage to faba bean. They are mainly found in the autumn-sown area and are seldom seen in the spring-sown area.

Morphology

The adult's body is 4.5-5.0 mm long and about 2.5 mm wide. It is dark brown, oval in shape and covered with yellowish-brown fine hair. The elytra are covered with notched striations of white hair. The antennae and most of the front legs are red. Short, blunt spines (tibiala) are found at the end of metapedes tibia. The eggs are long, elliptical and light orange in color. The larvae are 5.6-6.0 mm long. They are short, fat and milky-white. The pupae are 5.0-5.5 mm long, elliptical and light yellow (Fig. 32).

Life history

Only one generation occurs each year. The adults survive winter in seeds of faba bean, in seed-store corners or in cracks of storage materials. Some of them also survive winter in crop debris, weeds or in fields. Adults that survive begin to fly and feed on the crop at the end of March. In April, they lay eggs on pods of faba bean, which then hatch at the end of April or early May. The larvae get into the developing seeds and pupate in June or early July. The adults emerge in the middle of July.

Host and damage

Faba bean beetles specifically feed on faba bean after hatching. The larvae bore into seeds, forming black spots visible on the surface of infected seeds, and feed on the inside of the seeds, which results in the reduction of seed weight and nutrient value. If one beetle infests one seed, the weight of the seed will be reduced by 5-10%. Meanwhile,

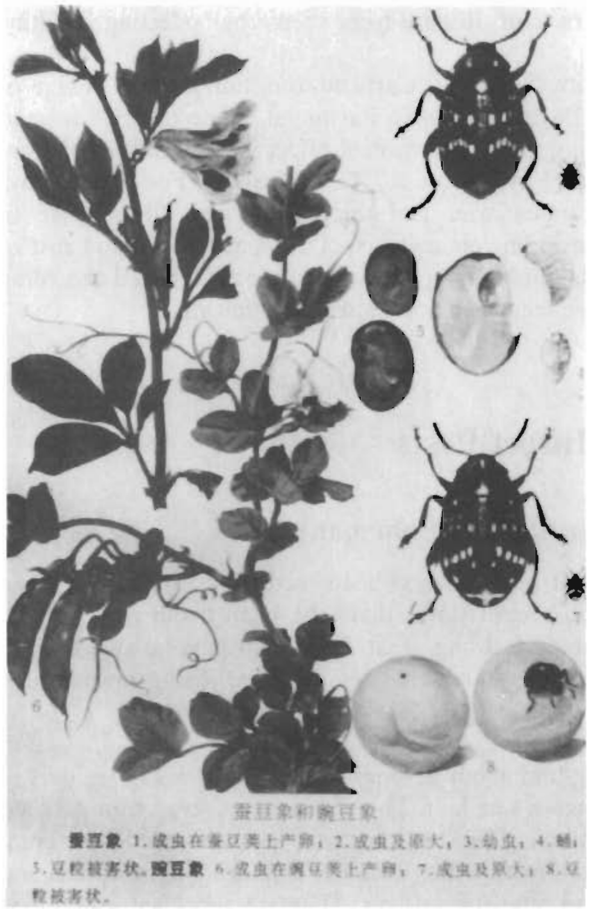

Fig. 32. Faba bean beetle (*Bruchus rufimanus* Boheman).

quality and nutrient value are also deteriorating. Infection of fungi is induced by the insect damage, resulting in blackening, bitterness and nutrient spoilage of seeds. In addition, germination rate and seed viability are reduced. The seed normally fails to germinate if it is infested by three beetles. As the infested seeds are planted, they are easily damaged by other pests and diseases, resulting in decay of seeds and missing plants in the rows.

Control methods

1. The spraying of chemicals can kill adults and larvae at the flowering stage of faba bean when adults fly to the fields to collect pollen, nectar and petals. The spray consists of 50% trichlorfon diluted with water at the ratio of 1:1000. Spraying in the

afternoon of a fine day usually results in over 90% of adults being killed. At the end of the flowering stage, spraying with 80% emulsified Dichlorvos or 25% emulsified Phosmet can kill over 80% of the larvae that are newly hatched.

2. Seed treatment with hot or boiling water is, at present, a simple, economic and effective method to control faba bean beetles by which almost all beetles are killed without affecting germination and edibility. The hot water treatment is to soak faba bean seeds in 50°C water for 5 minutes. The boiling treatment is to dip and shake the basket containing seeds into the boiling water for 30 seconds, then transfer it to cold water immediately and soak for a little while. After that, the seeds can be spread out to dry and store. This method is usually for treating a small quantity of seeds.
3. Chemical fumigation: Trichloronitromethane, at a dosage of 27-35.5 g/m^3, is used to fumigate the fully dried seeds in closed bins at room temperature of over 20°C for 48 hours, by which all faba bean beetles would be killed. It takes at least 1 week for the seeds to be edible after fumigation.
4. Vacuum storage: after drying, the faba bean seeds are kept in plastic bags and sealed under vacuum, by which beetles are killed because of the lack of oxygen. However, seeds cannot be used for sowing if they are stored under vacuum conditions exceeding 1 month; otherwise, seed viability will be affected.

Medic Aphid (*Aphid medicaginis* Koch)

Aphid is one of the major pests of faba bean. There are four species of aphids, including medic aphid (*A. medicaginis*), green peach aphid (*Myzus persicae*), pea aphid (*Acyrthsiphon pisum*) and *Aphis craccivora* Koch. Among them, medic aphid (Fig. 33) is the worst, causing a lot of damage in China. The occurrence and infection of aphids are negatively related to humidity among plants and positively related to average temperature. Low temperature and rainfall suppress the multiplication and damage by aphids.

Morphology

Alatae. The body length is 1.5-2.0 mm with black antennae and six segments. The first two and the last segments are black; the rest is yellow. Four to eight secondary rhinaria arranged in a row are found on the 3rd segment. The 6th segment is 2.0-2.5 times longer than the basal segment. The compound eyes are purplish-brown. Lateral tubercles are present on both sides of the prothorax. Mesonotuns are black, with two small projections on each side. The abdomen is purplish-brown with four black spots and the methathorax is black, and one-third longer than the second antennal segment. The caudal is oval in shape, bearing 6-7 short hairs. The tips of all legs and the apical region of femur, tibia and tarsus are black; the rest is yellowish-white. The wings are light gray and the stigma is yellow.

Apterae viviparae. The body length is 2.5 mm, shiny black and covered with wax. The antennae are light yellow; the two basal segments, apical region of the 5th and the 6th

Aphis craccivora Koch

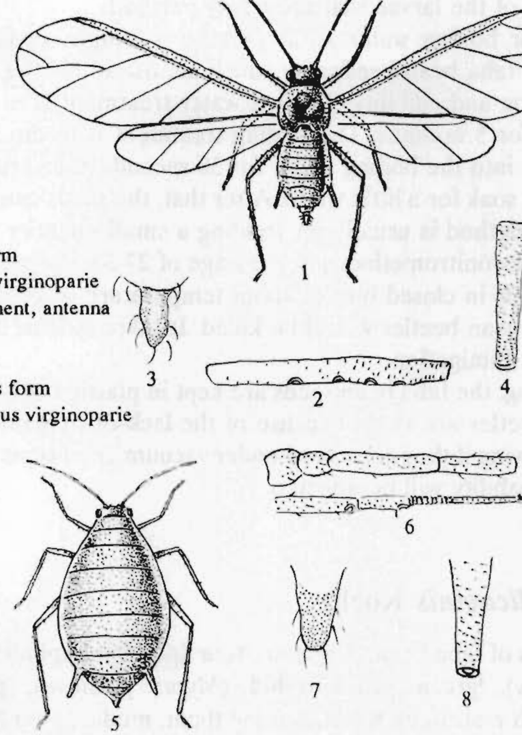

Fig. 33. Medic aphid (*Aphis medicaginis* Koch).

segments are dark colored. The 1st to 6th abdominal segments are combined together dorsally, with net-pattern markings.

Life cycle

Twenty to 30 generations may occur within a year. Adults and nymphs, and sometimes eggs, survive winter on host plants that face the sunlight on the leeward side. The optimum temperature for development and reproduction is around 15-24°C. Reproduction starts at 5-10°C. Above 25°C, the development will be inhibited. Severe infestation usually occurs in drought years.

Host and damage

Medic aphid has a wide host range including faba bean, alfalfa, pagoda tree, other Leguminosae and mustard. The adults and pupae feed on the young leaves, stems and flowers, resulting in leaf folding and shrinking. Plant growth will cease and affect the flowering and pod-setting. Aphids may cause a reduction of yield and sometimes they also transmit disease.

Control
Because of the rapid rate of multiplication of aphids, the best way to control them is to apply insecticides and to eradicate them earlier and completely when they are still a small population. The effective measures used at present are to eradicate infested weeds before aphids migrate into faba bean fields, and to spray insecticides to kill aphids on other host plants such as mustard and alfalfa. Chemicals such as 40% demethoate (emulsified) or 50% malathion or 50% fenitrothion diluted with water at the ratio of 1:1000 should be used for spraying.

Faba Bean Root Nodule Weevil (*Sitona amurensis* Faust)

Faba bean root nodule weevil is a severe pest on faba bean in Linxia of Gansu province and seriously affects the yield of faba bean. In order to deal with the problem, and take effective measures, Zhao (1987) of the Linxia Institute for Agricultural Research investigated the damage, host range, life history and behavior of faba bean root nodule weevils during 1978/79.

Morphology
The female adult body length is 3.2-4.1 mm, and the male adult body length is 3.1-3.7 mm. It is grayish-brown, covered by white scales. The mandible is covered with scales. Three striations are present on the back of the prothorax. The scututis are tubercle-shaped. Ten vertical grooves are found on each elytra. The antennae are elbow-shaped with 12 segments. The femur is well developed. The tibia is slender and reddish-brown. There is no hind wing. The egg is round, about 0.3-0.4 mm long, the surface is smooth, milky-white initially, turning black 2-3 days later (about 1% of the eggs remain light yellow throughout and are unable to hatch). The body length of the hatched larva is 0.8-1.0 mm with a brown head and light yellow body. Mature larvae are 3.0-3.5 mm long, milky white, curved and without legs. The pupae are 3.0-3.5 mm long, and 2-3 mm in width. They are white in the early stage, turning yellowish-brown later. The compound eyes are initially light brown, becoming black in the later stage. The abdomen consists of eight segments with one pair of brown tunji.

Life cycle
One generation occurs within a year. Adults survive winter in plant residues of faba bean, stones and the surface layer of soil in the fields. Surviving adults begin to move in early April the next year and migrate to faba bean fields to feed on the young leaves of faba bean seedlings. The first peak of damage is between late April and early May. As the plants mature, the adults continue to damage the leaves, calyxes and petals. The damage gradually reduces by the end of May. The adults cease feeding on plants in the middle of June. Eggs are laid in early May and larvae are hatched at the end of May. Some of the larvae pupate at the end of June. The new generation of adults appears successively in the middle of July to damage the top part of the plants. The second peak of damage occurs in the middle of August. The damage continues until the ripening of the crop, then the adults feed on spontaneous seedlings until the end of October (Table 67).

Table 67. Life history of faba bean root nodule weevil (*Sitona amurensis*).

March		April			May			June			July			August			September			October		
II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
+	+	+	+	+	+	+	+	+	+	+												
					.	.	.	.	.	.												
							-	-	-	-	-	-										
										o	o	o	o	o	o							
												+	+	+	+	+	+	+	+	+	+	+

\+ = Adult; . = egg; - = larvae; o = pupae.
I = 1st-10th; II = 11th-20th; III = 21st-30th.

The adults have a shamming death nature when they fall or are disturbed. They remain inactive for 1-2 minutes. The adults actively feed from 07:00-10:00 and 17:00-19:00 on a sunny day, and feed all day when it is cloudy. They often hide underneath leaves or stones on windy and rainy days. After feeding for a period of time, surviving adults mate at the end of April and lay eggs in early May. Each female adult can lay 104-420 eggs with an average of 192 eggs, and 10-18 days later, the larvae are hatched which then move into the surface soil at 2-6 cm depth around the faba bean root system to pupate after 11-13 days, at a temperature of 19-22°C. The newly emerged adults are yellow to white, and stay inactive for 2-3 hours before the color gradually turns darker and they begin to move. Adults usually come out from the soil when it is wet. The life cycle is about 330 days.

Host and damage

Besides faba bean, the other host species are vetch, pea, Villose vetch (*Vicia rillosa* Roth.) and sweet clover (*Melifotus* species). Faba bean root nodule weevil causes severe damage to faba bean. The adults chew leaves, petals and flowers. One single adult can consume 4-6 mm^2 of leaf/day. In a field of densely populated adults, particularly at the seedling stage, not only are all the leaves of faba bean eaten up, but also the unexpanded leaves and growth points are damaged. Larvae feed on root nodules and the injured nodules are left hollow and decayed. Each larva can destroy 4.2-7.2 root nodules. The larvae sometimes also feed on the epidermal cells of roots, causing wounds. According to the observation of Zhao (1987) working at Linxia during 1978/79, the root nodules of a plant are all destroyed if there are eight larvae feeding on it. The average density of larvae population in an infested field is 4.5-6.2/plant, which can destroy 62-71% of the root nodules (Table 68).

Control

1. Spray crystal trichlorphon or 50% fenitrothion (both diluted with water at a ratio of 1:1000) at the early stage of infestation by adult weevils.

Table 68. Effect of faba bean root nodule weevils on root nodules of faba bean plant.

No. plants damaged	No. larvae Total	No. larvae Average no./plant	Root nodules Total	Root nodules Damaged	Root nodules %
10	45	4.5	241	162	67.2
10	62	6.2	429	307	71.5
10	51	5.1	475	295	62.0

2. Use rotations of wheat, barley, and potato with faba bean.
3. Apply fertilizer for nodule bacteria on the root system.

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Chapter 8. Processing and Utilization of Faba Bean

A Brief Review of Food Processing and Utilization of Faba Bean

Faba bean is nutritious and is served as both staple and subsidiary food in different styles. Agronomist Xu Guangqi (1562 to 1633 A.D.) in the Ming dynasty evaluated faba bean as a versatile foodstuff, so did scientists in the Qing dynasty (1616 to 1911 A.D.).

For a long time, farmers in northwestern China have mixed faba bean flour with other kinds of flour such as maize flour to prepare meals. Because of rapid development of the national economy and the improvement in living standards, the demand for desirable food has become more intensive. Food processing of faba bean has changed from crude to refined products which are expected to be superior in color, smell and taste. At present, subsidiary food products of faba bean have had a ready market in China and abroad. Faba bean food products (Fig. 34) can be divided into three categories based on their processing and cooking methods.

Fig. 34. Products of faba bean processing in China.

Fried Products

Fried faba bean is a popular snack that is simple to prepare. Crispy faba bean can be obtained by frying with sand or salt. Fragrant faba bean such as "aniseed faba bean", "spiced faba bean" and "aromatic bean" are prepared by adding flavoring. Fried "orchid bean" is also one of the most popular snacks, as are cakes and puddings made from faba bean flour.

Brewed Products

The brewing industry in China has a long history, more than 3000 years. One type of brewed product is various kinds of sauces that are produced by mixing protein and starch. Different kinds of beans are used as the raw material in sauce production. Being rich in protein and various amino acids, faba bean has been used to brew different kinds of sauces and pastes. As a result of the development of science and technology, improvements have been made in the brewing industry of China. Sauces and pastes like "chili faba bean paste", "sesame faba bean paste", "chicken faba bean paste", "ham faba bean paste", "beef faba bean paste" and "huoguo paste" have been produced by adding specific flavoring ingredients to faba bean paste in Sichuan and Anhui provinces. Of these, "Juancheng" brand "Faba Bean Paste" made in Pi county, Sichuan province and "Anqing Chili Faba Bean Paste" are famous in China and abroad. Sauce is one of the essential seasonings for cooking delicious Chinese dishes. Proper proportion of different seasoning ingredients is also very important in cooking superb Chinese food.

Starch Products

Starch has variable uses as it can be used as food directly or processed into various subsidiary foods. After being extracted from faba bean, the bean starch can be further processed to make high-quality bean vermicelli, noodles, sheet jelly, etc. Having a quality similar to that of mung bean products and much better quality than other starch products, faba bean starch products are popular in the daily diet. Faba beans are cooked, hulled and mashed to turn into a kind of stuffing for dumplings and steamed bread. Oil, sugar, sweet osmanthus or mandarin peels are added to the stuffing to taste. Sometimes sesame and sugar are added to faba bean starch to make refreshments such as sweet bean pudding and sweet sesame bean pudding.

Processing Methods for Main Faba Bean Products

Fried Products

The majority of such products are made by individual families for their own consumption and the minority are produced by small factories. The processing techniques are quite simple.

Fried faba bean

Prepared with sand or salt at the proper temperature.

1. Soak faba beans in boiled water until they can be easily pricked through by a needle.
2. Drain the beans and spread them out to dry.
3. Put 1.0-1.5 kg dry loess soil (coarse sand, or raw salt) into a pan and fry it on high fire until the soil is very hot.
4. Add the dried beans to the pan and fry them over medium heat until they are well cooked.
5. Remove the beans from the pan and they are ready for serving. Furthermore, if the fried beans are wiped by a piece of wet cloth when they are still hot, they will look bright and appealing.

Orchid faba bean

1. Soak faba beans in boiled water until they can be easily pricked through by a needle.
2. Drain and drip dry the beans.
3. Use a knife to cut a cross on the top of each bean.
4. Dry the beans in the air until there is no water on the surface.
5. Deep fry them with oil over a high fire.
6. When the tops of the beans split and the hulls change from yellow to red, immediately remove the beans and spread them out to cool. Salt can be added before serving.

Chili orchid bean

Ingredients: faba beans, cooking oil, salt, saccharin, chili powder and Chinese five-spices powder. For 100 kg of fried orchid beans, use 3-4 kg of salt, 1 kg chili powder and 1 kg of Chinese five-spices powder.

1. Boil 60 kg of water and add 1 kg salt plus 100 g saccharin.
2. Turn off the fire, pour 100 kg faba beans into the boiling water. Cover and leave aside for 1 day.
3. Drain and drip dry the beans.
4. Use a knife to cut a cross on the top of each bean.
5. Dry the beans further in the air until all the water has evaporated.
6. Deep fry them in oil over a high fire.
7. When the tops of the beans split and the hulls change from yellow to red, immediately remove them from the oil and mix them well with the fried mixture of chili powder, Chinese five-spices powder and salt.

Spiced chili bean (or aromatic bean)

1. Grind and mix Chinese prickly ash, chili powder, caoguo, star anise, sugar and salt thoroughly.
2. Mix with top-grade flour and water to form a batter. Leave aside.

3. Soak faba beans and hull them.
4. Dip the hulled beans into the batter.
5. Deep fry until the beans are well cooked.

Five-spices faba bean (Wu Xiang Dou)

1. Wash faba beans before putting them into a pan.
2. Add enough water to cover the beans. Bring water to boil.
3. When the water is boiling, add salt, Chinese prickly ash, star anise, aniseed and cinnamon. Let beans simmer over a low fire. The amount of spices used is based on the amount of faba beans and individual taste.
4. When the shape of the beans starts to change and soften, drain the beans.
5. Dry the beans in the air, or
6. Fry the beans until the hull splits a bit. Add licorice powder and fry a bit more to dry the beans.

Brewed Products

Faba bean paste

Faba bean paste is made by using faba beans as the main ingredient and mixing them with flour, salt and water. If chili and other flavors are added, it becomes chili faba bean paste (Li 1987; Zhang 1987).

1. Soak washed faba beans in water.
2. When beans start to germinate, remove the beans to 80-85°C. Soak for 4-5 minutes in a 2% NaOH solution.
3. Remove the beans from the NaOH solution and hull them. Wash off the NaOH solution thoroughly. *The previous three steps are known as the soaking and hulling stages. An alternative dry method can be used for hulling, in which the "bean flesh" is separated from the hull after the beans are ground with a stone or steel grinder.*
4. Steam the beans until they are well cooked. For good maintenance of the original shape of the bean segments, the steaming is better done in small pans.
5. Remove steamed beans from pans and leave aside to cool. Mix with fried flour in the ratio of 100 (bean):30 (flour). *These two steps are known as the cooking stages.*
6. When the mixture has cooled to about 40°C, inoculate it with a mold starter. The amount of the starter is 1.5-3.0% of the total. An alternative way is to mix the starter with flour first and then add it to the bean segments to ensure that the starter is spreading out well.
7. Shape the well-inoculated mixture into bean cakes. Place them on bamboo mats and then store them in a room at a temperature of about 30°C for natural development of mold. Normally, mold will develop on the bean cakes in about 4 days. *These two steps are known as the bean mold formation stage.*
8. Place the bean mold under the sun for several hours. Crush them and put them into vats.

9. Add 15% saline solution, just enough to submerge the bean mold. Move the vats under the sun for fermentation. Cover the tops of vats with muslin cloth to prevent dust or insects from getting in. Stir every morning, and after about 30-40 days, when the color changes to dark brown and fragrance can be smelled, the beans are well fermented and the faba bean paste is ready. Ground pepper, chili and aniseed can be added according to taste to make into chili bean paste. *The last two steps are known as the fermentation stage.*
10. Steam empty tins for several minutes and fill them with the bean paste. Cover the tins and steam them for 10-15 minutes. Then fumigate and seal up the tins. *These two steps are known as the tinning and fumigation stages.*

Drunk bean petal

Drunk bean petal is a traditional seasoning paste produced by using white faba beans as the main ingredient and flour as the subsidiary raw material. It is especially suitable for middle-age and elderly people in summer (Meng 1989).

Ingredients: For 100 kg of faba bean segments, 12.5 kg of flour is used for making bean mold. 10 kg of bean mold starter, 10 kg of saline solution (19-21%) and 5 kg of yellow rice wine (14.8% alcohol) are then added for producing the end product. The process is to add mold starter to faba beans that have been selected, hulled, soaked, drip-dried and steamed. The next steps include making the mold, canning it, adding wine and salt for storing, and enjoying the end product.

1. Select whole, big and white faba beans with neither red nor brown color.
2. Hull the beans with a huller and select whole bean segments (shaped like flower petals). There should be no broken pieces.
3. Soak the beans in vats for 26-30 hours to enable them to absorb water sufficiently. *The first three stages are known as the bean treatment stages.*
4. Put the beans into uncovered pots for steaming. All bean segments should be complete and have no hard core after steaming.
5. Then immediately remove them to sterilized bamboo cases. Add flour before the beans have cooled. Mix well.
6. When the mixture is cool, add mold starter at 36-38°C with the starter amount being 0.30-0.35% of the total. *The fourth to sixth stages are known as the steaming stages.*
7. Move the bamboo cases into a room for mold development. The mixture should be spread out to form a 2-3 cm thick layer and the temperature should be kept at 32-35°C.
8. When the mixture agglomerates and the temperature increases because of the vigorous reproduction of fungi, turn the mixture over and over carefully to prevent it spoiling. Turn over the mixture once more when the temperature increases again. Within 2-3 days, bean mold is formed when green spores appear. *The seventh and eighth stages are known as the mold formation stages.*
9. Dissolve salt in water and filtrate to discard impurities. Adjust the saline solution to 19-21%.

10. Put a definite amount of saline solution into sterilized jars, add an accurate amount of bean mold and then wine. Tie and seal up the jars with bamboo strips and lotus leaves. Store in a cool dry place for 2-3 months or half a year to produce the end product. *The last two stages are known as the ingredients adjustment stages.*

The end product should have complete brown or yellow bean petals and clear sauce. They also must be tasty, and have a nice fragrance of faba bean and wine.

Starch Products

Faba bean starch

Faba bean starch can be obtained by either the wet or dry method. The wet method is presented here as an example of the process.

1. Wash the faba beans and soak them in water of 35-45°C until each bean has absorbed as much water as its own weight (or until the hull can be easily removed by hand and the core is no longer white when cut apart). The time needed for soaking is longer in winter than in summer. *This stage is known as the soaking stage.*
2. Clean the beans again by washing. Grind the beans and add water at the same time in case heat is generated during this process. Normally, the amount of water added is about 4-5 times as much as the soaked beans. The finer the beans are ground, the more the amount of bean flour produced. *This stage is known as the grinding stage.*
3. Filtrate with 80-140 "eye-holes" sieves to segregate starch liquid from bean hull residue. A little vegetable oil can be added to eliminate bubbles, which makes the filtration easier. Wash the residue 3-4 times again to retrieve all the starch. *This stage is known as the filtration stage.*
4. Keep the starch liquid static for sedimentation. The time for sedimentation is longer in winter (about 16 hours) than in summer (about 14 hours). Pour off the upper portion of starch liquid.
5. Add water for another sedimentation in which the time taken is about half as much as that of the first sedimentation. Again, pour off the upper portion of the starch liquid. As this contains lots of protein, it can be used for feeding livestock or for extracting edible protein. *These two steps are known as the sedimentation and segregation stages.*
6. After pouring off the upper portion of water, put starch paste in filtration bags and hang them to get rid of the water. Remove the starchy lumps from the bags and dry them under the sun. Thus, dry starch is obtained for making bean vermicelli and sheet jelly, etc. *This stage is known as the drying stage.*

Faba bean vermicelli

Faba bean vermicelli is produced by further processing of faba bean starch (Huang *et al.* 1987).

1. Spread out faba bean starch on trays and heat it by a low coal fire. The treatment is undertaken at 40-50°C for 10-12 hours in winter and at 30-40°C for 4-6 hours in summer. There must be no smoke during the treatment. *This stage is known as the heat treatment stage.*
2. From 100 kg of starch, take 4-5 kg starch and add 60-70°C water to mix them into a thick paste. Immediately pour the paste into boiling water and add alum (200 g in summer and 300 g in winter). Stir continuously in one direction to form a smooth transparent paste.
3. When the paste is cool enough to handle, add the remaining starch. Stir vigorously until it becomes very smooth. *The second and third stages are known as the stages of making smooth starch paste.*
4. Heat up water in a big pot. Set up a barrel (that has many tiny holes in its bottom) with a pressing machine over the pot. The distance between the bottom of the barrel and the water in the pot is decided by the demand for the thickness of the end product, i.e., the thicker the thread, the shorter the distance or vice versa. The temperature of the water in the pot must be kept at 95-98°C.
5. Pour the smooth starch paste into the barrel continuously. It passes through the holes and solidifies to form threads after falling into the hot water. Use chopsticks to remove the floating threads into barrels of 30-40°C water for cooling.
6. Cut the threads into 50-100 cm lengths and wash them again several times before hanging them on shelves to dry. The bean vermicelli is then ready for packing and storing.

Good bean vermicelli should have no white core, not stick together and have similar thickness among individual threads.

Extracting edible protein from the residual water of faba bean starch during processing
A large proportion of protein in faba bean is left in the residual water during bean starch production. Extracting protein from the residual water is therefore of great importance for supplementing the insufficiency of edible protein. At present, 85% of the protein in the residual water can be extracted with a two-step method by Qian and Hu (1984), in which low molecular and high molecular weight proteins are selectively segregated. This amount is about the equivalent of 42% of the total protein in faba bean. In such a case, 100 tonnes of dry protein can be extracted from a starch-processing factory using 1200 tonnes faba bean/year (Qian and Hu 1984). Most of the protein in faba bean seed is stored inside the cells. The protein granules will not be destroyed during the process of making bean starch. If the protein granules are left suspended in the residual water for several hours, the protein will not dissolve although the granules will expand and break apart.

If low concentrations of $CaCl_2$ and $Ca(CH_3COOH)_2$ are used as solvents in the first extraction, the precipitation will be slow after the pH value has been adjusted. In the second extraction, it is suggested to use a ratio of 0.04 mg NaOH:1 ml residual. Of course, the amounts and characters of extracted protein and nonprotein components will change with different kinds of solvents used.

The pH value is crucial for the precipitation of the protein. The precipitation will considerably decrease when the pH is less than 5. More than 60% of the total protein is precipitated in extract A if the pH value of 4 is used during the first extraction. In the second extraction, 85% of the protein in extract B precipitates if a pH value of 5-7 is kept for the precipitation of the high molecular weight protein.

Dry products of the extracted protein can meet the hygienic standard for food (Table 69) and have an abundant lysine content of 6%, which is much less in staple food. Therefore, they can be used as valuable raw materials in the food industry. In short, extracting protein from the residual water of the faba bean starch production can increase the utilization rate of faba bean and decrease environmental pollution.

Table 69. Main components and results of hygienic inspection of the dry products produced from Extracts A and B.

Item	Extract A	Extract B
Protein	72%	65%
Moisture	2.5%	2.8%
Ash	0.5%	1.0%
No. bacteria	2000-5000/g	2000-5000/g
No. colon bacilli	40/100 g	40/100 g
Harmful bacteria	none detected	none detected

Brewing sauce with residual liquid from processing faba bean vermicelli

The residual liquid of processing faba bean products contains plenty of protein which can be solidified by adjusting the pH value. After filtration, the paste can then be dried by toasting or cooking to form a dried matter named "dehydrated paste." The dehydrated paste obtained by toasting contains 8-14% moisture, 55-70% protein and 15-20% starch, and that obtained by cooking contains 55-60% moisture and 24-26% protein. Such pastes can be used to make sauce (Meng 1988). The process is: dehydrated paste is spread out to dry, ground and added to other ingredients, then steamed and cooled. The paste is inoculated with mold starter, ventilated, mixed with a salt solution, fermented, soaked, filtrated for sauce and stored until the end product is ready for use.

Ingredients: 350 kg dehydrated paste (55-60% moisture), 425 kg hulled faba bean, 200 kg wheat bran, 50 kg faba bean flour, 375-425 kg water and 3.25-3.5 kg mold starter.

1. Grind dehydrated paste on the same day it is produced in the factory.

2. Mix all the ingredients as described above. Cook the mixture at a pressure of 1-1.2 kg/cm^2 for 20-30 minutes or cook without pressure for an appropriate period of time. *The first two stages are known as the cooking stages.*
3. When it has been well cooked, pour out and rapidly cool to about 39°C. Add a mold starter and move it into a room for mold development.
4. About 6-7 hours later, ventilation is needed to have the temperature controlled at 35°C to enable the mold to develop. A strong smell develops as the mold enters a vigorous reproduction stage, and windows should be opened for good ventilation. The "mold paste" will be made in 22-23 hours. *The third and fourth stages are known as the mold development stages in which the optimum temperature is a crucial factor.*
5. Grind the mold paste and put it into a heat-preserved vat. Add saline solution of 11%, at 75-80°C. Spread out the mold paste evenly and add an appropriate amount of salt on top. Cover the vat for fermentation at a controlled temperature of 45-55°C. Ideal "sauce liquor" will be made in about 12 days. *This stage is known as the fermentation stage.*
6. Immediately combine the sauce liquor with the mixture of salt solution and mold paste at 75°C. Cover the vat with a bamboo lid and gunny sacks for preservation of heat.
7. Twenty hours later, open the valve to filtrate out the sauce for the first time.
8. Close the valve and add "less-colored" liquid. Soak for 6-8 hours and then open the valve to filtrate out the sauce for the second time.
9. Finally, add water at 75°C. Soak and filtrate out the sauce. The residue can be used for feeding livestock. *The sixth to ninth stages are known as the soaking and filtration stages.*
10. Adjust, heat and inspect the extracted sauce. Pump it to barrels for storing. *This is known as the storing stage.* Normally, 500 kg of sauce can be produced from 100 kg mixture.

Making sauce with the "dehydrated paste" is better than with faba bean itself in terms of quality, taste and the production rate of sauce. However, the process, especially the proportion of the ingredients, must be under strict control.

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