Broadbean (Faba Bean)

D. A. Bond  
*Plant Breeding Institute  
Cambridge, England*

D. A. Lawes  
*Welsh Plant Breeding Station  
Aberystwyth, Wales*

M. H. Poulsen  
*Royal Veterinary and Agricultural University  
Taastrup, Denmark*

The faba bean (*Vicia faba*) is an erect, annual legume thought to have originated in either Afghanistan (Ladizinsky, 1975) or the Near East (Zohary, 1977). It has been cultivated since Neolithic times (Schultze-Motel, 1972). No wild ancestor has been found. The faba bean is now grown as a cool-season crop in subtropic and Mediterranean climates, and mainly as a spring-sown crop in temperate climates. Some winter sowing of relatively hardy cultivars takes place in England and France. In 1971, the Food and Agriculture Organization (FAO) statistics showed China to have had 3 million out of the world’s estimated 4.7 million ha; other important faba bean-producing countries include Italy, Spain, the United Kingdom, Egypt, Ethiopia, Morocco, and Mexico.

Protein content of the grain varies from 25 to 35% of the dry matter. The smaller-seeded *V. faba equina* and *minor* may be handled with the same machinery as used for drilling and harvesting cereals. These types are mainly used as the high-protein fraction of animal feed, whereas the large-seeded *V. faba major* is mainly used as human food in fresh, conserved, or dry form. Faba bean is occasionally used in mixtures with other species for forage or for green manure.
I. PARENTAL MATERIAL

Taxonomically, *Vicia faba* is a member of the section *Faba* of the genus *Vicia*, and several wild species, including *V. narbonensis*, *V. galilaea*, and *V. hyaeniscyamus*, have been assigned to this section (Ladizinsky, 1975). No successful crosses have been made between *Vicia faba* and these or any other species.

Muratova’s (1931) intraspecific classification based mainly on seed size has been widely used. She recognized subsp. *faba* (vars. *major*, *equina*, and *minor*) and subsp. *paucijuga*. However, Hanelt (1972) recognized subsp. *faba* (vars. *faba* and *equina*) and subsp. *minor* var. *minor*, including *paucijuga*, as a geographical race. Cubero (1974) distinguished only the four varieties *faba*, *equina*, *minor* and *paucijuga*. The botanical variety *faba* is still commonly known as *V. faba major*, the largest seeded type within the species. All varieties are diploid with 2*n* = 12. Tetraploidy and polyploidy may be induced artificially by colchicine. However, only one verified case of a reproductive tetraploid *V. faba* is known (Poulsen and Martin, 1977).

Crosses between subspecies and between all botanical varieties of *V. faba* are possible, though Abdalla (1977) succeeded with *equina × major* and *paucijuga × major* only when *major* was the male parent. The breeder also has available variability in locally adapted populations from many parts of the world. Due to the partially allogamous breeding system of the species, a relatively wide variation is maintained within natural populations as well as populations and cultivars created by farmers or plant breeders. A series of naturally occurring and induced mutants has been described (Sjodin, 1971). Genetic collections are maintained at the Zentralinstitut für Genetik und Kulturpflanzenforschung, Gatersleben, East Germany; at the Swedish Seed Association, Svalov, Sweden; at the International Centre for Agricultural Research in the Dry Areas, Aleppo, Syria; at the Germplasm Institute, Bari, Italy; and at the U.S. Department of Agriculture, Beltsville, Md.

II. PLANT CULTURE

A. Field

Soil should be fertile and mineral content, particularly potassium, should be high. Soil pH is important and should be at least 6.5. An efficient *Rhizobium* strain should be present or mineral nitrogen supplied.

Soil moisture must be adequate to ensure good early plant establishment, successful seed set, and prevention of shedding of immature pods. Most faba bean crops are grown on fertile soils with high moisture-holding capacity.

Seed yield per area is relatively unaffected by plant spacing. The small-seeded types are usually grown at a density of around 40 plants per m², whereas the large-seeded types are spaced at about 15 plants per m².

Seeds should be sown deep, at least 8 cm, to ensure good establishment and to avoid damage by preemergence weed killers and birds. Seeds are usually sown at 5 to 25 cm spacing in rows 25 to 80 cm apart. At least 25 by 50 cm is necessary for access to single plants to be hand-pollinated.
The most common pest is *Aphis fabae*, but severe attacks may occur by weevil (*Sitona lineatus*), pollen beetles (*Meligethes* spp.), thrips (*Kakothrips robustus*), nematodes (*Ditylenchus dipsaci*), and bean beetles (*Bruchus* spp.). Common diseases are chocolate spot (*Botrytis fabae*), leaf spot (*Ascochyta fabae*), powdery mildew (*Erysiphe polygoni*), root rots (*Fusarium* spp. and *Rhizoctonia* spp.), and several viruses. *Ascochyta fabae*, nematodes, and two of the viruses (Broad Bean Stain and Echtes Ackermannmosaik) can be seed transmitted. In the Mediterranean region, the parasitic broomrapes (*Orobanche* spp.) may severely limit production. Control measures for pests and diseases have been described (Litzenberger, 1974).

### B. Growth Chamber and Greenhouse

Plants are best grown singly in pots that are no less than 15 cm in diameter. The growing medium should be compost which contains sufficient nutrients to promote growth and flowering and to sustain plants until seeds reach maturity. Because of hard seed coats, it may be necessary to scarify some seeds before sowing to improve evenness of germination. Growing plants should not be allowed to dry out, and automatic watering is preferred.

Hybridization is usually successful, provided the environmental requirements for full development of flowers are met. Except for very early flowering cultivars, flower initiation shows a quantitative long-day response, and long days are required for full development of the initiated inflorescences (Evans, 1959). Sixteen to 18 hours per day are commonly given in controlled environments. The red end of the spectrum is necessary for flowering. Mercury vapor lamps, supplemented by tungsten or by tungsten/halogen bulbs, and high-pressure sodium lamps (400 W/m²) have been used successfully.

Blondon (1975) reported that, with 18,000 lux of light, winter beans require either cool temperatures (12 to 17 C) or vernalization followed by long days. Use of 30,000 lux and long days eliminate the need for vernalization. Flowering of spring beans in his experiments was independent of temperature, photoperiod, and light level treatment.

Seeds will set under temperatures ranging from 10 C to 30 C, but tolerance of these extremes could depend on genotype. When the temperature is above 23 C in the dark period, a reaction inhibitory to flower initiation occurs.

Common pests in the greenhouse are aphids (*Aphis fabae*, *Acrithosiphon pismum*, *Myzus persicae*), red spider (*Tetranychus urticae*), and whitefly (*Trialeurodes vaporarious*). These must be kept out of the greenhouse or controlled chemically.

### III. FLORAL CHARACTERISTICS

Bees visiting the front of the flower for nectar, pollen, or both can cause cross-pollination. Pollen vectors other than bees have not been reported. Under field conditions, outcrossing may vary considerably, but
Figures between 25 and 50% have been most commonly reported (Fyfe and Bailey, 1951; Picard, 1953, 1960; Hanna and Lawes, 1967; Bond and Pope, 1974; Poulsen, 1975). Tripping of the flower (releasing the stigma and stamens from the keel petal) is necessary for self-pollination of some genotypes; thus, a bee’s visit to the front of a flower can result in self-, cross-, or, what is most likely, mixed pollination.

The complete flowers are borne in axillary racemes and have a typical papilionaceous structure (Fig. 1). Sepals combine into a single five-toothed calyx. The corolla is irregular and made up of five petals—the standard, two wings, and two lower petals that are united along their outer edge to form a keel.

The flower has 10 stamens, with the upper one being physically free. Filaments of the other nine are united in a sheath which encloses the ovary. There is a single ovary with two to four ovules or, in the large-seeded type, up to nine ovules arranged along the inner, upper suture. The fruit is a pod which opens in two valves. Seeds have two large cotyledons and may weigh from 200 to 2,000 mg each.

Fig. 1—Broadbean inflorescence with buds and flowers at various stages of development. The bud marked with the arrow is at the hooded stage and suitable for emasculation. The lowermost flower is at the stage which is usual for pollination, although this can be done at several stages after emasculation.
In most genotypes, flowers develop and mature starting from the 5th to 10th node progressing up the stem. Pollen is shed and forms a plug before the flower opens. The stigma is receptive from a few days before flower opening until the standard petal collapses, which may be a period of from 3 to 5 days.

Pollen-grain numbers and viability differ with genotype, as well as with environment. At high temperatures of 30°C, pollen life is limited to about 1 day, but at lower temperatures of 15°C pollen may survive for several days. Fertilization has been found to occur 24 hours after pollination (van Cruchten, 1977).

**IV. ARTIFICIAL HYBRIDIZATION AND SELF-POLLINATION**

**A. Equipment**

Emasculaton is usually carried out with small- to medium-sized forceps with fine, but not sharp points. Another technique which has been used successfully and with greater speed is to remove the anthers by means of suction. For this method, a glass tube drawn to a point of 1.5 mm aperture is fitted by a long flexible tube to a suction pump with 0.7 kg/cm² of negative pressure operating through a filter to collect the anthers. Pollen is usually transferred to the stigma with the points of forceps, a small paint brush, a piece of filter paper, or the pistil of the pollen donor.

**B. Preparation of the Female**

When selecting flower buds for emasculation, one should consider their stage of development and the physiological capabilities of the plant to supply the selected flower and the developing pod with nutrients until maturity.

Emasculaton must be carried out before the anthers dehisce. As a rule this means at the hooded stage of bud development, when the petals are about twice the length of the calyx (Fig. 1). If, in specific material, pollen has already been released by the hooded stage, younger buds with intact anthers must be chosen for emasculation.

For physiological reasons, the early inflorescences are believed to be the best choice. Good seed sets, however, have been obtained with late flowers under conditions where early seed set has failed or was deliberately prevented. Success is more likely with flowers on those parts of the inflorescence that are nearest the stem. The number of flowers per inflorescence is usually reduced to two or three; especially if many inflorescences on the same plant are to be used.

Selected flower buds may be emasculated at any time of the day. The flower is held between thumb and forefinger and two or three of the sepals covering the keel are torn off with forceps. By a sideways movement, the points of the forceps are inserted under the standard and wing petals. The pressure on the forceps is gently released and the standard and wing petals folded back and held (Fig. 2A and B). With forceps, the keel is slit open
along the suture of the two keel petals. For convenience, removal of part or all of the keel has been practiced, but this is not necessary and damage to the keel should be kept to a minimum to avoid exposure and desiccation of the style and stigma. When the keel is opened, the 10 anthers are removed, preferably by the filaments so that pollen is not squeezed out of the anthers (Fig. 2C). As an extra precaution, forceps and anthers should not be moved higher than the hair surrounding the stigma. Great care must be taken not

![Fig. 2—Emasculature procedure. A, insertion of forceps to part wing petals; B, folding back wing petals between thumb and forefinger; and C, removal of anthers by forceps around the filaments. Photo shows D emasculated bud with all 10 anthers removed.](image)
to cut or tear the style, which can easily break at the bend. When all the anthers have been removed (Fig. 2D), the bud is released and the standard and wing petals rearranged to cover the keel. If the suction pump method is used, the point of the glass tube is used to slit open the keel petals and the anthers are removed by suction. In other respects, the procedures are the same.

C. Pollination

Emasculated flowers may be pollinated immediately after emasculation, but for some genotypes it may be better to wait until the flower is fully developed, which at 25°C takes 2 to 3 days. Pollen may be obtained at any time of the day by tripping a flower, or by slitting the keel and collecting the plug of sticky whitish-grey pollen. Little is known about storage of viable pollen of *Vicia faba*, but experience has suggested that if detached flowers are kept at 5°C, pollen will stay viable for at least 1 week. The pollination technique is to apply ample pollen to the surface of the stigma with forceps or other instrument. The flower is entered either through the slit in the keel petal made for emasculation or by pressing down the wing and keel petals to expose the stigma. The keel petals should preferably appear closed after pollination. Dry conditions favor pollen ripening and flower opening, but petals should be left intact for hybridization to maintain humidity within the flower.

It is easiest to pollinate the flower when it is fully open in the late afternoon, but pollination is effective at any time of day. The stigma remains receptive until the standard petal collapses. It is general experience that application of a relatively large amount of pollen is necessary to ensure fertilization of all ovules in the ovary. When this is required, the pollen plug taken from one flower should not be used to pollinate more than three emasculated flowers. The forceps or paint brush used for pollinating must be cleaned of pollen by dipping into ethyl alcohol and drying before changing pollen donor.

Occasionally, unemasculated flowers are pollinated if genetic markers are being used to identify crosses in the next generation. Pollination of unemasculated young flowers or even buds with undehisced anthers does not prevent selfing.

If a bee-proof greenhouse or cage is not available, flowers may be protected against bee visitation by bagging the plant or stem in a net of about 2 mm mesh. Bags should be in position before the flowers open, and may be removed after emasculation and pollination have been completed and pods have set.

Often a single tagging of an inflorescence is sufficient to identify the emasculated flower and also later to add details of the pollination. Where many different crosses are made on the same stem, it is an advantage to keep a record of the number of the plant or stem, the inflorescence, and the flower. Flowers are easily numbered upwards from the base of the inflorescence because a scar remains if a flower drops or is removed. A record of the female parent, the dates of emasculation and pollination, the identity of the pollen donor, and the numbers of pods and seeds obtained is useful for reference, and for following the progress of the hybridization program.
Under good conditions in a greenhouse, a success rate of 50 to 70% is common for experienced personnel. The number of seeds per pod is usually three or four, although some large-seeded types may produce up to nine seeds per pod.

D. Factors Affecting Efficiency

It is important to have good access to the plants, especially to the females. Where plants can be grown in pots in a bee-proofed greenhouse, they can be moved to a convenient position for emasculation and pollination. It is general practice to encourage seed setting by reducing vegetative development. This is done by removing the stem apex and unwanted lateral tillers when a sufficient number of inflorescences have been developed or initiated.

Success of a crossing program also depends on the matching of flowering dates of the intended parents. The most common method is to plant at about 10-day intervals, so that the range of flowering dates will be covered. A difference of 10 days between sowings may result in only a few days between flowering dates. Early-flowering parents can be held at lower temperatures or their flowers removed when there are no flowers on the parent with which they are to be crossed.

Genetic markers are available for checking crosses or for determining the proportion of selfing when pollination is made without emasculation. Hilum color and testa color are maternally controlled and are frequently used to identify hybrid plants. No markers are known which can be used to identify hybrid seed; however, electrophoretic detection of isoenzymes may provide such a tool in the future. Simply inherited characteristics which have often been used to estimate the degree of outcrossing include black hilum (dominant to colorless), black testa (dominant to the common buff), green testa (recessive to buff), and all-white flower (recessive to normal-colored flower). Seed size and shape, though not simply inherited, are useful when examining progenies of minor × major or reciprocal crosses, and for roguing contaminated stocks.

V. NATURAL HYBRIDIZATION

In the production of synthetic cultivars, natural hybridization is under only partial control because of the amount of self-fertilization which occurs in the open field (Section III). Experimental attempts have, however, been made for complete control of hybridization by use of male sterility in the production of F₁ hybrid cultivars.

The components of synthetic cultivars may be inbred lines or populations. In some cases they number from 3 to 10, but more commonly 4 or 5 components are used. When first constituting the synthetic, seed of the components can be mixed in equal quantities and the crop pollinated in isolation. This method is common where the components are populations. An alternative method, which is often used when the components are inbred, is to plant the components so they can be identified in the plot or cage.
The seed they produce is then mixed in equal quantities, thereby controlling the proportions of the offspring of the components into the second generation. A cage of about 50 m² is sufficient with pollination by honey bees or bumble bees for production of the syn-1 generation, if commercialization on 3,000 ha is expected at about syn-5. The amount of selfing and sibbing relative to crossing in the syn-1 depends on the matching of the flowering periods of the components; their ability to self pollinate, which may be related to their degree of inbreeding; and the efficiency of the pollinating insects. If maximum crossing is not achieved in syn-1, relatively more is expected in later generations and equilibrium of yielding ability may be expected at syn-3 (Bond, 1971; Wright, 1977).

A genetic male-sterile, \textit{ms ms}, has been used to make crosses on a small scale (Bond et al., 1964). Two sterility-inducing cytoplasms have been found together with maintainer and restorer lines (Bond et al., 1966; Berthelem, 1976; Berthelem and Le Guen, 1976), but both are unstable and revert to too high a proportion of fertile plants during large-scale multiplication. Male sterility has, however, allowed the testing of hybrids and the combining ability of parents in more environments than would have been possible by hand crossing.

For small-scale production of hybrids, alternate rows of male-sterile and male-fertile parents, 60 cm apart, have been used. Where commercial hybrid production was experimentally simulated, alternating blocks of 1.5 m width to suit drilling and harvesting machines were employed. Male and female parents were in a 1:1 ratio. One problem is that pollen-collecting bees visit fewer flowers on male-sterile than male-fertile blocks (Bond and Hawkins, 1967; Tasei, 1976).

The isolation requirement for certified seed of commercial \textit{Vicia faba} is in most countries a distance of 200 m. Small plots of breeding material have shown 0.6% contamination at 180 m and even 0.4% when separated by 1 km (Pope and Bond, 1975). In areas where \textit{V. faba major} is frequently grown in gardens, the only way of achieving complete isolation is by caging. For caging, a net of 3-mm-mesh size to keep out pollinating bees is the main requirement. A very small mesh will keep out more light and should be avoided. Zips at corners of the cages facilitate entry and exit. Supports can be of any material which can be joined to make a frame for the nets. Cages should be about 2 m in height and anchored against wind. The size and shape usually vary according to locally available materials which are adapted according to the needs of breeders. Cages which can be dismantled and transported and which are erected only at flowering time are preferred to permanent structures. The costs of cages will depend on their size, the type of insect screens, and framing material available.

\textbf{VI. SEED DEVELOPMENT, HARVEST, AND STORAGE}

Once pods have developed to a length exceeding 3.0 to 3.5 cm, it is probable that they will develop further to maturity. Before this stage, abortion frequently occurs. Some genotypes may occasionally develop unfertilized ovaries.
In the field in northern and central Europe, seed is usually harvested during August and September, and in the Mediterranean area from April to June. In the United Kingdom, harvest is about 40 weeks after sowing for winter beans and 25 weeks after sowing for spring beans. In the Mediterranean region, the growing period is 20 to 30 weeks and in Scandinavia and Canada about 15 to 20 weeks. In a greenhouse following sowing in February, seed may be harvested within 20 weeks.

For hybridized flowers, seed is shelled from pods by hand. For harvesting field multiplication plots, a conventional cereal combine harvester fitted with the appropriate seed sieves, reduced cylinder speed, and a more open concave setting is used. The modern laboratory threshers are suitable for single plants.

Some mechanical admixtures can be identified by seed size and shape, hilum color, and testa color. This is easier with inbreds than for populations. A check on correctly hybridized seed has to wait until plants are grown in the next generation (Section IV D.).

Seed viability can deteriorate rapidly if the seeds are not either harvested dry or stored at a low temperature. Seed harvested at less than 14% moisture can be stored for 1 to 2 years at a temperature of +5°C or even in a normal laboratory without too much humidity. For storage of up to 5 years, the temperature should be in the range +2°C to −2°C, and it is important that airtight containers be used, as seed moisture content is more critical than temperature. For storage over 5 years, seed moisture content should be reduced to 7% and the temperature to −18 to −20°C.

REFERENCES

van Cruchten, C. 1977. Personal communication. Station d’Amélioration des Plantes, 21034 Dijon, France.