Growing barley

Barley (*Hordeum vulgare*) is a widely grown and highly adaptable winter cereal crop that is used mainly for stock feed and the production of malt for the brewing industry.

Barley is an annual plant that has been selected from wild grasses. It is thought to have been an important food crop from as early as 8000 BC in the Mediterranean/ Middle East region.

Because of barley's tolerance of salinity, by 1800 BC it had became the dominant crop in irrigated regions of southern Mesopotamia, and it was not until the early AD period that wheat became more widely grown.

Barley types

There are two forms of barley, determined by the number of rows of grain along the head. Two-row barley types have only one fertile spikelet per side of the head. In six-row barley, all three spikelets per side of the head are fertile.

Two-row types are the most commonly grown. The two-row barleys can be used for malting, human food or stock food, with the quality required and the price varying for each end-use. The only current use of the grain of six-row barley is for stock feed. It is generally sown for grazing only.

Winter and spring varieties

Barley grown in NSW can also be divided into winter and spring types. The main difference between the two is that winter barleys need a period of cold temperature (vernalisation) to initiate reproduction, whereas spring barleys do not have a cold requirement.

Spring barleys

The vast majority of barley varieties grown in NSW are spring barleys. Spring barleys grow and develop in response to increasing temperature and photoperiod (daily hours of light). They do not have a vernalisation requirement to initiate flowering. It is very important to sow spring-type barleys at the recommended time to minimise the risk of frost damage during flowering. Recommended sowing times are published each year by Industry & Investment NSW in the *Winter crop variety sowing guide*.

Winter barleys

Winter barleys are used in the mixed farming zones. They need to experience a period of cold temperatures, between 0 and 10°C, to trigger a switch from vegetative growth to reproductive growth. This cold requirement is known as vernalisation. Varieties need different periods of vernalisation, so it is important to take this into consideration when selecting a variety. The cold requirement allows winter barley varieties to be sown earlier than spring types – from February to early April for grazing.

Life cycle

The growth and development of the barley plant is a complex process. During the life cycle of the plant, many of the growth stages overlap, and while one part of the plant is commencing development, another part may be towards the end of development and changing little, at a minimum rate (Figure iv).

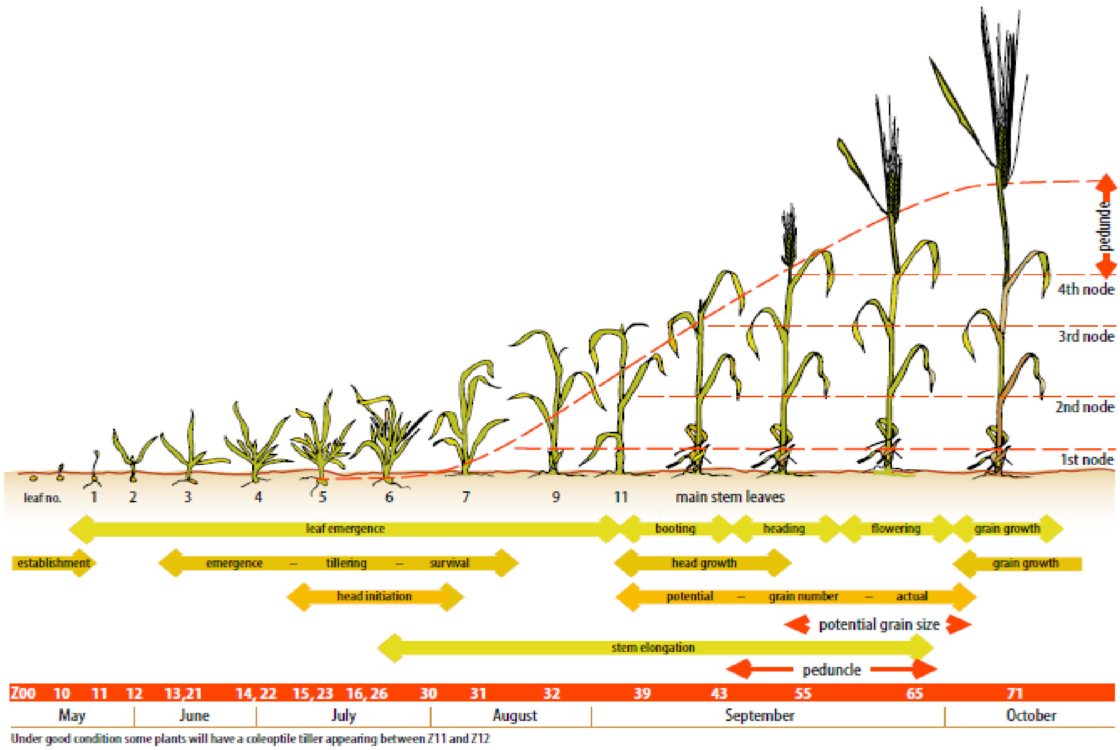


Figure iv. Life cycle of a barley plant

Table i: Zadoks decimal growth scale for cereals.

GERMINATION	
00	Dry seed
01	Start of imbibition
03	Imbibition complete
05	Radicle emerged from seed
07	Coleoptile emerged
09	Leaf just at coleoptile tip
SEEDLING GROWTH	
10	First leaf through coleoptile
11	First leaf unfolded
12	2 leaves unfolded
14	4 leaves unfolded
16	6 leaves unfolded
18	8 leaves unfolded
TILLERING	
20	Main shoot only
21	Main shoot & 1 tiller
22	Main shoot & 2 tillers
24	Main shoot & 4 tillers
26	Main shoot & 6 tillers
28	Main shoot & 8 tillers
STEM ELONGATION	
30	Stem starts to elongate (*head at 1 cm*)
31	1st node detectable
32	2nd node detectable
34	4th node detectable
36	6th node detectable
37	Flag leaf just visible
39	Flag leaf/collar just visible
BOOTING	
41	Flag leaf sheath extending
43	Boot just visibly swollen
45	Boot swollen
47	Flag leaf sheath opening
49	First awns visible
HEAD EMERGENCE	
50	1st spikelet of head just visible
53	1/4 of head emerged
55	1/2 of head emerged
57	3/4 of head emerged
59	Emergence of head complete
ANTHESIS (FLOWERING)	
61	Beginning of anthesis
65	Anthesis 50%
69	Anthesis compete
MILK DEVELOPMENT	
71	Seed watery ripe
73	Early milk
75	Medium milk
77	Late milk
DOUGH DEVELOPMENT	
83	Early dough
85	Soft dough
87	Hard dough
RIPENING	
91	Seed hard (difficult to divide by thumbnail)
92	Seed hard (can no longer be dented by thumbnail)
93	Seed loosening in daytime
94	Overripe, straw dead & collapsing
95	Seed dormant
96	Viable seed giving 50% germination
97	Seed not dormant
98	Seed dormancy induced

Source: Based on Zadocks et al. (1974)

The barley grains

The barley grain is the reproductive unit of the barley plant as well as the end-use product (Figure v). A barley grain can be broadly divided into three components (Figure vi): husk, endosperm and embryo (the young plant, including the coleoptile, three or four embryonic leaves, and the rootlets).

In most varieties, the proportion of each component of the grain is 7% to 13% husk, 70% to 80% endosperm and 2% to 5% embryo.

Once filled, the barley grain is 70% carbohydrate, and 97% of this is starch (Figure vi). The protein content is between 8% and 15%, depending on the final grain weight; this equates to 4 to 10 mg. The type and content of protein and of other constituents such as cell walls can significantly affect the brewing process and final beer quality. Therefore, only specific varieties are suitable for malting.

Husk

The outer protective covering of the seed. Lemma and palea generally adhere to the endosperm.

Aleurone

A layer of protein surrounding the endosperm that secretes enzymes to break down starch reserves in the endosperm during germination.

Endosperm

Tissue that surrounds the embryo and provides energy for germination. The germinating seed relies on these reserves until it has developed a root system and sufficient leaf area for photosynthesis. The endosperm makes up the bulk of the grain and stores carbohydrate in the form of starch from which the fermentable sugars are formed during malting.

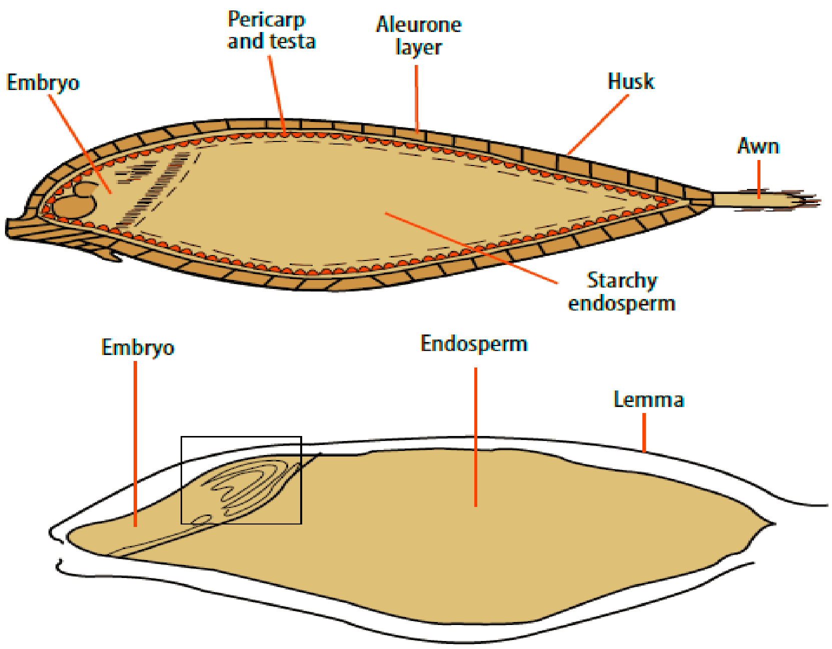


Figure vi. The basic composition of the barley grain. Source: Based on Kirby and Appleyard (1984)

Embryo

Contains the main plant structures, so it holds all the elements of the growing plant. It is made up of the scutellum, plumule (shoot) and radicle (primary root). It is found at the point where the grain is attached to the spikelet.

Scutellum

A shield-shaped structure that absorbs the soluble sugars from the breakdown of starch in the endosperm. It also secretes some of the enzymes involved in germination.

Embryonic leaves (plumule)

The growing point of the seed that develops into the shoot bearing the first true leaves. At the growing point are the coleoptile, the three-leaf primordia (the young leaves recently formed by the apical meristem of the shoot) and the shoot apex.

Radicle

Develops into the primary root and is the first structure to emerge after germination. The rootlet is protected by a root cap as it penetrates the soil.

The barley plant

The main structures of the plant are the coleoptile, leaves, tillers, stem, roots and head.

Coleoptile

The coleoptile is a protective sheath that encases the first leaf. It pushes through the soil to the surface.

Leaves

The leaf consists of a sheath, which wraps around the newly emerging leaf, and a leaf blade. The leaf sheath contributes to stem strength. The leaf collar is the point where the leaf sheath joins the leaf blade. The leaf collar has two features, the ligule and the auricles. The ligule is a thin colourless membrane around the base of the collar. The auricles are large hairless projections that extend from the side of the leaf collar.

These features can be used to help identify grass species (see Figures vii and viii). Leaves are produced in a set order, on alternate sides of the stem. A leaf is counted as emerged when the ligule is fully visible. The final leaf to grow before head emergence is the flag leaf.

Tillers

Tillers are lateral branches or shoots that arise from buds in the axil of the leaves at the base of the main stem. Primary tillers are produced from the leaves of the main stem and can form their own, secondary tillers.

Stem

The stem is made up of nodes and internodes. Nodes are where structures such as leaves, roots, tillers and spikelets join the stem. The internode is the tissue between adjacent nodes that elongates as the stem grows. The stem is wrapped in the sheaths of the surrounding leaves. This structure of stem and leaves gives strength to the shoot, helping to keep the plant upright. As the stem grows it changes function from providing support for leaves to storing carbohydrates and nutrients for grain-filling.

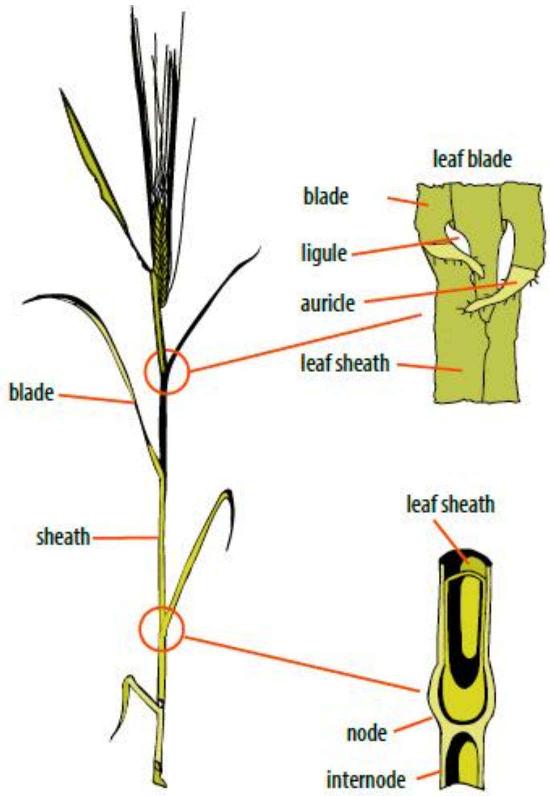


Figure vii. Structure of the barley leaf.
Source: Based on Anderson and Garlinge (2000)

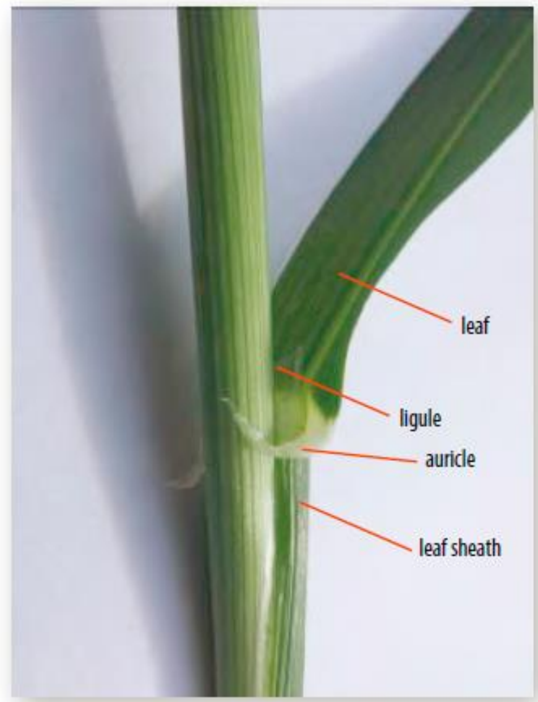


Figure viii. Leaf collar showing the ligule and auricles.
Photo: Tim McNee

Roots

Barley has primary and secondary root systems (Figure ix). The first roots to appear are the primary roots (also called seminal or seedling roots). At germination, the radicle breaks through the seed coat, followed by four or five lateral roots. These form the primary root system that supports the plant until the secondary roots (also called adventitious, nodal or crown roots) initiate from nodes within the crown.

Head

There are two basic types of barley, determined by the number of rows of grain along the head. In two-row types the side spikelets are sterile, with only one fertile spikelet per side of the head. In six-row barley, all three spikelets per side of the head are fertile (Figure x). Three rows of grain grow from each node of the rachis on alternate sides of the head. Two- row barley varieties are more commonly grown commercially in NSW.

The head of the barley plant has a rachis (stem) made up of nodes and short, flattened internodes. At the nodes are the floral structures, called spikelets, that hold up to six florets containing the flower of the barley plant, where the grain is formed. Figure xi shows a mature barley head.

Each floret is enclosed within two protective bracts called the lemma and palea. These structures wrap around the carpel. The carpel contains the ovary with the feathery stigmas, three stamens holding the anthers (pollen sacs), and the ovule. Once fertilised, the ovule forms the grain. Figure xii shows a dissected barley spikelet.

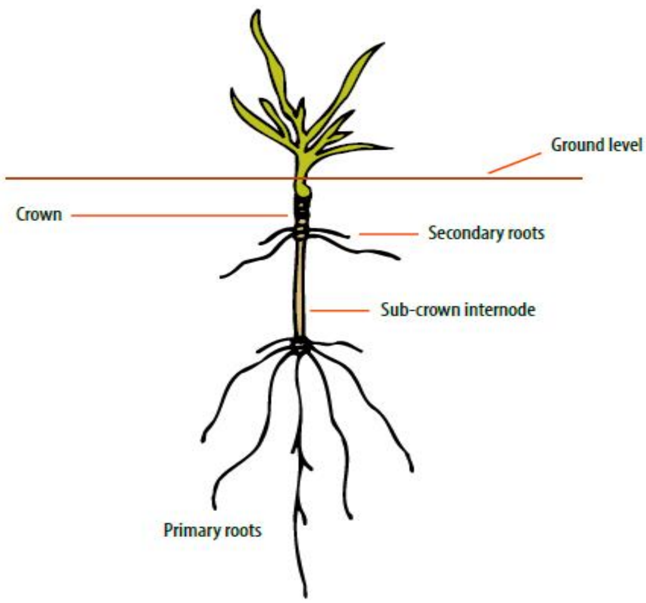


Figure ix. The barley plant, showing the primary and secondary root systems
Source: Anderson and Garlinge (2000)

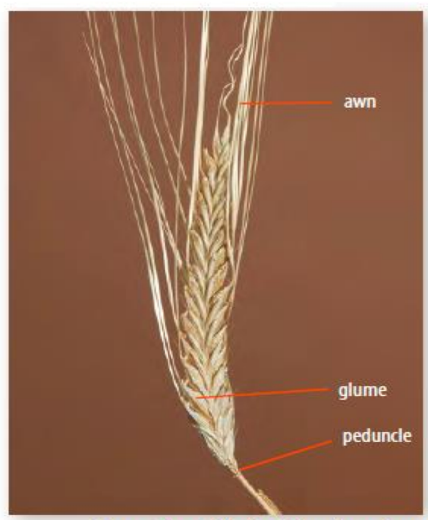
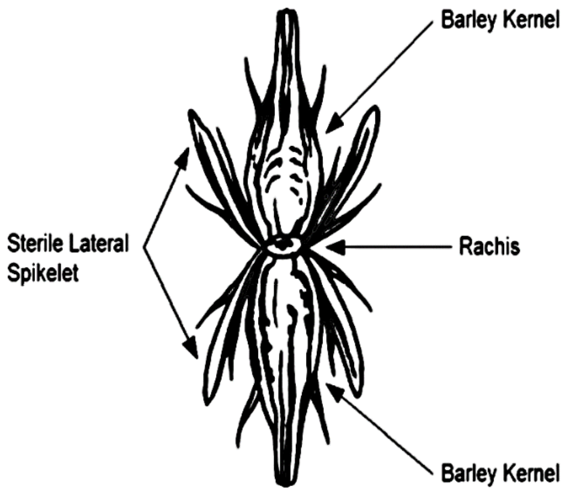
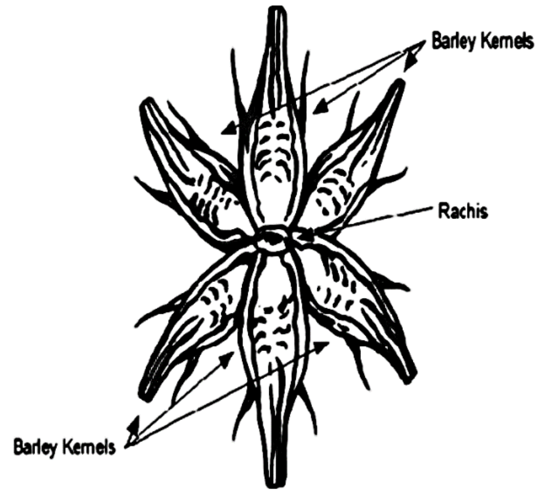


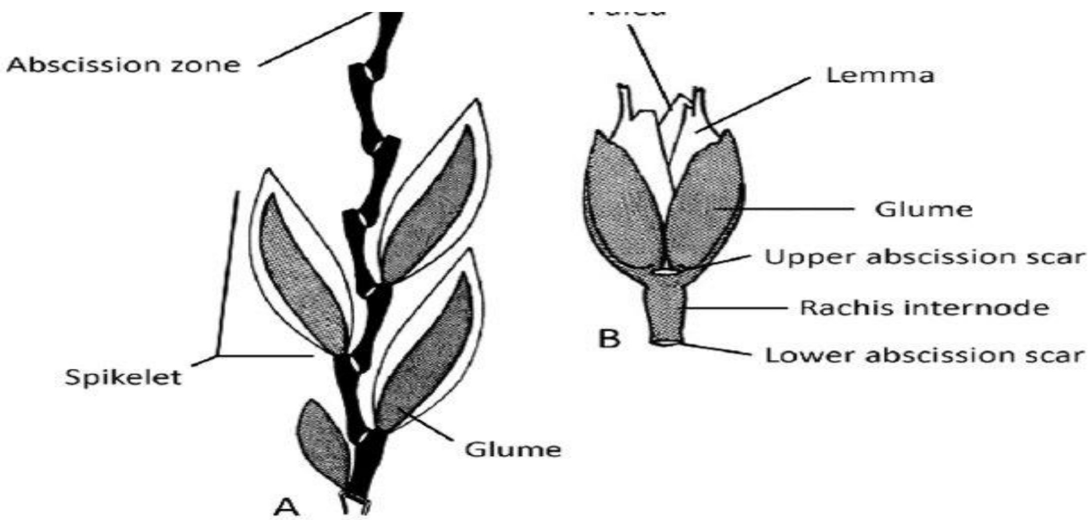
Figure xi. Mature barley head. Photo: Lowan Turton

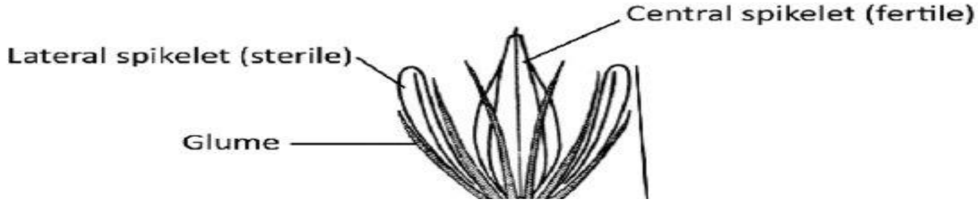


Two-row barley head



Six-row barley head





Plant growth and physiology Chickpea

Key messages

• Under optimum moisture and temperature conditions, chickpea seeds imbibe water quickly and germinate within a few days, providing temperatures are >0°C.

• Emergence occurs 7–30 days after sowing, depending on soil moisture and temperature conditions and depth of sowing.

• Flowering is invariably delayed under low temperatures but more branching occurs.

• Chickpea in its reproductive stage is sensitive to heat stress (20°C or higher as day/night temperatures) with consequent substantial loss of potential yields at high temperatures

• Chickpea is a photoperiod sensitive, long-day plant, where flowering is delayed as day length becomes shorter than a base photoperiod (17 h).

• Starting soil water can have a strong influence on the yield expectation of chickpea as well as the riskiness of production. Chickpea, being a legume, belongs to the botanical family of *Fabaceae*, subfamily *Faboideae*. It is a semi-erect annual with a deep taproot. Worldwide, two main types of chickpea, Desi and Kabuli are cultivated. Kabuli types, grown in temperate regions, are large-seeded and mainly consumed as a whole seed, whereas Desi types, grown in semiarid tropical and subtropical regions, are mainly consumed as spli dhal or turned into flour. Chickpea seed contains about 20% protein, 5% fat and 55% carbohydrates.

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

1. Sowing to germination

2. Germination to emergence

3. A period of vegetative growth after emergence, called the basic vegetative phase (BVP), during which the plant is unresponsive to photoperiod

4. A photoperiod-induced phase (PIP), which ends at floral initiation

5. A flower development phase (FDP), which ends at 50% flowering

6. A lag phase prior to commencement of grainfilling (in chickpea this period can be very long, up to two months in some cases, under cool temperature conditions (<15°C), which inhibit pod set and pod growth)

7. A linear phase of grainfilling

8. A period between the end of grainfilling and physiological maturity

9. A harvest-ripe period prior to grain harvest.

These stages of development are generally modelled as functions of temperature (phases 1–8) and photoperiod (phase 4). Chickpea is a medium-duration crop, usually beginning flowering within 90–110 days of planting, depending on photoperiod and temperature (Figure 1). Chickpea is a photoperiod sensitive, long-day plant, where flowering is delayed as day length becomes shorter than a base photoperiod (17 h). 1

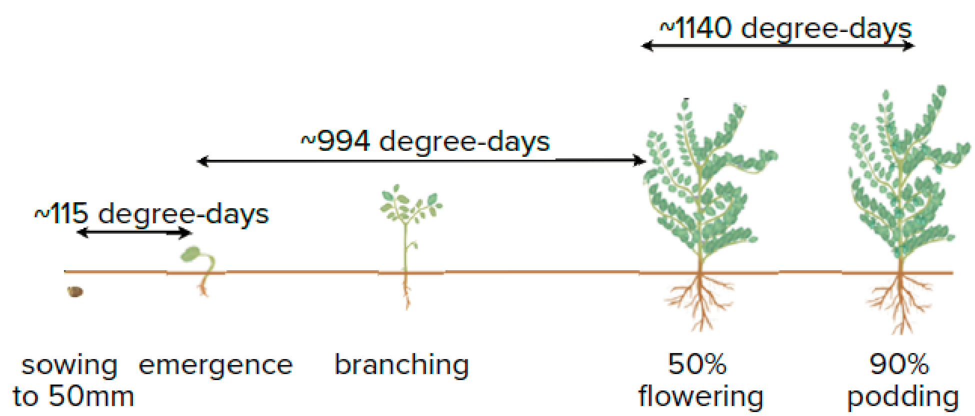


Figure 1: *Key developmental stages of chickpea and their thermal time targets.*

Source: J. Whish, CSIRO

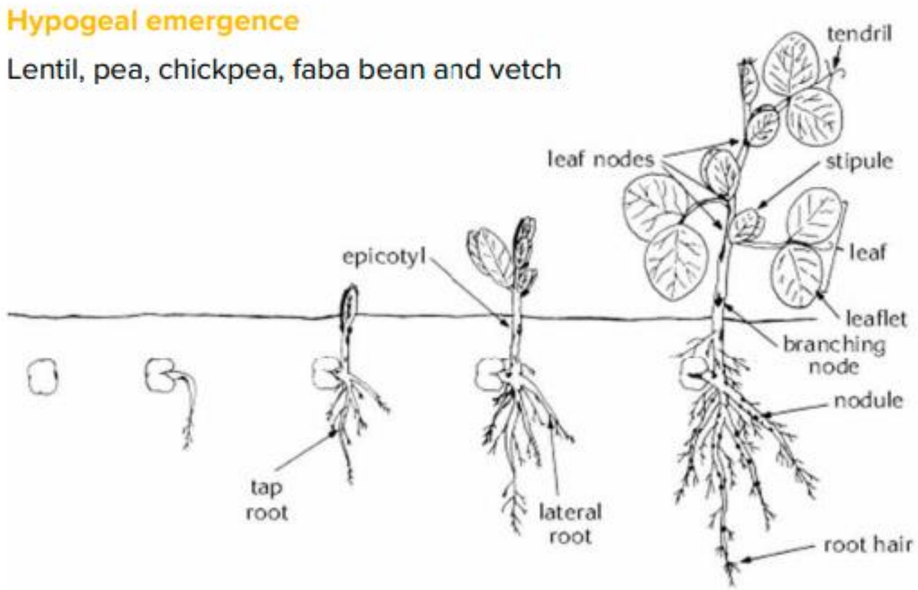


Figure 2: *Hypogeal emergence of chickpea seedlings makes the plant less prone to environmental stress and damage in the early growth stages.*

Plant growth stages

The chickpea crop germinates, matures, senesces, and dies within 100 to 225 days from sowing, depending on environmental conditions before and after flowering, the magnitude of seed yield, and the rate and synchrony of seed filling (Figure 8). 23

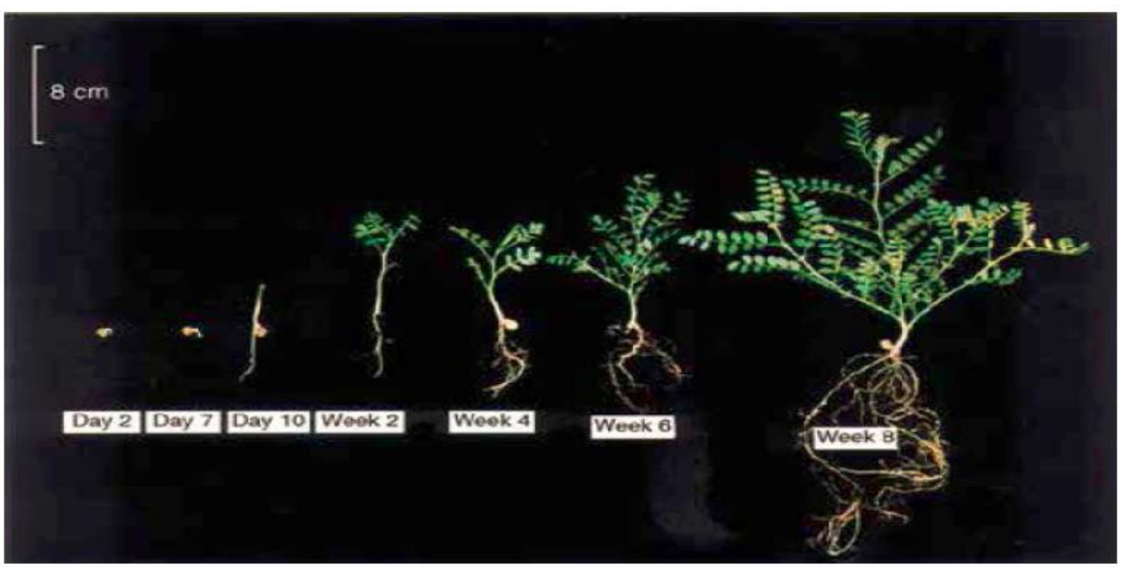


Figure 8: *Chickpea growth and development from germination to two months. Plants may vary according to variety and environment.*

The chickpea plant is erect and freestanding, usually 15–60 cm in height, although well-grown plants may grow to 80 cm. The plants have a fibrous taproot system, a number of woody stems forming from the base, upper secondary branches and fine, frond-like leaves. Chickpea is considered very indeterminate in their growth habit, i.e. their terminal bud is always vegetative and keeps growing, even after the plant switches to reproductive mode and flowering begins. 24

The chickpea growth stages key is based on counting the number of nodes on the main stem (Table 2). Uniform growth stage descriptions were developed for the chickpea plant based on visually observable vegetative (V) and reproductive (R) events. The V stage was determined by counting the number of developed nodes on the main stem, above ground level. The last (uppermost) node counted must have its leaves unfolded. The R stages begin when the plant begins to flower at any node.

Table 2: *Growth stages of a chickpea plant (Nolan 2001).*

Designation	Growth stage	Description
Vegetative growth stage (V-stage) in chickpeas		
VG	Germination	Cotyledons remain underground inside the seed coat and provide energy for rapidly growing primary roots (radicle) and shoots
VE	Emergence	The plumule emerges and the first two leaves are scales. The first true leaf has two or three pairs of leaflets plus a terminal leaflet

Designation	Growth stage	Description
V1	First node	Imparipinnate (terminal unpaired) leaves attached to the first node are fully expanded and flat while the 1st imparipinnate leaf attached to the upper node starts to unroll
V2	Second node	1st imparipinnate leaf attached to the second node is fully expanded and flat while the 2nd imparipinnate leaf on the upper node starts to unroll
V3	Third node	2nd imparipinnate leaf attached to the third node is fully expanded and flat while the 3rd imparipinnate leaf on the upper node starts to unroll. The bulk of the yield is found on the branches stemming from the first three nodes
V(n)	N-node	A node is counted when its imparipinnate leaf is unfolded and its leaflets are flat
Reproductive growth stage (R-stage) in chickpea		
R0	False flowering	In the transition from vegetative to include reproductive growth, a number of false flowers (called pseudo flowers) may develop from the axillary buds. These flower buds lack fully developed petals and typically appear if flowering is triggered before mean temperatures are high enough for true flowers to develop, especially if soil has high moisture content coinciding with flowering, which enables it develop a bigger canopy
R1	Start flowering	One flower bud at any node on the main stem (see p. 5 in 'The chickpea book', Loss et al. 1988)
R2	Calyx opening	Bud grows but is still sterile, sepals begin to form
R3	Anthesis	Pollination occurs before the bud opens

R4	Wings extend	Flower petals extend to form a flower
R5	Corolla collapses	Flower collapses and petals senesce and peduncle reflexes so that the developing pod usually hangs below its subtending leaf
R6	Pod initiation	One pod is found on any node on the main stem
R7	Full pod	One fully expanded pod is present that satisfies the dimensions characteristic of the cultivar
R8	Beginning seed	One fully expanded pod is present in which seed cotyledon growth is visible when the fruit is cut in cross-section with a razor blade. (Following the liquid endosperm stage)
R9	Full seed	One pod with cavity apparently filled by the seeds when fresh
R10	Beginning maturity	One pod on the main stem turns to a light golden-yellow in colour
R11	50% golden pod	50% of pods on the plant mature
R12	90% golden pod	90% of pods physiologically mature (golden yellow), usually about 140–200 days after planting depending on season and cultivar

A reproductive stage should remain unchanged until 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 (Figure 9). 25

Figure 9: *Growth habit of a chickpea plant.*

Leaves

Leaves in chickpea are alternate along the branch (Figure 10). The first true leaf has two or three pairs of leaflets plus a terminal one. Fully formed leaves, with 5–8 pairs of serrated leaflets (10–16 leaflets), usually develop after the sixth branch (node) stage. Leaflets can fold slightly in dry conditions to minimise transpiration. Despite having more leaves and branches than other legume crops such as faba bean, canopy development in chickpea is slow, especially during the cool winter months.

Figure 10: *Alternate leaves along the branch, with multiple leaflets on each leaf.*

The entire surface of the plant shoot, except the flower, has a thick covering of glandular hairs (trichomes) that secrete a strong acid (mostly malic acid), particularly during pod set (Figure 11). The malic secretions from all vegetative surfaces of the plant seem to play a role in protecting the plant against pests such as red-legged earth mite, lucerne flea, aphids and pod borers. Similar substances are also secreted from the root system and can solubilise soil-bound phosphate and other nutrients. The acid also corrodes leather boots.

Figure 11: *A green pod covered in glandular hairs excreting acid.*

Roots

Chickpea root systems are usually deep and strong, and contribute to the plant's ability to withstand dry conditions. The plant has a taproot with few lateral roots. Root growth is most rapid before flowering but will continue until maturity under favourable conditions. Although rare, in deep well-structured soils, roots can penetrate more than 1 m deep (Figure 12); however subsoil constraints such as soil chloride >800 mg/ kg soil in the top 60 cm will restrict root growth and water availability. nodules with the Rhizobium bacteria, capable of fixing atmospheric nitrogen. Theplant provides carbohydrates for the bacteria in return for nitrogen fixed inside the nodules. Chickpea plants can derive more than 70% of their nitrogen requirement from symbiotic nitrogen fixation. These nodules become visible within about a month of plant emergence, and eventually form slightly flattened, fan-like lobes (Figure 13). Practically all nodules are confined to the top 30 cm of soil and 90% are within the top 15 cm of the profile. When cut open, nodules actively fixing nitrogen have a pink centre. Nitrogen fixation is highly sensitive to waterlogging so it is essential that chickpea crops are grown on

well-aerated and drained soils. 26

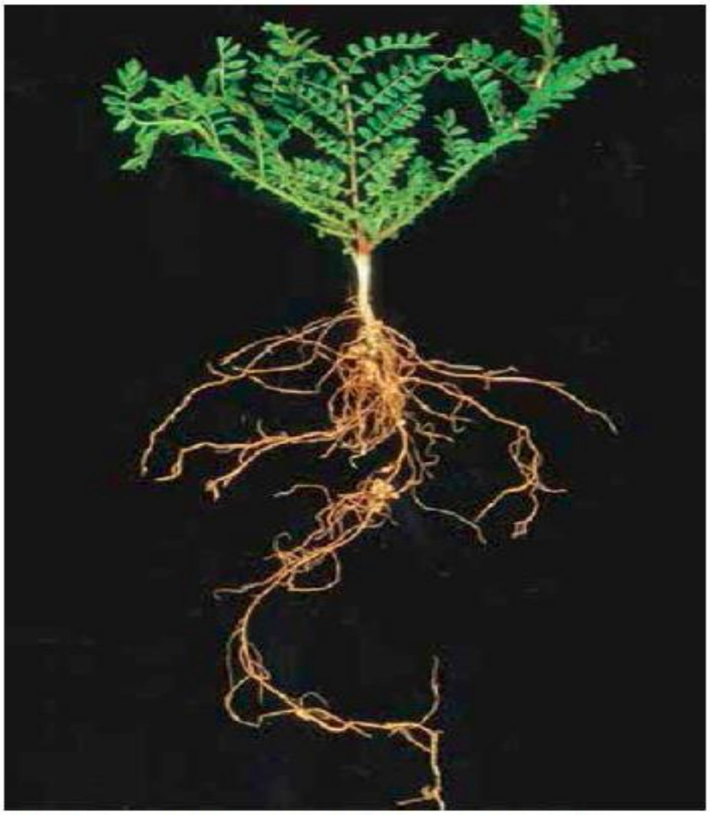


Figure 12: *Chickpea usually has a deep tap root system.*

Figure 13: *Well-nodulated chickpea plants.*

Branches

Primary branches, starting from ground level, grow from buds at the lowest nodes of the plumular shoot as well as the lateral branches of the seedling. These branches are thick, strong and woody, and they determine the general appearance of the plant (Figure 14). The main stem and branches can attain a height of about 40–100 cm. Kabuli varieties are generally taller than Desi varieties. growing from buds on secondary branches are more leafy and carry fewer pods. The number of primary branches can vary from one to eight depending upon the variety and growing conditions. In chickpea, five branching habits based on angle of branches from the vertical are classified: erect, semi-erect, semi-spreading, spreading and prostate. Most modern varieties are erect or semi-erect, to enable mechanical harvesting. The final height of the plant is highly dependent on environmental conditions and the variety being grown, but in general range from 50 to 100 cm. Secondary branches are produced by buds on the primary branches. They are less vigorous but contribute to a major proportion of the plant yield. Tertiary branches

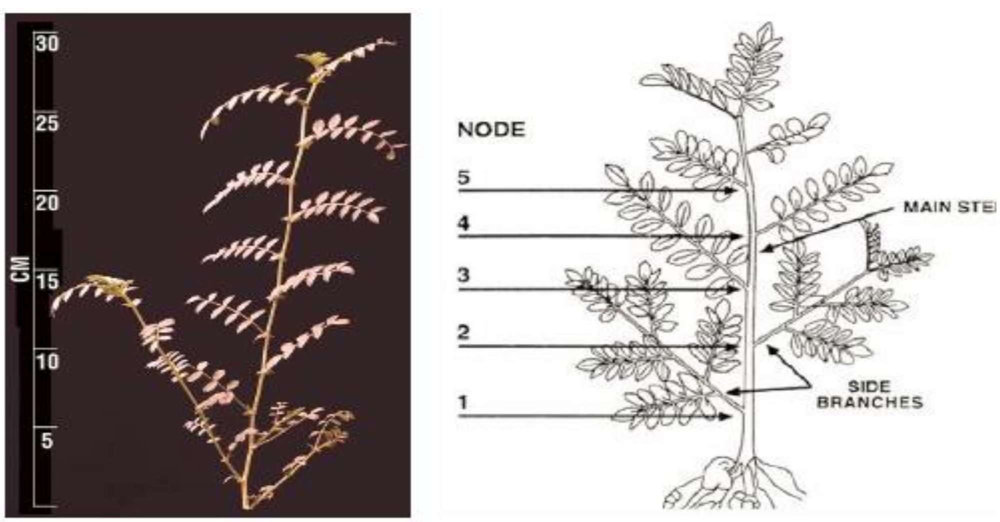


Figure 14: *Chickpea at the 5–7-node stage of development, prior to flowering.*

Flowering

Growth in chickpea 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 (Figure 15).

The onset and duration of flowering in chickpea are functions of genotype, photoperiod, and temperature. Flowering is indeterminate and can extend for up to 60 days with leaf initiation and stem elongation continuing into the reproductive period.

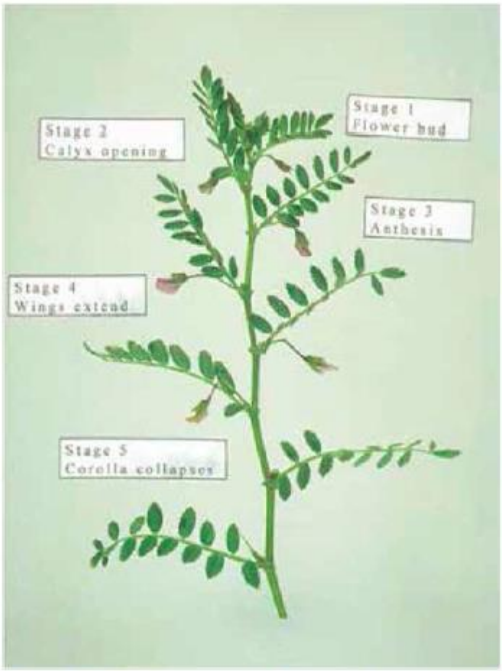


Figure 15: *Different stages of flower development on the same chickpea branch.*

Chickpea is peculiar among pulses in that a number of pseudo-flowers or false flower buds develop during the changeover from leaf buds to flower buds on the stem. Therefore, there could be a period of ineffective flowering when pod set does not occur. In warmer tropical and subtropical environments this period is minimal, but in cooler temperate–subtropical environments, it can be as long as 50 days. Flowering commences on the main stem and lower branches and proceeds acropetally at intervals averaging 1.5–2 days between successive nodes along each branch. The bulk of the yield is found on the branches stemming from the first three nodes. The fruit develops in an inflated pod containing 2–4 ovules, of which one or two usually develop into seeds. At any location, seasonal variations in temperature can bring about a significant shift in flowering times 10 days from the figures quoted below). In general, warmer temperatures hasten development. Petals are generally purple in the Desi type and white to cream in the Kabuli type (Figure 16). Purple-flowered Desi types generally contain high amounts of the red pigment anthocyanin, and their leaves, stems and seed coats are generally dark. By contrast, the white-flowered Kabuli types lack anthocyanin, have light green leaves and stems, and pale seeds. Increased pigmentation is evident following environmental stresses such as low temperature, salinity, waterlogging, drought, and virus infection, especially in Desi types.

Figure 16: *Desi chickpea purple flower (left) and kabuli chickpea flower (right). Kabuli chickpea lack anthocyanin, hence their white flowers.*

Pollination in chickpea takes place before the flower bud opens, when the pollen and the receptive female organ are still enclosed within a fused petal, called the keel. Natural cross-pollination has been reported, however most studies indicate 100% self-pollination. Flower terminals normally develop from the axillary bud at the base of each node. Flowers are borne on a jointed peduncle that arises from nodes. Flowers are primarily self-pollinated. Chickpea plants generally produce many flowers. However, around 30% do not develop into pods, depending upon the variety, sowing date and other environmental conditions.

Podding

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 six days (Figure 17). The seed then fills over the next 3–4 weeks (Figure 18). Once a pod has set, the jointed peduncle of the senescing petals reflexes, so that the developing pod hangs beneath its subtending leaf. After pod set, the pod wall grows rapidly for the first 10–15 days, with seed growth occurring later. Chickpea pods vary greatly in size between varieties. Pod size is largely unaffected by the environment. By contrast, seed filling and subsequent seed size are highly dependent on variety and weather conditions.

Seeds are characteristically 'beaked', sometimes angular, and with a ridged or smooth seed coat. Seed colour varies between varieties from chalky white to burgundy and brown, to black, and is determined by the colour and thickness of the seed coat and the colour of the cotyledons inside. Seeds vary from one to three per pod. In southern Australia, chickpea crops can reach maturity 140–200 days after sowing, depending on the sowing date, variety, and a range of environmental factors including temperature. Chickpeas become ready to harvest when 90% of the stems and pods lose their green colour and become light golden yellow. At this point, the seeds are usually hard and rattle when the plant is shaken (Figure 19).

Figure 17: *Chickpea podding (left) and chickpea plant seven weeks before harvest (right).*

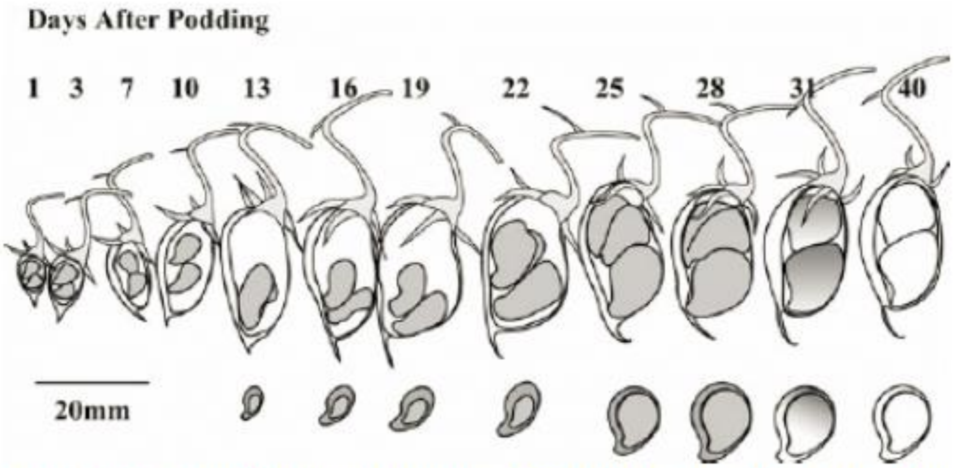


Figure 18: *Seed and pod development in chickpea showing the relative sizes of the pod, seed coat, embryo, and the internal pod gas volume.* [29]

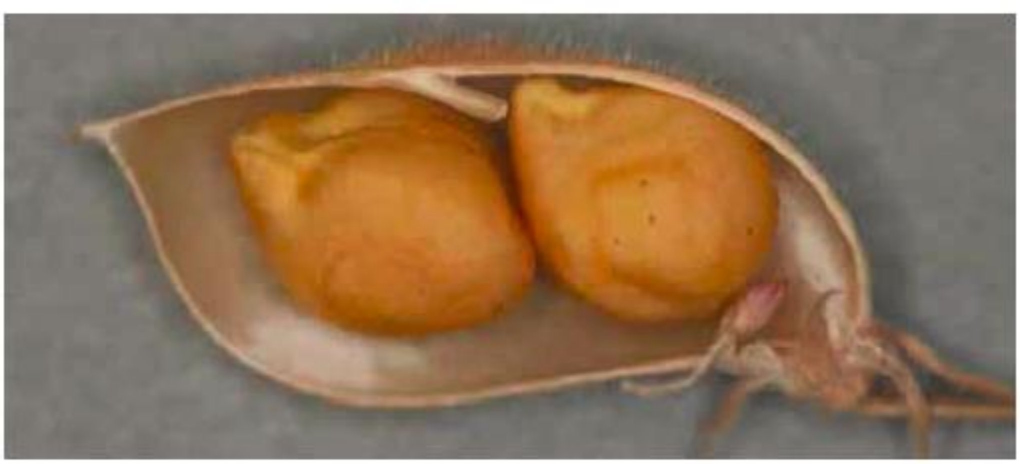


Figure 19: *Physiologically mature grains 'rattle pod'.*