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GRDC GROWNOTES™

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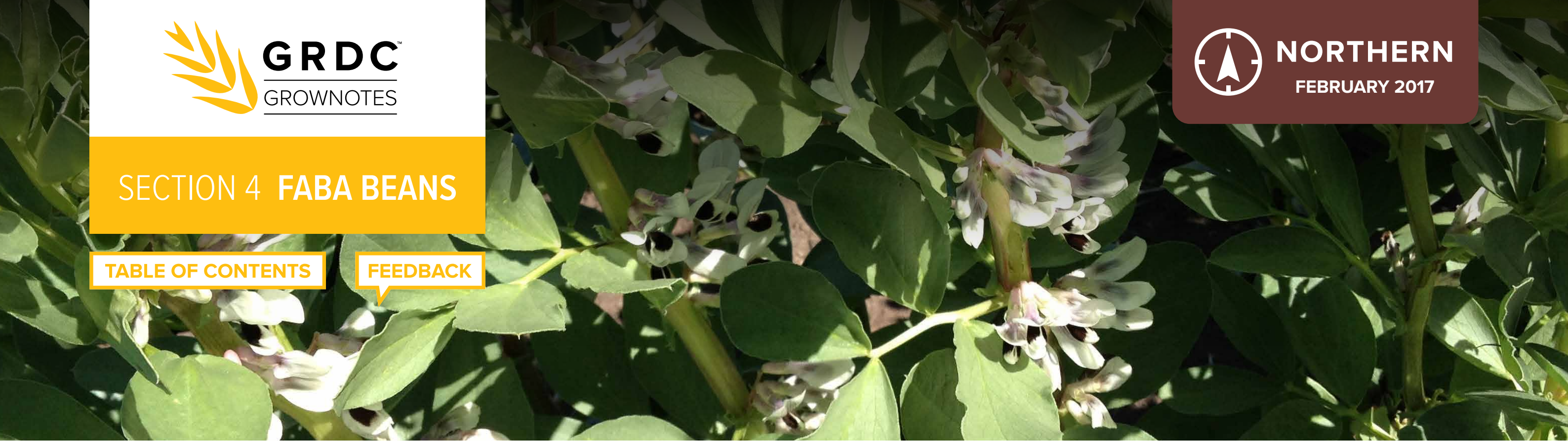
FABA BEAN

SECTION 4

PLANT GROWTH AND PHYSIOLOGY



Plant growth and physiology

4.1 Introduction

Vicia faba, also known as the faba bean, broad bean, fava bean, horse bean, field bean, bell bean, Windsor or tic bean, is a species of bean (Fabaceae) native to North Africa and south-western Asia, and extensively cultivated elsewhere including Australia.

It is grown as a winter annual in warm temperate and subtropical areas. Hardier cultivars grown in the Mediterranean region can tolerate winter temperatures of –10°C without serious injury, whereas the hardiest European cultivars can tolerate up to –15°C (Robertson *et al.* 1996).

Although usually classified in the same genus *Vicia* as the vetches, some botanists treat it in a separate monotypic genus *Faba*.

In much of the English-speaking world, the name 'broad bean' is used for the large-seeded cultivars grown for human food, while 'horse bean' and 'field bean' refer to cultivars with smaller seeds used for either animal feed or human food. Their strong flavour is preferred in some human foods, such as falafel. The term 'fava bean' (from the Italian fava, meaning 'broad bean') is often used in English-speaking countries such as the USA, but the term 'broad bean' is the most common name in the UK.

There is some variation in the way that faba beans have been classified botanically. Based on seed size, two subspecies of *Vicia faba* have been recognised, *paucijuga* and *faba* (Muehlbauer and Tullu 1997). The latter (*faba)* has been subdivided into *Vicia faba* var. *minor* with small rounded seeds (1 cm long), *Vicia faba* var. *equina* with medium-sized seeds (1.5 cm) and *Vicia faba* var. *major* with large broad flat seeds (2.5 cm). Taxonomically, the crop belongs to Section *Faba* of the Genus *Vicia*.

Cubero (1973) had previously suggested four subspecies, namely: *Vicia faba* ssp. *minor, Vicia faba* ssp. *equina, Vicia faba* ssp. *major,* and *Vicia faba* ssp. *paucijuga*. According to Cubero (2011) now, the correct name of the family is Fabaceae*,* faba beans belonging to the subfamily Faboideae and tribe Fabeae*,* but paradoxically to the genus *Vicia*.

The scientific classification is: Kingdom Plantae*;* Division Magnoliophyta*;* Class Magnoliopsida*;* Order Fabales*;* Family Fabaceae*;* Tribe Vicieae*;* Genus *Vicia;* Species *Vicia faba.* [1]

4.2 Key to growth stages

The key is based on counting the number of nodes on the main stem.

Uniform growth stage descriptions were developed for the faba bean plant based on visually observable vegetative and reproductive events.

The vegetative stage is determined by counting the number of developed nodes on the main stem, above ground level. The last node counted must have its leaves unfolded (Figure 1).

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The reproductive stages begin when the plant begins to flower at any node. The standard description of the development of a faba bean plant aids faba bean research planning and communication and assists extension recommendation of timing of cultural practices.

Germination is hypogeal, with the cotyledons remaining below the soil surface. This enables it to emerge from sowings as deep as 25 cm. In drier regions, faba beans are sown deep, because surface moisture is often inadequate to enable crop germination and establishment. The node at which the first leaflet arises from the main stem above the soil is counted as node one. A node is counted as developed when leaves are unfolded and flattened out. Scale leaves at the base of the plant and close to the ground are not counted as true nodes.

In faba beans, alternate primary branches ('tillers') usually originate from the base just above ground level (usually 1–5 primary branches on the main stem, depending on variety and growing conditions).

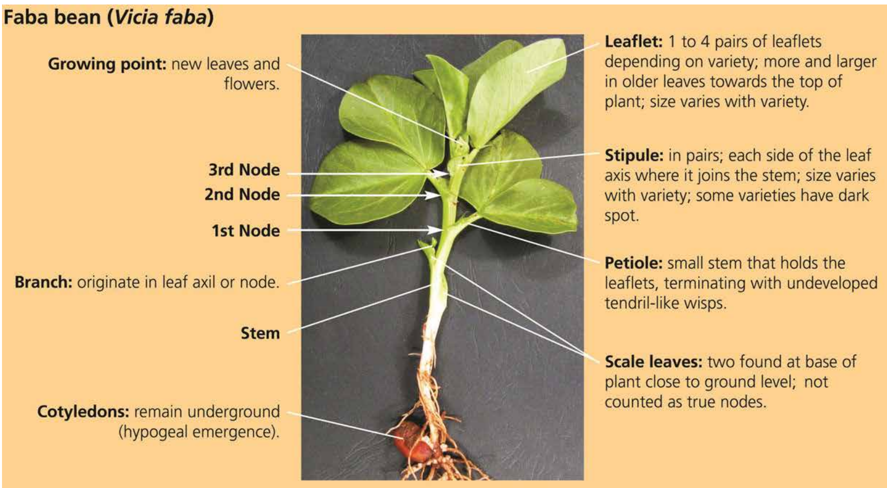

Figure 1: *Faba bean early growth stages.*

Source: Weeds in Winter Pulses (2004), CRC for Australian Weed Management

Nodes are counted from the point at which the first true leaves are attached to the stem.

Faba bean varieties generally exhibit either indeterminate or semi-determinate growth habits. The terminal bud of an indeterminate plant is always vegetative and keeps growing. Vegetative growth continues even as the plant switches to reproductive mode and flowering begins. For a semi-determinate growth habit, vegetative growth continues initially after the plant switches to reproductive mode and flowering begins, but can terminate before moisture becomes limiting. Australian faba bean varieties are semi-determinate (Figure 2); determinate lines have been bred (Figure 3).

Flower terminals develop from the auxiliary bud at the base of each node, with flowering commencing at approximately the 6th–10th node, depending on the variety, location and time of sowing. Faba bean flowers are white with some purple or black markings. Flowers are borne on a peduncle that arises from nodes. Flowers are both self-pollinated and cross-pollinated. [2]

The growth stages of faba beans are described in Figure 4 and Table 1.

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Figure 2: *An Australian semi-determinate faba bean type that is typical of our current varieties.*

Photos: W. Hawthorne, Pulse Australia

Figure 3: *A breeding line that is determinate. No new growth appears above the pods.*

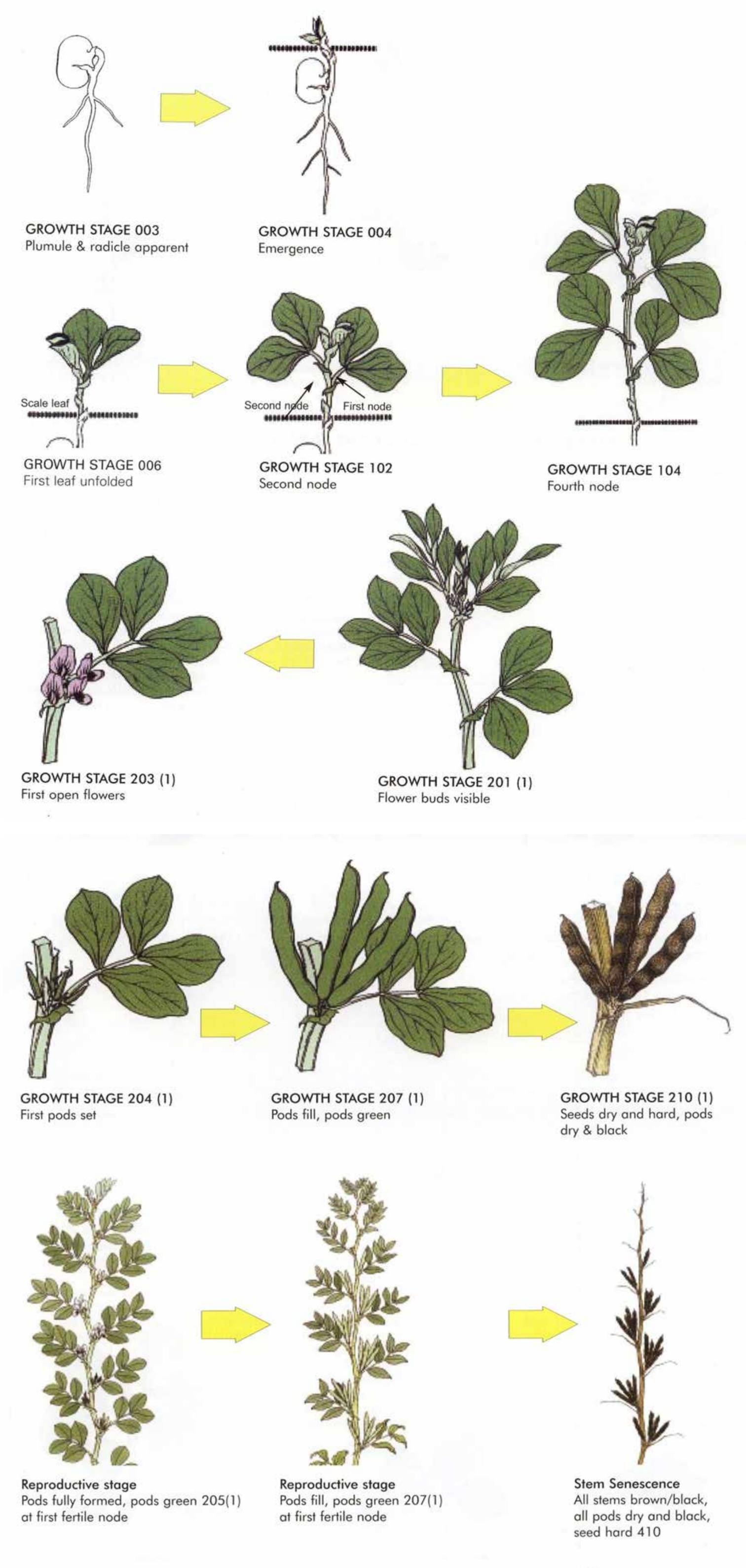

Figure 4: *Stages in the development of the faba bean (Vicia faba).*

Source: PGRO, UK

Table 1: *Growth stages of a faba bean plant.*

Development phase	Growth stage (GS)	Description
00 Germination and Emergence	GS 000 Dry seed GS 001 Imbibed seed GS 002 Radicle apparent GS 003 Plumule and radicle apparent GS 004 Emergence GS 005 First leaf unfolding GS 006 First leaf unfolded	
10 Vegetative	GS 101 First node GS 10(X) X node GS1(N) N, Last recorded node	First leaf fully unfolded with one pair leaflets X, leaf fully unfolded with more than one pair of leaflet N, any number of nodes on the main stem with fully unfolded leaves according to cultivar
20 Reproductive	GS 201 Flower buds visible GS 203 First open flower GS 204 Pod set GS 205 Green pods fully formed GS 207 Pod fill GS 209 GS 210 Dry seed	First buds visible and still green First open flowers on fist raceme First pods visible at first fertile node Small immature seeds within Seeds maximum size fill pod cavity Seeds rubbery, pods still pliable turning black Pods dry and black, seed dry and hard
30 Senescence	GS 301 10% pods dry and black GS 305 50% pods dry and black GS 308 80% pods dry and black, some upper pods green GS 309 90% pods dry and black, desiccation stage GS 310 All pods dry and black, seed hard	
40 Stem senescence	GS 401 10% stem brown/black or most stem green GS 405 50% stem brown/black or 50% stem green GS 410 All stems brown/black, all pods dry and black, seed hard	

Source: PGRO, UK.

For populations, vegetative stages can be averaged if desired. Reproductive stages should not be averaged.

A reproductive stage should remain unchanged until the date when 50% of the plants in the sample demonstrate the desired trait of the next reproductive (R) stage. The timing of a reproductive stage for a given plant is set by the first occurrence of the specific trait on the plant, without regard to position on the plant. [3]

4.3 Crop development

Crop duration is highly correlated with temperature such that crops will take different times from sowing to maturity under different temperature regimes. The concept of thermal time is the mechanism used to represent a crop's requirement to accumulate a minimum time for development through each essential growth stage (e.g. vegetative or reproductive growth). Consequently, crops growing under low air temperatures generally require more time to develop than crops growing at warmer temperatures.

Progress to flowering in faba beans is significantly influenced by temperature and can be described by the accumulation of thermal time ((max T° – min T°)/2, assuming a base temperature of 0°C) (Ellis *et al*. 1988; McDonald *et al.* 1994).

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Thermal time is also referred to as heat units, degree-days or growing degree-days. The base temperature for calculating thermal time for faba bean is 0°C. Once a certain number of degree-days are reached (accumulated), flowering commences, but the actual number of thermal units required varies with the location, photoperiod and variety. Similarly the end of flowering is controlled by thermal unit accumulation.

When sufficient heat units have been accumulated, the plant will enter its reproductive phase and start flowering. It is at this point that the stress tolerance of faba bean tolerance is significantly reduced. Low light or low average daily temperatures (probably <10°C) can cause flower abortion. Sub-zero temperatures can cause flower, pod and seed abortion, and severe frost can cause vegetative distortion total defoliation and death. Temperatures >30°C can also cause flower loss and water stress.

Faba beans are most sensitive to water logging at flowering, with a similar response to low light or low temperatures with flower and pod abortion and leaf senescence. Sowing date and canopy closure are other factors that can impact on pod-set and yield.

The phenology of most crops can be described using nine phases:

i. Sowing to germination.
ii. Germination to emergence.
iii. A period of vegetative growth after emergence, called the basic vegetative phase (BVP), during which the plant is unresponsive to photoperiod.
iv. A photoperiod-induced phase (PIP), which ends at floral initiation.
v. A flower development phase (FDP), which ends at 50% flowering.
vi. A lag phase prior to commencement of grain-filling. This period is relatively short in faba bean, but in chickpeas can be up to 2 months in some cases under cool temperature conditions (<15°C average daily temperature) that inhibit pod set and pod growth.
vii. A linear phase of grain-filling.
viii. A period between the end of grain-filling and physiological maturity.
ix. A harvest-ripe period prior to grain harvest.

These stages of development are generally modelled as functions of temperature (phases i–viii) and photoperiod (phase iv).

Faba beans are a medium duration crop, usually beginning flowering within 29 –96 days of sowing, depending on photoperiod and temperature. Faba beans are either day-neutral or long-day requiring, depending on variety. European germplasm is generally more photoperiod-sensitive. A day length of >12 hours might be required for them to flower under southern Australian conditions while Mediterranean types flower under much shorter days (Stoddard 1993).

Photo-thermal response of flowering in faba beans over the range of environments normally experienced by the crop may be described by the equation: $1/f = a + bt + cp$, where f is the number of days from sowing to first flower, t is the mean temperature and p is the photoperiod. The values of the constants a, b and c vary between genotypes and provide the basis for screening genotypes for sensitivity to temperature and photoperiod (Ellis *et al* 1988; McDonald *et al* 1994). [4]

4.3.1 Flowering and fruit development

If every flower on every faba bean plant produced a pod and each of those pods produced three seeds, the yield potential of the crop would be ~38–43 t/ha (Patrick and Stoddard 2010). However, 4 t/ha is a more realistic figure. The explanation is in the amount of sunlight hitting the leaves adjacent to open flowers for the following three days. Those leaves photosynthesise and produce sugars that feed the flowers. If there is no or very little photosynthesis, then there are insufficient assimilates to

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sustain the flowers. Necessity for sunlight to improve podset has implications for time of sowing, sowing rate and for row spacing in faba bean.

Figure 5: *Flowering faba bean.*

Photo: Drew Penberthy, Penagcon

It is not unusual for <20% of the flowers set by faba beans to develop into pods (Figure 5). Faba beans are both self- and cross-pollinated, so poor podset cannot always be blamed on the absence of bees. In some circumstances, lack of bee or pollinator activity, due to either absence of bees or environmental factors might reduce yield. A high proportion of the flowers that a bean crop sheds have been pollinated.

Fewer pods per node are set at lower nodes for an early sown crop. At a low seeding rate, more pods are set per node at lower nodes, whereas at higher sowing rates pods are more evenly distributed along the stem (Figure 6). This means that matching the variety with the time of sowing and sowing rate is particularly important with faba beans. Using a high seeding rate with early sown crops produces dense, vigorously growing crops early in the season that shade the flowers, reducing pod set and therefore the yield potential.

Figure 6: *Distribution of pods depends on seeding rate.*

Photo: Drew Penberthy, Penagcon

Lack of sunlight is a major factor in determining the level of podset in some environments, such as the winter-rain Mediterranean climate. Total radiation, rainfall, evaporation, temperature, humidity and wind strength have all been investigated, but the amount of radiation hitting the flower from when it opens and for the following 3 days is the main contributing factor (Stoddard 1993). Plant density is also an important factor in podset. Stoddard (1993) states that the primary determinant of whether a flower would be retained was weather during the 4 days from anthesis; incident light and rainfall accounted for >55% of the variation in the retention of flowers within a genotype. Availability of assimilate at the time of pod-setting is critical for the development of adequate yield.

There are significant differences between varieties for time between producing first flower and first podset, and this contributes to the variation in podset between varieties. The old variety Barkool sets a pod very soon after producing a flower. There is a delay of several days between the flower and the production of a pod in the variety Fiesta. Consequently, there is a significant difference in podset between Barkool, Fiord and Fiesta, even though they all begin flowering at about the same time.

Weight of individual seeds is more uniform along a stem for an early sown than for a late-sown crop, which has more small seeds towards the plant top.

Opportunity exists to breed varieties with better pod retention, and cultural practices contributing to competition and plant shading should be investigated.

Flowering commences at the appropriate node on the main stem and lower branches and proceeds acropetally (from the base to the apex of the plant) at intervals averaging at least 5–7 days between successive nodes along each branch. The node of the first flower, and the interval between successive nodes, vary depending on the month, season, variety and sowing time. Duration between nodes is particularly slow during vegetative and early reproductive stages (≥7 days) in winter, but shorter than this interval during spring.

At any location, seasonal variations in temperature can bring about a significant shift in flowering times for the same time of sowing (i.e. +10 days to the values quoted later in the section). In general, warmer temperatures hasten development, as reflected in thermal-time calculations.

Once flowers begin to develop and fertilisation has occurred, the pods remain erect and beneath the leaf canopy. Pods only bend and point downward when seeds are near maturity in some bean varieties. The pod can contain 3–8 ovules, of which most usually develop into seeds. The bulk of the yield is found on the lower flowering nodes of the main stem and basal branches.

Faba beans are like other cool-season legumes in their susceptibility to extreme hot or cold conditions, especially at flowering. In chickpeas, the average day/night temperature is critical for flowering and podset, rather than any specific effects of maximum or minimum temperatures (Singh 1996). This is not necessarily so with faba beans. If there is a critical mean or average daily temperature for faba beans to flower, in most current varieties it would be <10°C.

Unlike in chickpeas, low temperatures with faba beans are not known to cause pollen sterility. In chickpeas, if the average daily temperature falls below 15°C, pollen abortion occurs because the pollen becomes sterile and reproductive structures do not develop. Flowers that may develop below this temperature contain infertile pollen. In faba beans, poor light and hence lack of photosynthates lead to poor podset.

Once true flowers are produced in faba beans, a period of cool weather or lack of sunlight for three days can cause flower or pod abortion to varying degrees (Figure 7). Frosts can have an impact.

At Turretfield Research Centre, Rosedale, South Australia, Fiesta always flowers 90 ± 3 days after sowing with a mid-May sowing. Hence, it commences flowering in temperatures that average 11.4°C (maximum 16.5°C, minimum 6.3°C) (Figure 8).

If moisture and temperature conditions are favourable, additional crop growth, node production, flowering and crop height occurs until flowering ceases (Figure 9). Hot conditions (maximum temperatures >30°C) or lack of moisture causes flowering, and hence additional crop growth, to cease.

If the crop is able to continue to grow taller as it flowers, it will use more soil water. Water-use efficiencies will decline under such circumstances.

Note that the impacts of low air temperatures will be moderated by topography and altitude, so there will be warmer and cooler areas in undulating country.

In faba beans, selection of sowing date is a trade-off between:

- early sowing with high yield potential in those years where excessive frosts are avoided; and
- delayed sowing with lower yield potentials to ensure flowering occurs in warmer temperature and sunlight conditions, but before temperatures become excessive or moisture stress sets in.

The pods of faba beans are green and leathery, maturing to be blackish-brown, with a dense downy internal surface. Modern cultivars developed for human food use have pods 15–25 cm long and 2–3 cm thick. Each pod contains 3–8 seeds; round to oval, usually flattened and up to 20–25 mm long, 15 mm broad and 5–10 mm thick. [5]

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Figure 7: *Faba bean with poor pod set. Note the pedicel indicating lost flowers at each node above and below the single pod.*

Photo: W. Hawthorne, Pulse Australia

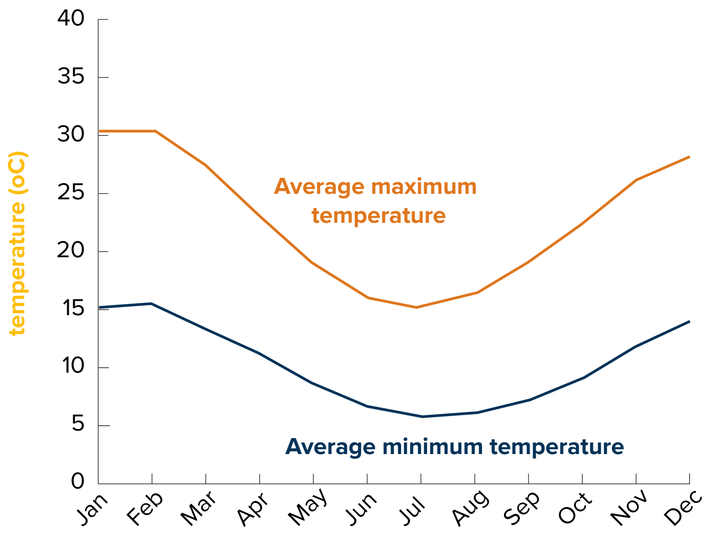

Figure 8: *Minimum and maximum daily temperature averages by month at Roseworthy, South Australia.*

Source: CropMate

Figure 9: *Faba bean with excellent podset, but note the need for fungicide protection of flowers (and leaves) in a disease-risk situation.*

Photo: W. Hawthorne, Pulse Australia

4.4 Growth and development

Faba beans, being legumes, belong to the botanical family of Leguminosae. They are semi-erect annuals with medium-fibrous roots (Figure 10). Worldwide, three main types of *Vicia fabae* are cultivated, and are classified based on seed size. Faba beans, horse beans and broad beans are all are grown in temperate regions and are large-seeded relative to many other pulses.

In European countries, there are winter- and spring-sown beans. In Australia we grow what are internationally considered Mediterranean-type beans (Patrick and Stoddard 2010). Spring beans flower over an extended period and do not ripen in southern Australia.

Faba bean types are mainly consumed whole (canned product), split for dhal, crushed for falafel or turned into flour.

Faba bean seed contain about 25% protein, 10% fat and 55% carbohydrates.

Figure 10: *A display of faba bean plants at various stages of development.*

Photo: W. Hawthorne, Pulse Australia

4.4.1 Emergence

Under optimum moisture and temperature conditions, faba bean seeds imbibe water relatively quickly and germinate within a few days provided temperatures are >0°C. Unlike lupins, faba bean seedlings have hypogeal emergence, that is, their cotyledons (embryonic leaves) remain underground inside the seed coat while providing energy to the rapidly growing roots and shoots.

Emergence occurs 7–30 days after sowing, depending on soil moisture, temperature conditions and depth of sowing. Growth of the shoot (plumule) produces an erect shoot and the first leaves are scales. The first true leaves have a single pair of leaflets (i.e. two leaflets), and from the 5th to 8th node, leaves have two or three pairs of leaflets. The development of multiple pairs of leaflets per leaf generally corresponds with development of the first flower bud.

When placed in a moist environment, the seed goes through three stages of water uptake during germination as it imbibes water (Mares 2005), as follows.

Phase 1 is water movement into the grain, imbibition, which occurs because the moisture content in the soil is greater than that in the seed. The seed swells. Water enters primarily at the hilum end of the grain where it was originally attached to the funiculus and nutrient-conducting tissues of the plant. There is also some minor movement of water through the seed coat. Water uptake into the embryo (germ) proceeds very rapidly, depending on the soil moisture content, to the point that normal cellular processes (metabolism, cell division, etc.) can occur. Seed moisture needs to reach ~35% dry weight before germination can occur in wheat. Too much water can impede germination by restricting diffusion of oxygen to the seed. All seeds, whether viable or non-viable, dormant or non-dormant, go through this phase 1 process.

Phase 2 is when there is minimal uptake of water, and it extends through to the first visible signs of germination. The major metabolic events required to prepare the seed for germination occur during phase 2 only in viable and non-dormant seeds. These changes are conserved if the seed is dried, and the seed can remain dry for considerable period without significant reduction in viability or germination potential. When these seeds are re-wetted, they again rapidly imbibe and show accelerated germination as the phase 2 duration is markedly shortened.

Phase 3 is associated with visible germination and subsequent growth (Figure 11). As part of this growth, there is rapid uptake of water again and new metabolic activity, including the start of mobilisation of stored food reserves in the endosperm. Visible germination starts with rupture of the seed coat over the germ and the protrusion of the shoot and radicle. As this process advances, the seedling becomes increasingly vulnerable to damage through drying, and there is a reducing capacity to regenerate following re-wetting.

Until the establishment of green leaves, the seedling is dependent on the stored food reserves in the endosperm. During the early stages of germination, the embryo produces gibberellic acid, which triggers the synthesis of enzymes that ultimately lead to the production of sugars and amino acids required by the growing seedling. [6]

Implications of this information are that:

- Seeds that are sown into marginal moisture and have imbibed some moisture may have either dried down or not taken up sufficient moisture to germinate. These 'primed' seeds will germinate quickly when the soil is again wetted up, as part of the germination process had commenced.
- Seed with a cracked seed coat can allow direct access of water and microorganisms into the stored starch and protein reserves in the endosperm.
- Seed with a cracked seed coat may imbibe moisture too quickly and impede oxygen diffusion into the seed.

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- If there has been pre-harvest sprouting, it may have limited effects on germination percentage when tested at harvest, but will cause a decline in germination percentage, germination vigour and seed viability during storage. [7]

Figure 11: *Germinating bean seed.*

Leaves

Leaves in faba beans are alternate along the branch. Each leaf is 10–25 cm long, pinnate and consists of 2–7 leaflets each up to 8 cm long and of a distinct glaucous grey–green colour (Figure 12). Leaflets are not serrated. Unlike most other members of the *Vicia* genus, it is without tendrils or with rudimentary tendrils.

Leaflets fold and become limp in dry, hot conditions to minimise transpiration. Canopy development in faba beans is quite rapid, especially during early sown and warmer winter conditions.

The entire surface of the leaflets is free of fine hairs (trichomes). [8]

Figure 12: *Nura⏀ faba bean plants showing alternate leaves along the branch, with multiple leaflets on each leaf. Note chocolate spot incidence and loss of lower leaves.*

Photo: W. Hawthorne, Pulse Australia

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Roots

Faba beans have a robust taproot with profusely branched secondary roots that increase in size near the soil surface as the season develops. The root systems are strong, but do not always penetrate to depth (Figure 13).

Faba bean roots can leave moisture at depth late in the season, and this can result in a reduced ability to withstand dry conditions. Root growth is most rapid before flowering but will continue until maturity under favourable conditions. Faba beans are susceptible to hard pans, and prefer deep, well-structured soils so that roots can penetrate deeply. Subsoil constraints, such as soil chloride in excess of ~800 mg/kg soil in the top 60 cm, will restrict root growth and water availability.

At Pinery, South Australia, with soils showing chloride levels >1000 mg/kg in the top 100 cm, there was a significant relationship between yield and salt tolerance.

As well as their role in water and nutrient uptake, faba bean roots develop symbiotic nodules with the rhizobial bacteria *Rhizobium leguminosarum* bv. *Viciae*, a species capable of fixing atmospheric nitrogen (N_2) (Figure 14). The plant provides carbohydrates for the bacteria in return for N_2 fixed inside the nodules.

These nodules are visible within about a month after plant emergence, and eventually form slightly flattened, fan-like lobes. Almost all nodules are confined to the top 30 cm of soil and 90% are within 15 cm of the surface. When cut open, nodules actively fixing N_2 have a pinkish centre (Figure 15). Nitrogen fixation is highly sensitive to waterlogging; hence, faba beans need well-aerated soils.

Waterlogging and drainage

Faba beans are considered tolerant of waterlogging. They will survive despite periods of waterlogging, especially in cool conditions of winter. However, waterlogging will reduce yields. Irrigated faba beans grown at Kerang on drained soils (tile drains at 1.0 m) yielded 4.2 t/ha, whereas the undrained crop yielded 2.7 t/ha when sown on raised beds and 1.9 t/ha where sown into a conventionally laser levelled bay (Drew 1994). The watertable was maintained at about 1.0 m below the soil surface for the season on drained soils, but on undrained soils, it was 0.1–0.3 m from the surface until September, and then fell away to be 0.8–0.9 m by the end of November.

Figure 13: *Faba bean usually has a robust, but not deep, taproot system.*

Photo: W. Hawthorne, Pulse Australia

Figure 14: *Nodulated roots.*

Figure 15: *Active nodules have pinkish centre.*

Photo: G. Cumming, Pulse Australia

Soil nitrate and temperature effects on nodulation

Nitrate in the soil can delay nodulation, decrease nodule number and decrease nodule activity (Herdina and Salisbury 1989); bean seedling growth and nodulation were poorer at 10°C than at either 15°C or 20°C. Nodulation was markedly reduced by the low temperature, and it is likely to be slow in the field when the soil temperature is low (10°C) as may occur after a late sowing. The known yield advantage of early planting of faba bean may in part be due to better nodulation under warm (15°C) soil conditions (Herdina and Salisbury 1989).

Root mass and penetration

Faba bean roots do not penetrate to the same soil depths as those of wheat or barley (Gill and Kleeman 2008). In their study, extractable water through the soil to 130 cm depth showed small differences due to row spacing in May but larger ones due to crop type in October. Water use by wheat and barley over the growing season was unaffected by row spacing; however, both cereals were more effective than faba bean at extracting soil water. In contrast to the cereals, faba bean used 50 mm less water, which was related to its inability to extract water below 85 cm depth and its failure to dry soil below 20% volumetric water content. This additional soil water could be of benefit to the following wheat crop in dry seasons if it could be stored in the profile until the next growing season.

Faba bean roots do not produce as much biomass as chickpea or wheat roots (Figure 16). [9]

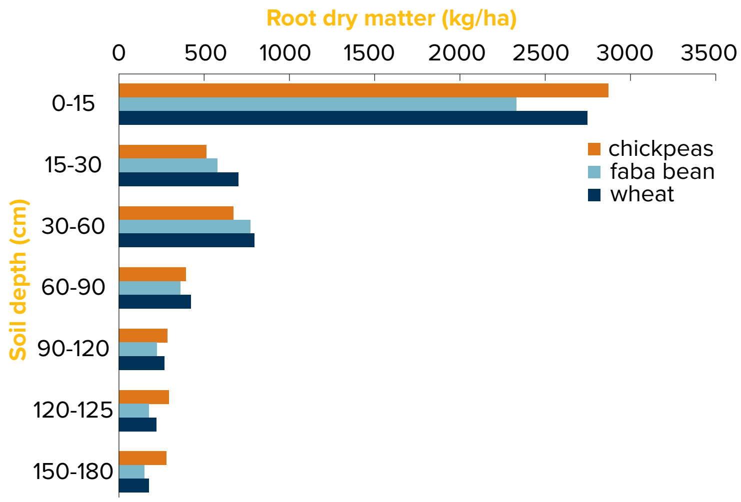

Figure 16: *Root biomass (kg/ha) at each soil depth of chickpea, faba bean, and wheat.*

Source: Turpin et al. 2002

4.4.2 Stem and branches

Vicia faba is an annual with rigid, erect plants, ideally 0.5–1.8 m tall, with stout, hollow but erect stems of a square cross-section.

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Figure 17: *Maturing, well-podded faba bean plants showing their basal branching habit and multiple-podding nodes.*

Photo: W. Hawthorne, Pulse Australia

Primary branches, starting from ground level, grow from buds at the lowest nodes or plumular shoot as well as the lateral branches of the seedling (Figure 17). These branches are thick, strong and woody, and determine the general appearance of the plant. Height achieved by the main stem and branches depends on soil moisture or rainfall conditions, length of growing season and variety.

Unlike lupins and some other pulses, there are no secondary or tertiary branches that develop from the main stem or branches.

Pollination

Faba beans are allogamous, or have a mixed mating system, with both cross-pollination and self-pollination, but require insect pollinators to maximise seed set. If low numbers of bees are present, introducing commercial pollinating bees through the crop in a grid of at least 2 hives/ha can increase yield by 30–100%.

Apiarists must manage hives as ‘pollinators’, not honey producers, placing hives throughout the crop, not in a paddock corner (Figures 18 and 19). Bees must be removed or housed when insecticide or fungicide is used.

Growers must tolerate beehives through the crop but will see a yield benefit to pay for the pollination service. Apply and time chemical use wisely, use integrated pest management (IPM) and communicate intentions with the apiarist.[10]

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Figure 18: *Bee hives need to be strategically placed within the crop and well managed to ensure adequate pollination.*

Photo: W. Hawthorne, Pulse Australia

Figure 19: *Placing multiple hives in a corner of the paddock does not effectively pollinate the whole crop.*

Photo: W. Hawthorne, Pulse Australia

Pollination trials

All pulse crops are open-pollinated to varying degrees, which means in order to achieve seed-set, pollen must be transferred between flowers. Mechanisms such as wind can achieve pollen transfer or cross-pollination, but the most effective method is utilising insects to carry the pollen from one flower to the next. Several insects will do this, including bees, lacewings, flies and even ants. Because of the density of flowers in a pulse crop and the short flowering period, the number of insects required to pollinate the crop effectively is far beyond what can naturally occur. Therefore, the most effective way to increase the number of insects in the crop is to introduce honeybees.

The role of the forager bee is primarily to collect food for the hive. Bees collect two different foods, pollen, which is used to feed their young (brood), and nectar, which is converted into honey to feed the adults. As the bees collect pollen, and to a lesser degree nectar, they transfer pollen from one flower to the next and inadvertently fertilise the crop.

Trials are being conducted across South Australia employing a technique of hive management that is used in other parts of the world but only just starting to be adopted commercially in Australia. This more intensive form of hive management uses a technique that creates an overwhelming demand in the hive for pollen. Hives are serviced every fortnight to maintain the demand. This technique significantly increases the proportion of forager bees collecting pollen. The overwhelming demand for pollen means that the bees travel to the closest source of pollen and this reduces the distance they travel from the hive. Trials indicated that the flight of the bees was restricted to around 200–300 m from the hive. This means that, in order to achieve effective pollination, precise placement and density of hives is crucial for uniform pollination.

Why is this different?

Apiarists currently supply hives that contain a significantly greater amount of stored honey and pollen than the hives managed with this new technique. As a result, there is not a large immediate demand in the hive for pollen and nectar, because the bees have stores to sustain the hive for some time. With reduced demand in the hive for pollen and nectar, the bees will travel further from the hive to find preferable areas to forage. This might include gullies that are warmer and protected from wind within the crop, or alternative flora such as flowering Mallee trees. The bees may travel up to 5 km to find alternative flora. Due to the lack of demand in the hive for pollen, bees often selectively forage on the easiest to reach flowers in the crop, usually on the top of the canopy. This leaves many flowers in the lower part of the canopy untouched, meaning that they do not set seed and drop off. By placing an immediate demand in the hive for pollen, the bees will visit every flower in the crop, including the older flowers and flowers in the lower part of the canopy.

Trials conducted in 2007 and 2008 across South Australia have indicated that yield increases of up to 50% may be easily achieved with the addition of the managed hives to pulse crops (Figure 20). Trials have mainly focused on beans, but funding has been sourced to investigate other crop types and their yield responses to managed pollination.

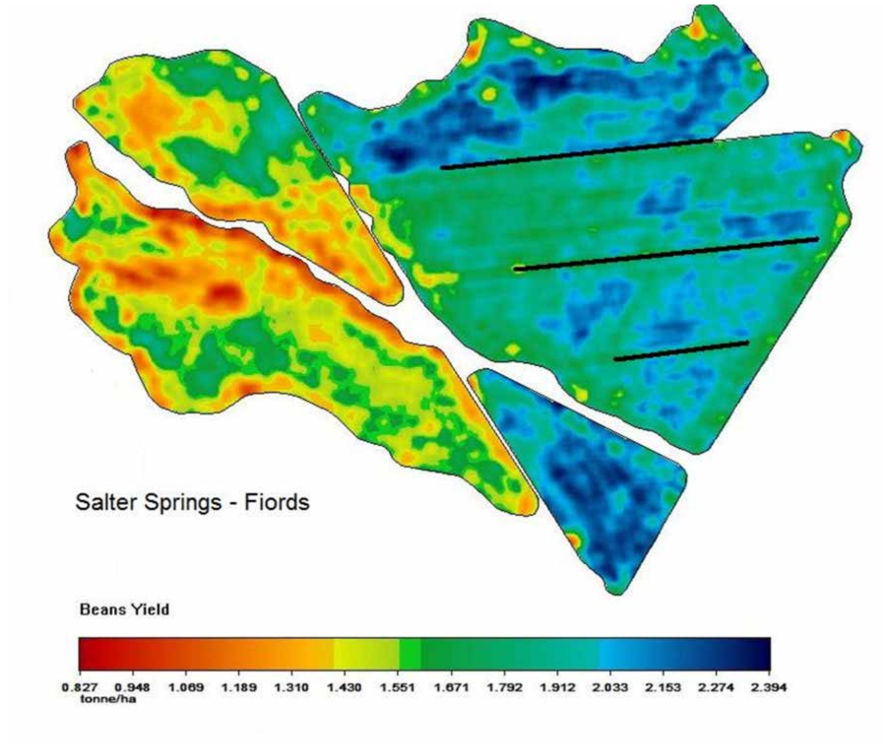

Figure 20: *Yield map of Fiord faba beans showing increased yield where beehives had been strategically placed through the crop (top right side, black lines).*

Source: Danny Le Fevure, formerly Ag Consulting Company

Climatic requirements for flowering

The timing of flowering is an important trait affecting the adaptation of crops to low-rainfall, Mediterranean-type environments (such as southern Australia). Seed yields of many crops in these areas have been increased by early sowing, the development of early flowering varieties and use of stubble-retention systems to maximise moisture use efficiency.

Apart from daylight, the three major factors affecting flowering in faba bean are temperature, daylength, and drought. Temperature is generally more important than daylength. Flowering is invariably delayed under low temperatures but more branching occurs.

Progress towards flowering is rapid during long days, whereas under short daylengths, flowering is delayed but never prevented. However, some faba bean varieties are less sensitive to daylength than others. This has enabled breeders to identify improved varieties that flower early in our short-day, winter growing season in southern Australia.

Faba beans are like many other cool season pulses in that they are reasonably tolerant of cold conditions, even at flowering. Unlike chickpeas, some advantage can be derived from early flowering, despite increased flower and pod abortion at lower temperatures. There are, however, temperature and daylight limits that constrain photosynthesis.

In many parts of southern Australia, mean daily temperatures fall below 10°C during winter. This is not necessarily an impediment to flowering or podset unless frosts occur. Faba bean producers in high-rainfall areas do complain about poor early podset with early sowing; however, poor light in dense canopies, and hence low photosynthesis, is likely the major cause, often in conjunction with low levels of pollinator activity and possible chocolate spot incidence on flowers.

In many well-grown faba bean crops, podset does not occur until temperatures rise in August–September, when there is also more sunlight and less wind and rain (for pollinator activity). More consistent podset and seed-filling then commences. Disease incidence in flowers (i.e. chocolate spot) is implicated in poor podset in some situations, and thus, many faba bean growers consider fungicide protection of early flowers important. When temperatures rise and environmental conditions improve, pods can develop quickly, within 3–6 days. Even after flowers develop into pods, periods of low temperature and poor conditions may result in abortion of seeds or whole pods before filling commences.

In addition to the effects of cold described above, sub-zero temperatures in winter can damage leaves and stems of the plant. This occurs particularly in northern Australia. These severe frosts can cause a characteristic ‘hockey-stick’ bend in the stem (Figure 21). However, beans have some ability to recover from this damage by being able to regenerate new branches in severe cases. New growth occurs from the base of the frost-affected plants if moisture conditions are favourable.

Figure 21: *Severe vegetative frost can cause bends like a hockey stick in faba bean stem and branches in northern Australia.*

Photos: G Cumming, Pulse Australia

Frosts can also cause flower, pod and seed abortion. Pods at a later stage of development are generally more resistant to frost than flowers and small pods (Figure 22), but may suffer some mottled darkening of the seed coat (Figure 23).

Frost will normally affect the smallest pods first, even though they are the higher pods on the plant. Similarly, pod abortion induced by moisture stress is normally also noted on the last formed pods in the upper parts of the plant. Visual symptoms of frost and moisture stress damage to pods are, however, quite different.

In southern Australia, frost or low minimum temperatures (<5°C) during the reproductive stage will not physically damage the crop as might occur in northern Australia (Figure 21). There may be a slight leaf tipping on upper leaves to indicate a frost has occurred.

Frost during early flowering that affects early podset can be compensated for later by subsequent pods that set higher up the plant, provided the seasonal conditions are favourable to fill them.

Figure 22: *Frost can cause flower or pod abortion (usually smaller pods). Damage to the seed depends on the size of the pod or seed and the severity of the frost.*

Photo: W. Hawthorne, Pulse Australia

Figure 23: *Frost can cause seed staining from 'burning' the seed coat next to the pod wall.*

Photo: W. Hawthorne, Pulse Australia

Maximum temperatures >30°C in spring may also reduce yield in faba beans, causing flower abortion, cessation of flowering and a reduction in the time available for seed-filling. Faba beans are considered one of the least tolerant of the winter pulses to moisture stress (drought) and high temperatures.

On the other hand, high levels of humidity and low light also reduce podset in faba beans. [11]

Tolerance to low temperature

Some varieties of faba bean released in the northern region have been bred for their tolerance to frosts during the vegetative growth stage. This tolerance in the varieties PBA Warda⦇, Cairo⦇ and Doza⦇ means less death of stems and 'hockey-stick', symptoms from the severe frosts seen in northern Australia, but not in southern areas. Current varieties grown in southern Australia (e.g. Fiesta, Farah⦇, Nura⦇ and PBA Rana⦇) are susceptible to severe vegetative frost damage when grown in northern Australia.

Tolerance to frost at either vegetative or reproductive stages is not a breeding priority in southern Australia. However, improved early podset under conditions of low temperatures and low light is a breeding priority.

In other parts of the world, 'spring faba bean' crops are sown after winter. 'Winter faba bean' crops are sown before winter and are able to survive under snow. Winter varieties tolerate freezing conditions and can be sown in autumn, survive over winter, and are ready to grow, flower and set pods when temperatures rise in spring and summer. [12]

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Flowering, podding and seed development

Flowers are large, borne on short pedicels in clusters of 1–5 on each axillary raceme, usually from the node where flowering commences. There can be up to 15 flowering nodes in well-grown faba beans in Australia; 1–4 pods develop from each flower cluster. Growth is largely indeterminate. Flowers are 1.0–2.5 cm long, with five petals, the standard petal white, the wing petals white with a black spot (not deep purple or blue) and the keel petals white (Figure 24).

Figure 24: *Faba bean flowers are not completely white, because of the tannins that occur in their seeds. Only tannin-free faba beans lack anthocyanin, hence only they produce white flowers.*

Photo: W. Hawthorne, Pulse Australia

About 30% of the plants in a population are cross-fertilised and the main insect pollinators are honeybees in Australia. Bumblebees are not present in mainland Australia.

The development of flowers and then of seeds are key processes in the formation of yield in faba beans, as in other grain legumes.

Mediterranean-type faba beans as grown in Australia do not have a high vernalisation requirement (McDonald *et al* 1994). Winter faba beans, however, generally have a quantitative vernalisation requirement, allowing flowering to occur at a lower node than in unvernalised plants. Some germplasm is day-neutral; other germplasm is long-day with a critical day length between 9.5 and 12 h.

Progress toward flowering follows a conventional thermal-time model. For commercial faba bean varieties, ~830–1000 degree-days (>0°C) is required for the onset of flowering, but this varies with location, time of sowing and variety. Optimum temperature of flowering is 22–23°C.

Flowers may abscise from the crop because of:

- lack of pollination
- proximal flowers on the same raceme being fertilised
- vegetative–reproductive competition for assimilate
- stresses such as drought

Seed-filling in the retained pods proceeds through well defined, pre-storage and storage phases, described in detail by Patrick and Stoddard (2010). During the pre-storage phase, cell expansion occurs mostly in the endosperm and seed coat while the embryo is in a cell-division phase.

Growth in faba beans is often described as indeterminate. This means that branch and leaf (or vegetative) growth continues as the plant switches to a reproductive mode and initiates flowering. Hence, there is often a sequence of leaf, flower bud, flower and pod development along each branch.

The duration of vegetative growth before flowering is dependent on many factors, as discussed earlier.

There can be an early period of ineffective flowering, during which podset does not occur. In warmer environments, this period is minimal, but in colder temperate environments, it can be as long as 30 days.

Pollination takes place after the flower bud opens. Faba beans have a mixed mating system with both self- and cross-pollination. Faba bean pollen is very heavy and sticky and is not is not released into the air. Virtually all cross-pollination is via insect transfer of the pollen. The rate of cross-pollination in a faba bean crop is typically 30%, but varies with environmental conditions, presence of insect vectors and variety.

Faba bean plants generally produce many flowers; however, a large proportion (~80–90%) does not develop into pods, depending upon the variety, sowing date and other environmental conditions (Figures 25–28). Some pods that set do not progress to fill seeds either.

Figure 25: *Flower raceme indicates flowers that did not set pods.*

Photo: W. Hawthorne, Pulse Australia

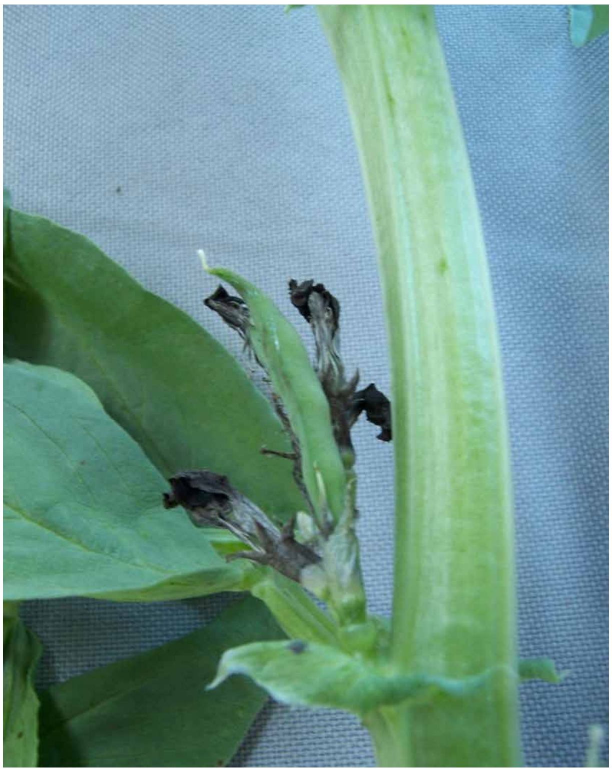

Figure 26: *Faba bean pod and dead flowers that when removed may show small pods.*

Photo: W. Hawthorne, Pulse Australia

Figure 27: *Faba bean branches showing small pods, pods that have formed but not developed and flower raceme left after flower abscission without setting pods.*

Photo: W. Hawthorne, Pulse Australia

Figure 28: *Faba bean canopy showing full flowers*

Photo: W. Hawthorne, Pulse Australia

Under favourable temperature and soil moisture conditions, the time taken from fertilisation of the ovule (egg) to the first appearance of a pod (pod set) is about 6 days. The seed then fills over the next 3–4 weeks. The developing pod stands above its subtending leaf. It may become too heavy (e.g. in broad bean) and then hang below the flowering node for harvest. After podset, the pod wall grows rapidly for the first 10–15 days, while seed growth mainly occurs later.

Faba bean pods vary greatly in size between varieties because of varying seed sizes. Pod size is largely unaffected by the environment. Seed-filling and subsequent seed size are highly dependent on variety, number of seeds set and weather conditions.

Seed are characteristically oval and flat, sometimes with a ridged, dimpled or smooth seed coat. Seed colour varies between varieties from white (tannin-free) to light tan/green (commercial varieties), brown (aged beans), even purple or black (specific lines). Kernel colour is yellow. Seed numbers vary from one to eight per pod, and not every ovule in a pod necessarily develops.[13]

4.4.3 Erectness

Faba beans are prone to lodging, 'necking' or both, which are two different processes. Either way the end result is a crop that is no longer erect and becomes more difficult to harvest.

Lodging is the condition when the stems bend and the crop is less erect as it becomes taller late in the season (Figure 29). Taller (e.g. early sown) and dense crops are more prone to lodging than shorter, thinner crops. Strong winds and rain can cause lodging. There are varietal differences in erectness, and disease (Ascochyta blight in particular) in the stem can also make a crop more prone to lodging. Chocolate spot becomes more severe in lodged crops, and penetration of foliar fungicide into the canopy becomes more difficult.

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Necking occurs in beans under strong wind conditions, and seems more pronounced when the crop is under moisture stress. The stem bends over sharply (virtually snapping) at about pod height, and so the upper part of the plant either dies or becomes less able to assist in grainfill (Figure 30). Sometimes there is plant recovery from necking, and the growing points turn to grow upright again (Figure 31). These plants then appear to have stems that are bent into an 'S'-shape. These plants are often considered lodged. [14]

Figure 29: *Faba bean crops can be subject to lodging, often severe, when the stem bends gently. Dense, tall crops, windy conditions and disease can make the crop more prone to lodging.*

Photo: W. Hawthorne, Pulse Australia

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Figure 30: *Faba bean can be subject to 'necking' when the stem bends sharply to be virtually snapped off. Hot winds and moisture stress make the crop more prone to 'necking'.*

Photo: W. Hawthorne, Pulse Australia

Figure 31: *Faba beans that shows some mild 'necking' when the stems have bent but not so as to appear snapped off. In such cases, there is recovery, and plants appear to have bent stems and are often considered lodged.*

Photo: W. Hawthorne, Pulse Australia

Maturity

Soon after the development of pods and seed-filling, senescence of subtending leaves begins. If there is plenty of soil moisture and maximum temperatures are favourable for growth, flowering and podding will continue on the upper nodes.

However, as soil moisture is depleted or if temperatures increase, flowering ceases and eventually the whole plant matures. This is typical of pulse crops and annual plants in general.

In northern New South Wales, flowering ceases and plants ripen in response to temperature increase even though there could be adequate of soil moisture.

Faba beans are unlike chickpeas, which can tolerate high temperature if there is adequate soil moisture. Hence, chickpea is normally one of the last pulse crops to mature in Mediterranean-type environments.

As leaves begin to senesce, there is a rapid re-translocation of dry matter from leaves and stems into the seeds.

Under mild moisture stress, faba bean and most winter pulses other than chickpea are incapable of accumulating solutes (sugar, proteins and other compounds) in their cells. Stomatal conductance and low levels of photosynthesis are therefore not maintained in these winter pulses, but are in chickpea via a process known as osmoregulation.

In southern Australia, faba bean crops can reach maturity 180–220 days after sowing, depending on the sowing date, variety, and a range of environmental factors including temperature (Figure 32). Faba beans are ready to harvest when >90% of the stems and pods lose their green colour and become black (Figure 33). At this point, seeds are usually hard but do not rattle when the plant is shaken as occurs in chickpea and lentil.

Figure 32: *Mature, well-podded faba beans before their pods and stem dry for harvest.*

Photo: W. Hawthorne, Pulse Australia

Figure 33: *Mature faba beans are black, and in this photo have been desiccated (front and right) for earlier maturity and harvest compared with that allowed to mature naturally (centre).*

Photo: W. Hawthorne, Pulse Australia

Pulses can be desiccated or windrowed pre-harvest to enable earlier harvest and to dry out green weeds, although growers in northern New South Wales have moved away from this practice. Timing of desiccation is based on crop stage, and is similar to or later than that for windrowing.

Potential dangers of premature desiccation are the presence of excessive green cotyledons in the sample, staining of the seed coat and small seed, all of which create marketability problems.

Windrowing or desiccation of bean crops can commence when the majority of seeds are physiologically mature. This is assessed as being when the hilum (scar-like area where the seed attaches to the pod) is turning black on the seeds in the upper most pods. At this stage the upper pods are still bright green, and green leaf is still present, but the lowest pods are starting to turn black and have seeds with completely black hilums. If windrowing is delayed beyond this stage, it needs to be done in cool and moist conditions otherwise pod loss can become unacceptable. [15]

For more information on frost in faba beans please see Section 14.

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