MORE INFORMATION

DAFWA Bulletin 102008 'Producing Lupins': http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins

DPIRD website hub 'Lupins – germination and seedling development': https://www.agric.wa.gov.au/lupins/germination-and-seedling-development-lupins

Plant growth (phenology) and development

3.1 Overview

Lupin plant growth and development are overlapping and complex.

Growth refers to the increase in size and number of leaves, stems and roots – which produce biomass. Fuelled by SOURCEsynthesis, this is directly related to water use and light interception.

Development is the process by which the plant moves from one growth stage to the next. Rate and timing depend on variety, SOURCEperiod and temperature.

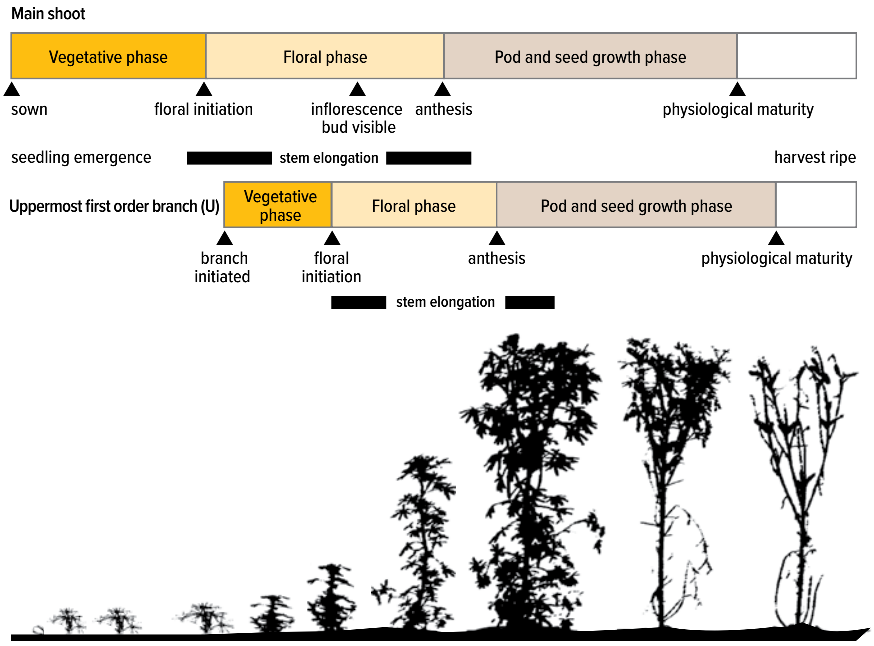
Correct identification of lupin plant growth stage enables effective crop management, especially for herbicide and pesticide applications and timing of harvest.

A growth scale is used to describe each developmental stage of the lupin plant and this is similar to the Zadoks Growth Scale for wheat.

The lupin growth scale covers six stages, starting with germination and finishing with seed ripening, and is sub-divided into 10 units per stage.

Some of the growth stages overlap during the plant's evolution, as can be seen in Figure 1.

Figure 1: *Life cycle of lupin plant.*



(SOURCE: DAFWA)[1]

1 Walker, J, Hertel, K, Parker, P, Edwards, J (2010) Lupin Growth and Development, Industry and Investment NSW, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

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But the stages are recognised as separate in plant development, as outlined in Table 1.[2]

Table 1: Lupin growth stages and numeral system

STAGE	DECIMAL SCORE
GERMINATION AND SEEDLING EMERGENCE	**0**
Dry seed	0.0
Start of imbibition (water absorption)	0.1
Radicle (root) protruding through the testa (seed coat)	0.3
Radicle 5 mm long (germination)	0.5
Hypocotyl protruding through the seed coat	0.7
Part of the seeding protruding through the soil	0.9
LEAF EMERGENCE	**1**
First pair of leaves protruding beyond upright cotyledons	1.0
1 leaf emerged from bud	1.1
2 leaves emerged from bud	1.2
3 leaves emerged from bud	1.3
4 leaves emerged from bud	1.4
5 leaves emerged from bud	1.5
7 leaves emerged from bud	1.7
10 leaves emerged from bud	1.10
STEM ELONGATION	**2**
Little separation between bases of leaves	2.1
Bases of some basal leaves clearly separated	2.3
Bases of several leaves clearly separated from each other	2.5
Flower spike (inflorescence) bud clearly visible	2.7
Flower spike bud clearly separated from the base of the highest leaf	2.9
FLOWERING	**3**
Bracts completely hiding corolla	3.0
Pointed bud stage	3.1
Hooded bud stage	3.2
Diverging standard petal stage (anthesis)	3.3
Open flower stage	3.4
Coloured corolla stage	3.5
Senescent corolla stage	3.7
Floret abscised	3.8
Pod set	3.9
POD RIPENING	**4**
Young green pod. No septa between seeds, seeds abutting	4.0
Seeds separated	4.1
Green pod, septa between seeds, slight bulging of walls, seeds filling 50% of the space between the septa	4.2

2 Walker, J, Hertel, K, Parker, P, Edwards, J (2010) Lupin Growth and Development, Industry and Investment NSW, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

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STAGE	DECIMAL SCORE
Seeds filling 75% of the space between the septa	4.3
Green pod, clear seed bulges in pod walls, seeds filling all space between septa	4.4
Green pod, septa split	4.5
Pod turning khaki-coloured	4.7
Pod pale reddish-brown and wrinkled	4.9
SEED RIPENING	**5**
Seed small, dark green with watery contents	5.0
Seed medium, dark green with watery contents	5.1
Seed large, dark green with watery contents	5.2
Seed large and soft, light green coat, no watery contents, green cotyledons	5.4
Seed light green to pale greyish-blue coat, green cotyledons	5.5
Green to yellow cotyledons	5.6
Pale fawn coat, yellow to golden orange cotyledons (physiological maturity)	5.7
Seed hard but dentable, mottling of pale fawn coat	5.8
Seeds hard and harvest ripe	5.9

(SOURCE: DAFWA)[3]

The plant is formed by leaves, flower spikes, branches, stem, roots, pods and seeds.

Historically, lupin categories have fitted into early, mid and late flowering varieties.

But early flowering varieties now make up the bulk of plantings in Western Australia and have no vernalisation (cold period) requirement before flowering.

If sown before mid-April, these varieties can start flowering in the cold and frosty conditions experienced during the winter growing period across southern Australia. Mid and late flowering varieties will often flower after typical cold and frosty periods. In some warmer, more northern, environments, late types may flower during periods of heat stress, which can affect yield.

Older narrow leafed lupin varieties, such as Wonga, will branch and flower as long as the season permits. These produce most grain yield in the primary and first lateral pod set stages.

Newer, restricted branching types, such as PBA Leeman⁄, PBA Jurien⁄, PBA Barlock⁄, Mandelup⁄ and Gunyidi⁄, are limited in branching habits.

These lines can typically compensate for poor early pod set, as a lower proportion of grain yield potential comes from the primary and first lateral flowers.

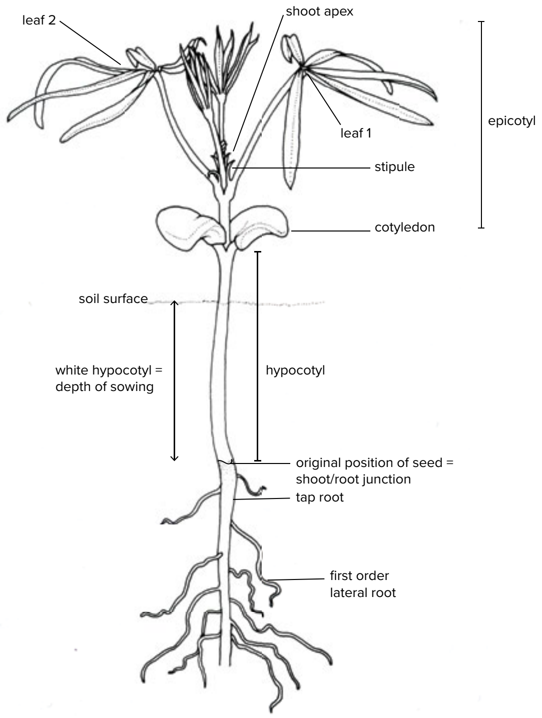
Australian lupin breeding advances have led to the development of varieties with less branching and more pods on the primary stem.

This has been in response to key productivity limitations of excessive and indeterminate vegetative growth and branching habits of traditional varieties, especially in narrow leafed lupin.

3 Walker, J, Hertel, K, Parker, P, Edwards, J (2010) Lupin Growth and Development, Industry and Investment NSW, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

3.2 Germination and seedling emergence

Figure 2: *Diagram of narrow leafed lupin seedling to indicate the positions of various parts*



(SOURCE: Dracup, M. Kirby, E.J.M (1996) University of Western Australia, Lupin: Development Guide, trove.nla.gov.au/work/21902398)

Germination includes the three phases of water absorption, activation and visible germination and can take from five to 15 days.

The length of the phase depends on soil temperature, moisture and sowing depth, but is typically not determined by variety.

This growth stage starts when seed water content reaches about 60 percent of the seed weight.

The seed has the ability to grow in very dry soils and will not stop growing during moisture stress.

The swollen seed produces hormones and this engages enzymes and metabolism activity needed for starch to be broken into sugars for growth.

It is after this occurs that the radicle (growing plant embryo) ruptures the seedcoat (testa) of the seed and forms the anchor in the soil.

The roots form as a taproot system and then lateral roots grow out to form the secondary root system.

The root system size and pattern change between species and the nodules containing the important rhizobia bacteria to fix nitrogen (N) in the soil form on this root system.

The hypocotyl, which is the long and white stem, simultaneously grows towards the surface.

3.3 Leaf emergence

Figure 3: *Lupin at early stages of development.*

(SOURCES: GRDC)

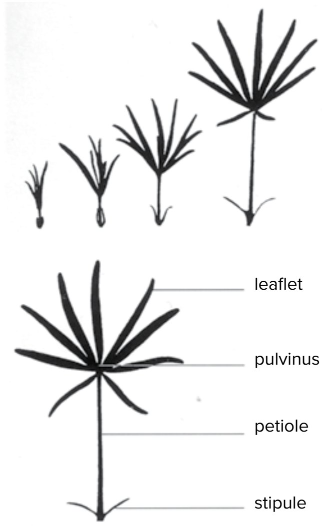
This is known as the epical seedling stage and is where cotyledons form and expand above the ground. The first leaf will grow from the centre of the cotyledons, while at the same time, root formation continues.

The leaves are formed as a palmate structure, with leaflets coming from a central point.

Narrow leafed lupin has narrow, pointed leaves, which increase in number towards the top of the plant.

As shown in Figure 4, initially, there are five leaflets per leaf and – towards the top of the plant – there can typically be between nine and 12.

Figure 4: *Stages of lupin leaf emergence.*



(SOURCE: Dracup, M. Kirby, E.J.M (1996) University of Western Australia, Lupin: Development Guide, trove.nla.gov.au/work/21902398)

The plant is heliotropic, turning out in the day for sunlight interception and moving back to face the rising sun. This process occurs until flowering begins.

A crop is said to be established when 50 percent of seeds have germinated, emerged and are developing with strong seedling vigour.

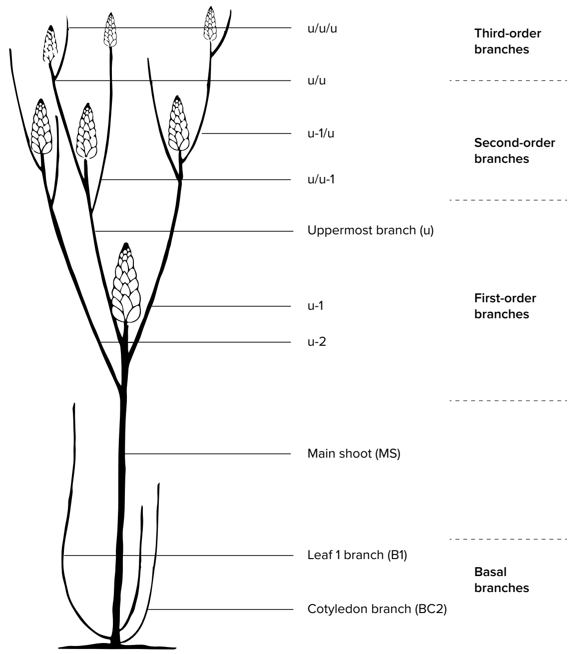
Germination, emergence and establishment of the seed can be affected by several factors, including moisture, temperature, soil crusting and seed quality.

3.4 Stem elongation and branching

Figure 5: *The lupin plant has a branching habit and each branch has its own flower spike.*

(SOURCE: GRDC)

Figure 6: *Branching in lupin plants occurs in stages illustrated in this diagram*



(SOURCE: Dracup, M. Kirby, E.J.M (1996) University of Western Australia, Lupin: Development Guide, trove.nla.gov.au/work/21902398)

This phase occurs during the vegetative and reproductive phases of growth.

If the plant has access to adequate moisture, nutrients and sunlight, the branches and stem grow new lateral branches with flower spikes through to the reproductive phase.

The stem develops first and then each branch has its own flower spike, on which pods tend to mature at the same time.

Stem elongation is affected by accumulated temperature. This means that in the vegetative phases in winter, stem growth can be slow.

Stem growth occurs as the internodes of the stem develop. This development can be at a rate of 0.1–0.2 millimetres per growing degree day (GDD), which is a measure of heat accumulation used to predict plant and pest development rates.

The main stem reaches its maximum length at about 1050 GDD.

Each variety will vary, with early flowering varieties having fewer nodes than later flowering varieties.

Nodules containing the N fixing bacteria (*Bradyrhizobium lupini*) are mainly formed on the top 5–10 cm of the taproot and first appear three to four weeks after germination.

3.5 Flowering

Figure 7: *Crop of flowering narrow leaf lupin with white flower heads standing above a lush green crop.*

(SOURCE: Cox Inall Communications)

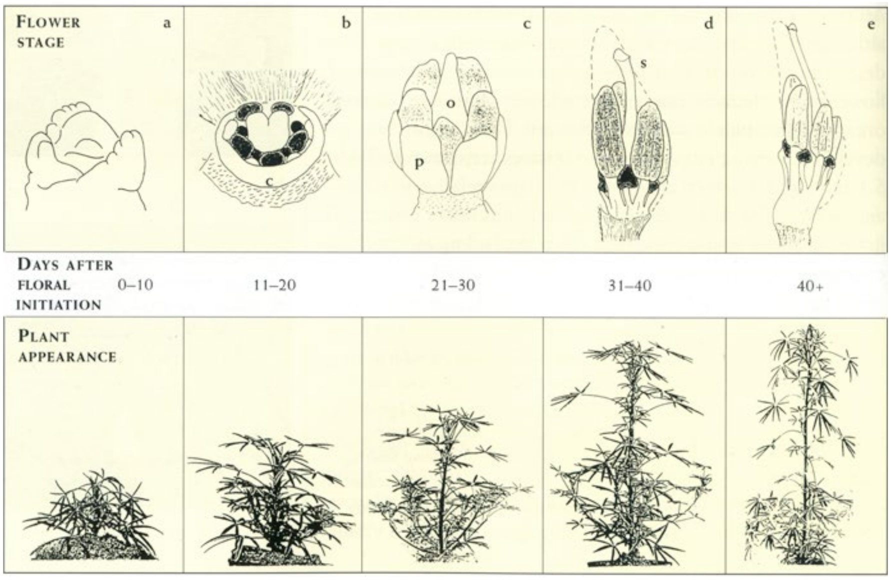


Figure 8: *Flower development of lupin plants.*

(SOURCE: Dracup, M. Kirby, E.J.M (1996) University of Western Australia, Lupin: Development Guide, trove.nla.gov.au/work/21902398)

Typically, flowers form on the upper branches and these produce most of the lupin grain yield.

The flowering forms part of the reproductive development stage of the plant, which starts after the main stem stops forming leaves. Flowers begin to grow over several days to form a flower spike (raceme).

The flower spike forms at the end of each branch and consists of several individual flowers.

The flowers have five petals and will flower for about 10–14 days. The whole plant tends to have flowers for a period of four to eight weeks.

Flowering occurs along the whole length of the flower spike, from the base to the end of the stem.

The pollination and fertilisation stages of the flower must occur for pod ripening to start.

Narrow leafed lupin is self-pollinating and little cross-pollination can occur via insects. Varieties remain pure through this mechanism and insects do not increase pod development or yield.

The albus lupin has a similar pollination process, but cross-pollination can occur more readily.

Branch growth is very sensitive to moisture and temperature stress, so earlier sowing and flowering typically enables the production of more branches.

Varieties such as PBA Leeman⍉, PBA Jurien⍉, PBA Barlock⍉ and Mandelup⍉ carry a high proportion of yield on the main stem relative to other varieties, which is an additional advantage.

These varieties can produce high yields without relying heavily on late maturing lateral branches, which also reduces the need for very early sowing.

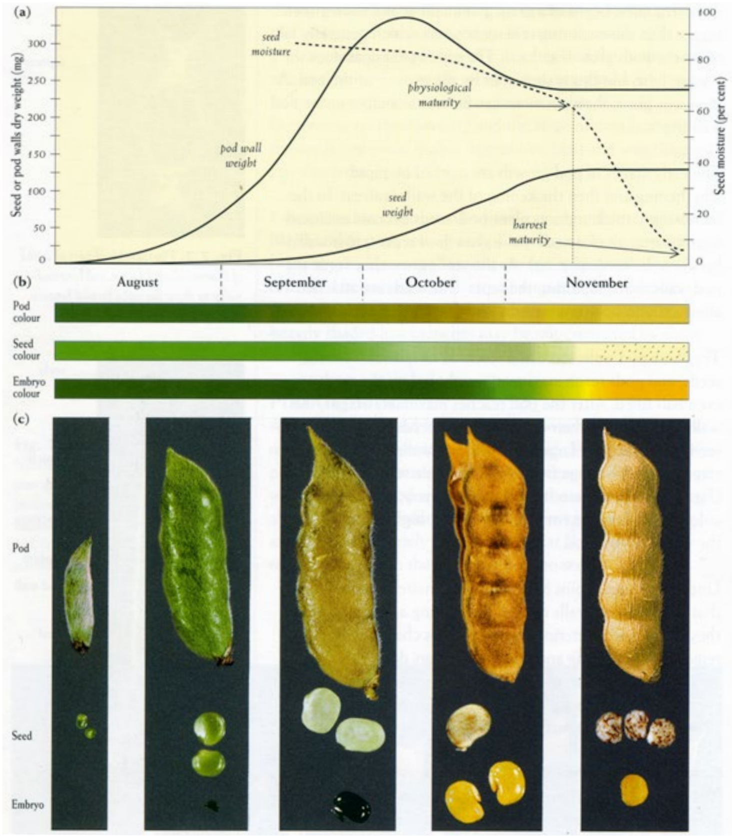
Older varieties, such as Wonga, rely more on the lateral branches for yield. This variety performs better at high and medium rainfall locations where the season length is long and early sowing is not as critical to ensure that seed in lateral pods will fill.

3.6 Pod ripening

Figure 9: *Lupin pod walls harden close to the stem and keep the pod attached to the flower spike.*

(SOURCE: GRDC)

Figure 10: *Pod and seed development, note the dates are typical for conditions in WA.*



(SOURCE: Dracup, M. Kirby, E.J.M (1996) University of Western Australia, Lupin: Development Guide, trove.nla.gov.au/work/21902398)

Pod formation occurs as a result of a fertilised flower ovary. Not all fertilised flowers will set pods and these can be identified by a stalk changing from green to yellow before being shed.

Newer lupin varieties are bred to have higher levels of pods than older varieties, but it is common for a high number of flowers to be shed as a result of environmental factors, such as moisture stress and high temperatures.

If a fertilised flower ovary is to create a pod, the pod wall will harden close to the stem and keep it attached to the flower spike.

A pod that reaches 8–10 millimetres in length is considered to be set and, typically, is unlikely to fail. Pod walls continue to thicken before seeds develop and then provide nutrients for developing seeds.

During the early stages of pod development there is strong competition with vegetative growth elsewhere in the plant and this influences successful pod set.

Colour changes of the pod (from green, through to khaki and to light brown) and the developing cotyledons in the seed (from green to yellow) are useful indicators of the physiological stage of maturation of the lupin plant.

Breeding advances in lupin have addressed previous problems with pod shattering during this phase of plant growth and harvest. PBA Leeman, PBA Jurien, PBA Barlock and PBA Gunyidi are some of the varieties benefitting from improvements in this trait, having resistance to pod shatter.

3.7 Seed ripening

Seeds expand as they develop, taking on protein, carbohydrates and nutrients when the pods have reached full length and thickness.

Most pods develop five or six seeds over a period of 38 to 72 days.

Seed maturity is reached when the seeds complete collection of nutrients from the pod, there is no functioning connection to the plant and the maximum dry weight is achieved.

Leaves on the main stem and lateral branches die off. From here, the seed, which can have a 62 percent moisture content reading at this stage, will continue to dry out to 13–14 percent moisture.

Total plant maturity is reached when more than 90 percent of the pods on the highest branches have reached maturity.

3.8 Lupin breeding advances

Australia is recognised as a world leader in lupin production due to a coordinated breeding and agronomic research effort, linked to an innovative farming community.

Weed management, herbicide tolerance, anthracnose resistance and yield reliability are the biggest agronomic issues being addressed by national lupin breeders to continue improving the productivity of this crop.

The Department of Primary Industries and Regional Development (DPIRD) – formerly The Department of Agriculture and Food Western Australia (DAFWA) – was the breeding centre for lupin crop development for 45 years and consistently released varieties for higher production and crop legume rotation benefits.

Initially, breeding efforts focused on early flowering and resistance to grey leaf spot, which threatened the industry in the 1970s. In more recent years, breeders have been working on improving adaptation, yield potential and resistance to other diseases.[4]

This led to the development and release of varieties with resistance to phomopsis, which causes lupinosis in grazing animals, in 1988 and anthracnose in 1996.

DPIRD then increased its emphasis on breeding for better herbicide tolerance and grain quality.

At the same time, there was development of narrow leafed varieties with less (or restricted) branching to reduce excessive plant growth and boost pod set and pod seed-fill.

Restricting branching curbs the competing demands of vegetative and reproductive growth in the plant, which often occurs when growing conditions are deteriorating in southern Australia.

Researchers in the late 1990s started selecting for restricted branching in narrow leafed lupin and this led to germplasm being included in national breeding programs for the development of current varieties with these traits.[5]

The Grains Research and Development Corporation (GRDC) and DPIRD announced in 2016 that Australian Grain Technologies (AGT) would take forward Australia's lupin breeding program.

AGT advises it will be examining how to best increase the value of lupin in Australian farming systems through improved yield, disease resistance, broader adaptation, herbicide tolerance and seed quality.[6]

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4 White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins

5 Dracup, M, Thompson, B (2000) Narrow Leafed Lupins with Restricted Branching, DAFWA, CLIMA, http://aob.oxfordjournals.org/content/85/1/29.full.pdf+html

6 Watt, S (2016) AGT Brings lupins into its fold, GRDC Ground Cover magazine, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-122-May-Jun-2016/AGT-brings-lupins-into-its-fold