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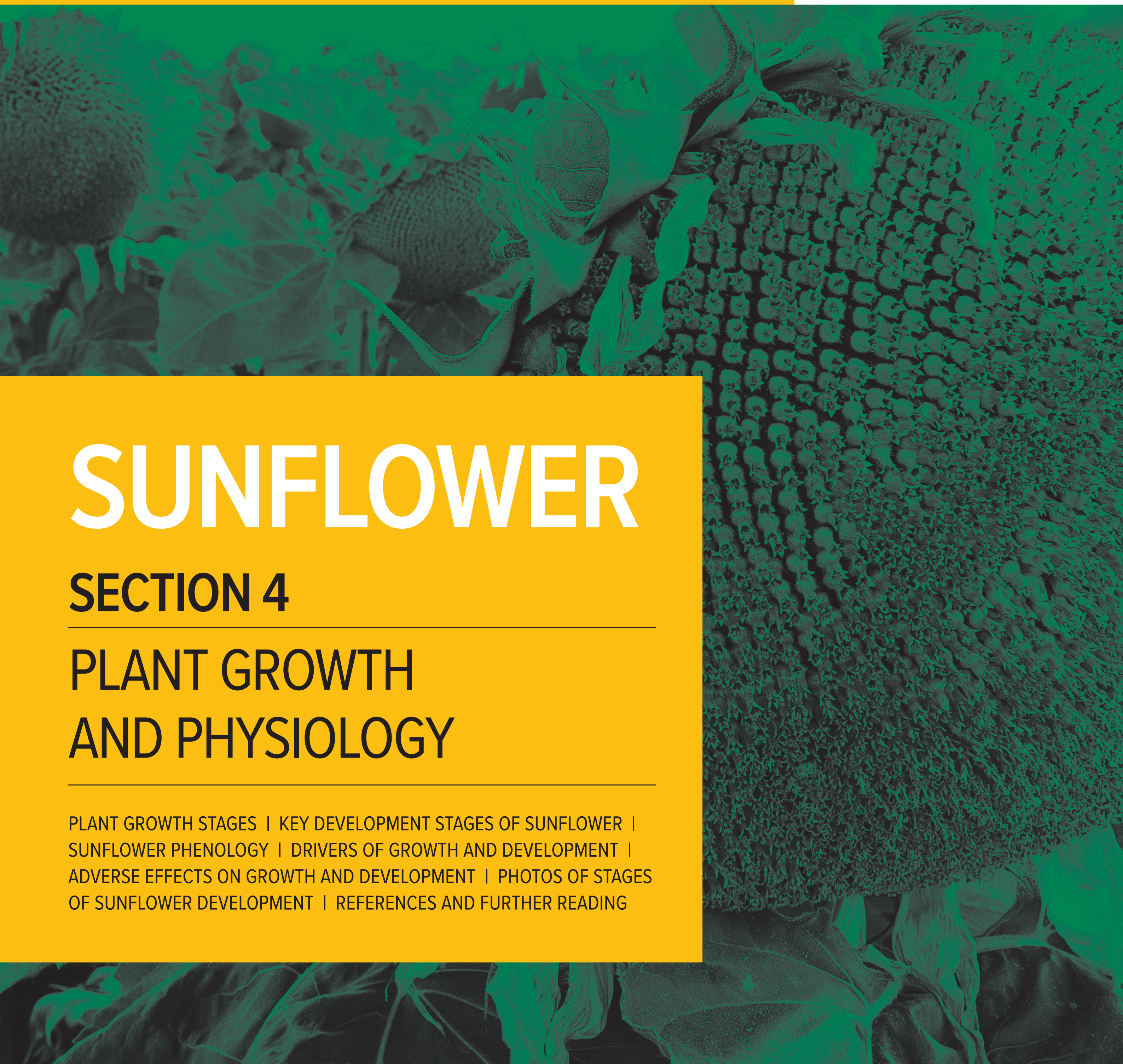

SUNFLOWER

SECTION 4

PLANT GROWTH AND PHYSIOLOGY

PLANT GROWTH STAGES | KEY DEVELOPMENT STAGES OF SUNFLOWER | SUNFLOWER PHENOLOGY | DRIVERS OF GROWTH AND DEVELOPMENT | ADVERSE EFFECTS ON GROWTH AND DEVELOPMENT | PHOTOS OF STAGES OF SUNFLOWER DEVELOPMENT | REFERENCES AND FURTHER READING

Plant growth and physiology

4.1 Plant growth stages

The time taken for a sunflower plant to develop through the various growth stages is affected by planting time, temperature, photoperiod and soil moisture. Sowing location and hybrid maturity also affect the length of the growing season. Table 1 shows the sunflower growth and development definitions. [1]

Table 1: *Sunflower growth and development definitions.* [2]

Stage		Description
VE	Vegetative Emergence	Seedling has emerged and the first leaf beyond the cotyledons is less than 4 cm long.
V (number) (i.e.) V-1 V-2 V-3 etc.	Vegetative Stages	These are determined by counting the number of true leaves at least 4 cm in length beginning as V-1, V-2, V-3, V-4, etc. If senescence of the lower leaves has occurred, count leaf scars (excluding those where the cotyledons were attached) to determine the proper stage.
R-1	Reproductive Stages	The terminal bud forms a miniature floral head rather than a cluster of leaves. When viewed from directly above, the immature bracts form a many-pointed star-like appearance.
R-2		The immature bud elongates 0.5 to 2.0 cm above the nearest leaf attached to the stem. Disregard leaves attached directly to the back of the bud.
R-3		The immature bud elongates more than 2.0 cm above the nearest leaf.
R-4		The inflorescence begins to open. When viewed from directly above immature ray flowers are visible
R-5 (decimal) (i.e.) R-5.1 R-5.2.,R-5.3 Etc.		This stage is the beginning of flowering. The stage can be divided into sub stages dependent upon the percent of the head area (disk flowers) that has completed or is in flowering Eg. R-5.3 (30%), R-5.8 (80%) etc.
R-6		Flowering is complete and the ray flowers are wilting.
R-7		The back of the head has started to turn a pale yellow colour.
R-8		The back of the head is yellow but the bracts remain green.
R-9		The bracts become yellow and brown. This stage is regarded as physiological maturity.

1 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

2 AA Schneiter, JF Miller (1981) Description of sunflower growth stages. Crop Science 21, 901–903.

4.2 Key development stages of sunflower

The time taken for a sunflower plant to develop through the growth stages from planting to maturity is affected by planting time, temperature, day length, nutrition and moisture. Geographic location and hybrid maturity also have an effect on the length of the growing season. [3]

The following sections outline the various stages of sunflower development.

4.2.1 Germination and emergence

The time taken for germination and emergence of a sunflower seedling is variable, but usually takes between 5 and 10 days, however it may be up to 30 days in certain situations. The speed of germination is dependent on three factors; soil temperature, moisture and oxygen.

The preferred soil temperatures for planting sunflower are 10–12°C. However germination will occur as low as 4°C. Planting into cold soil temperatures means it takes longer for germination and establishment and, as a result, the risk of insect damage or disease is also higher. Planting into warmer soil temperatures results in faster emergence but soil moisture around the seed will decline faster. As long as the establishment has not been affected no yield loss should occur from plants germinating at soil temperatures as low as 7°C.

Sunflowers have epigeal emergence, meaning their cotyledons are pulled rather than pushed through the soil with the seed coat intact and only, once the above ground, does the seed coat then fall off to expose the cotyledons. [4]

4.2.2 Development of the root system

Initially the rate of development of the plant root is greater than the rate of development of the sunflower stem. As an example, when the plant has 8–10 leaves (~25 cm to 30 cm tall) the taproot is about 40 cm to 50 cm deep. The taproot reaches its maximum depth at flowering.

This taproot allows sunflowers to extract more water than wheat or maize and to extract moisture and nutrients from deep in the soil profile. While sunflowers have a primarily tap root system they also develop strong lateral roots in the surface soil area around the top 10–30 cm of the soil which may extend up to 60–150 cm beyond the taproot. (Warmington 1981).

The size of the root system is also an indicator of the crop with a positive relationship between root surface area, leaf surface area and photosynthetic productivity being well documented. [5]

4.2.3 Vegetative growth

Sunflowers can tolerate temperatures ranging from 8°C to 34°C during their growth phase but grow best between 25°C to 28°C, although there is very little difference in growth rates between 18 to 33°C.

Leaves initially develop in pairs (opposite) and then emerge as singular alternate leaves up the stem, until the final number of leaves is reached. The change in leaf arrangement is gradual and the point at which the distinction occurs is not always clear, resulting in a margin for error. The point at which the change occurs may vary from plant to plant, within a given hybrid grown under similar environmental conditions (Schneiter & Miller 1981). Final leaf number may vary from between 20 to 40 leaves in most hybrids.

3 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

4 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

5 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

Leaf formation and development is initially controlled by sunlight and is influenced by hybrid, day length and crop nutrition. Photosynthesis, which is the driver of plant growth, is the process of converting inorganic material into organic material to create sugars for the plant to grow. Plants take in carbon dioxide (CO_2) through their leaves, water through the roots and use chlorophyll (the green in leaves) and sunlight to produce oxygen and sugars. Chlorophyll traps the solar energy in the leaf and through a series of biochemical pathways, the end result is oxygen, released out through the stomates; and sugars, which are further converted to carbohydrate used as plant food for growth and development (Abbott, 2003).

Sunflowers accumulate significant dry matter through the mass of their leaves, with the greatest accumulation being between budding and flowering (Dusanic, 2008).

Ralph (1982) measured that each individual leaf reaches its peak photosynthesis between 10–14 days after emergence and then goes into a slow decline, so that after 40 days photosynthetic capacity has fallen to only 25% of the maximum potential.

In the vegetative stage of growth, most assimilates produced in the leaves are transported towards the root system, which develops intensively during this stage. However, once bud initiation occurs the plant is triggered to invert the main direction of assimilate transportation and direct it towards the top of the plant (Merrien, 1986).

A sunflower plant can have a very large leaf surface area, documented to reach between 2,000–6,000 cm^2 depending on the growing conditions, namely moisture and nutrition. A plant develops about 50% of its total leaf area by the start of head development and more than 75% by the start of flowering (Warmington, 1981). The retention of leaves is important as a reduction in the photosynthetic area means a reduction in the amount of photosynthate available to the growing seed. Lower photosynthate levels generally mean lower yields.

Younger leaves, which are higher up the plant, have better access to light and there is also an age relationship to photosynthetic capacity. As such, bottom leaves, which senesce earlier are thought to have less impact, when compared to the middle and top leaves.

The middle and top leaves make greater contributions to yield, along with the head. However there is still a direct relationship between total leaf area and yield.

The largest leaves, usually between the 4th and 10th pairs, are said to account for between 60–80% of the total leaf area and play the most important role in seed and oil development (Warmington, 1981). These middle leaves provide nutrients to support the top leaves and the flowering head.

Sunflower leaves are unique in their ability to respond to stress, in particular moisture stress. Plants will commonly wilt in the middle of the day as sunflower leaves do not have the ability to close their stomates to reduce evapo-transpiration losses at night. Many plant species are able to regulate stomatal behaviour at night particularly in response to limited soil nutrient conditions. However is appears sunflower is not able to do this, which is a disadvantage in terms of higher crop water use, but an advantage in relation to nutrient uptake into the plant and continued plant growth (Howard & Donovan, 2006)

A crop simulation model developed in France has suggested that stomatal regulation had the greatest influence on grain yield in sunflower. Late maturation and a high leaf area index also increased grain yield but not to the same extent. In this study, the ability to close the stomates early (as opposed to late) could result in increasing potential yield in drought prone environments (Casadebaig and Debaeke, 2008). In the more reliable production zones, longer maturing, large leaf area with late stomatal closure hybrids may result in the best yield.

Few studies and information is available on the exact contribution of individual leaves to yield. Most studies have instead focused on the impact of defoliation at various growth stages. Johnson (1972) showed that the middle leaves had a greater role in seed yield than leaves in other parts of the plant, mostly thought to be as a result of the greater photosynthetic capacity of these leaves.While leaf area is a major part of the vegetative stage in sunflower growth, the stem of a sunflower plant also plays an important role. The stem is normally straight and comprised of a thick, pith filled centre with rough hairs on the outside.

Defoliation

Knowing which leaves contribute to maximum yield and oil content helps inform decisions around disease, pest and general crop management. Defoliation has been shown to impact:

- yield
- oil content
- number of seeds filled
- hull:kernel ratio

The key questions for industry are: which leaves should be protected; and what is their contribution to final yield and oil content. [6]

NSW DPI researchers conducted three trials over the 2014–15 and 2015–16 seasons. Each treatment involved physically cutting leaves off the sunflower plants, leaving the leaf petiole intact; and measurement of plant structures, final grain yield and oil content. Researchers found that:

- yield was reduced by 76–93% if all leaves were removed
- removing the top one third of leaves had the least impact on yield
- greatest impact on yield was from total leaf removal at R2, R5 and R6
- a reduction in oil content of 5–6% occurred when all leaves were removed at R5 or R6. [7]

Leaf removal at various stages during sunflower growth have been conducted by several overseas researchers and typically conclude that the most sensitive stage is during flowering and seed fill, however, others suggested the stages of R1 through to R6 are most important.

Muro et al. (2001) suggested R3 to be the most critical of all of the stages, as shown in Figure 1. In this series of experiments portions of the total leaf area were removed by cutting with a blade, hence part of each of the leaves of the plant were removed to achieve either 33, 66 or 100% leaf defoliation. Interestingly there was little impact of removing 33% of the total leaf area. However removing 66 and 100% had major impacts on all three measured components.

Muro also utilised his own work and the work of several colleagues to produce a series of graphics showing the effect of stage of growth and % leaf loss (Figure 2). This figure shows clearly the major impact on yield which can be caused by defoliation of greater than 33% leaf area in growth stages R2 through to R7. As expected by growth stage R9 (physiological maturity) there is minimal impact on yield by even total leaf loss. [8]

6 L Serafin, M Hellyar, B Brennan, P Perfrement (2016) Sunflower: what is the cost of losing your leaves? Australian Summer Grains Conference 2016, http://yrd.com.au/ASG16 Program_Presentations V5.pdf

7 L Serafin, M Hellyar, B Brennan, P Perfrement (2016) Sunflower: what is the cost of losing your leaves? Australian Summer Grains Conference 2016, http://yrd.com.au/ASG16 Program_Presentations V5.pdf

8 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

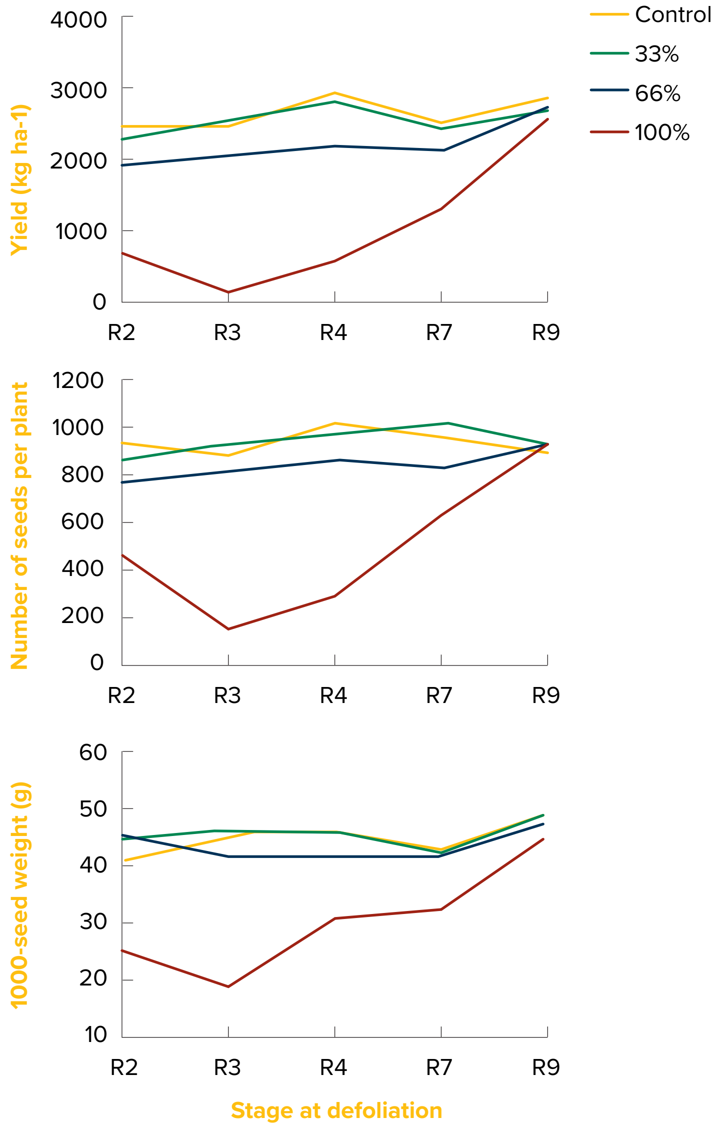

Figure 1: *Effect of defoliation on sunflower yield, number of seeds per plant and 1000 seed weight.*

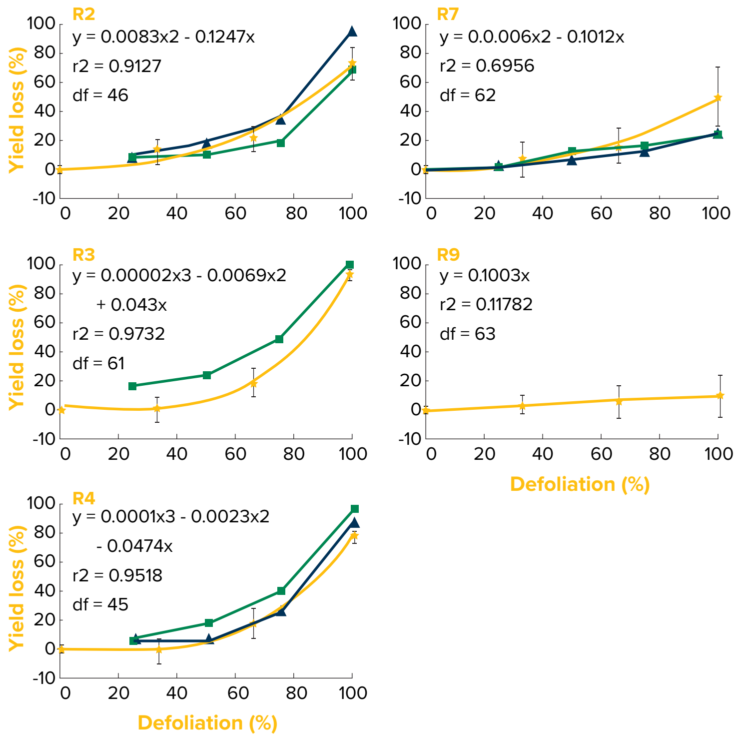

Figure 2: *Regression functions between yield loss (%) and defoliation level for each phenological stage. Measured mean yield losses (star) with standard deviations, and results published by Schneiter et al. (1987, square) and De Beer (1983, triangle) are shown.*

The sunflower stem may grow as tall as 220 cm but, when under drought stress, stems may be as short as 50–60 cm. There should only be one stem on a sunflower plant. Sunflowers have been selected to have only one stem as there is a negative correlation between the number of stems and yield.

Both the stem and the leaves combine to have an impact on final yield, taller plants with higher total leaf areas being positively correlated with seed yield. In contrast, the total number of leaves per plant has a negative impact on seed yield. (Hladni et al. 2004). Research by Habib et al. (2006) demonstrated that stem diameter is positively genetically correlated with 100 seed weight, seeds per plant and seed yield. However stem diameter:stem length ratio were not correlated. Further trials in Pakistan found that sunflowers with increased stem diameter, produced plants that were less prone to lodging due to stouter, shorter plants and produced larger heads with larger seeds, culminating in higher grain yields (Khokhar et al. 2006). [9]

9 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

4.2.4 Bud initiation

Once bud initiation starts, no more leaves will develop, but the leaves will continue to unfold.

The plant will begin developing the bud, during this time each of the disc florets in the bud will be fully differentiated. This process will be completed by around 2 weeks prior to the start of flowering. During this time of bud formation any stress can cause floret abortion, which is often visible in large numbers in the centre of the head as missing seeds.

The total potential number of seeds is determined by the number of florets which are initiated between 20 to 40 days after sowing (Steer and Hocking, 1984). The final number of florets is dependent on the number of florets in each ring which forms in the head and the number of rings.

The bud will continue to grow in diameter until the ray petals become evident. At this stage the bud is usually at least 10 cm in diameter. The ray petals, which are the bright yellow petals which surround the head, will then begin to unfold prior to the commencement of flowering.

Sunflowers turn to follow the sun during the day, referred to as heliotropism, which increases photosynthesis by 9%. This will cease at flowering, when, at this point most of the heads will remain facing north-east. The movement is caused by a bending of the stem and a lifting and lowering of the leaves on the opposite sides of the plant. [10]

4.2.5 Flowering

Sunflowers have a compound head which consists of two types of flowers; the ray flowers and the disc flowers. Once these are evident, flowering has commenced (Figure 3).

The yellow ray petals have a minimal role but are highly attractive to bees and other insects. Ray flowers usually occur in two rows and are sterile. Usually there are between 30 to 70 ray flowers per head, also known as petals.

Figure 3: *Ray petals opening; once the sunflower ray petals are fully open, flowering will commence.*

Photo: Drew Penberthy

The disc flowers which form the centre of the head are the start of developing seeds. The disc flowers progressively open in concentric rings, beginning from the outside

10 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

and working towards the centre. Individual disc flowers complete flowering in 3 days. Commencing early in the morning, typically from 6–8 am the disc flowers open and the anthers are exerted and the pollen is released. Between 1 and 4 rings of flowers open each day, usually over a period of 5 to 10 days. There are between 800 and 3,000 disc flowers per head and between 30 to 50 concentric rows of disc flowers. Each disc flower is capable of producing a seed.

If the disc floret is fertilised, then a seed which will comprise the hull and the kernel, starts to develop If the floret is not fertilised, then a hull may begin to form but the kernel will be absent, resulting in empty hulls at harvest.

Sunflower pollen is fairly large, yellow and oval in shape, with a prickly appearance which allows it to be transported by insects. Sunflower pollen is generally not moved about by wind.

Currently most hybrids are generally largely self-pollinating, however numerous bees usually forage in the crop during flowering. In commercial hybrids all plants produce pollen.

In a hybrid seed production field, two lines are used. A female or A line which does not produce pollen and a male or R (restorer) line which does produce pollen. In this process the synchronisation of flowering between the two lines, favourable environmental conditions and importantly insects to transfer the pollen are all critically important to ensure seed fertilisation and production.

The introduction of hybrid sunflowers was made possible by the discovery in 1968 of cytoplasmic male sterility by a french scientist, Le Clerq. In 1972 using this technology Pacific Seeds released the first hybrid sunflower in Australia, Hysun 30. Hybrids brought significant advances in yield, oil content, disease resistance and plant uniformity to the industry.

At the completion of flowering, the ray petals wilt and fall off, which is referred to as petal drop. The disc flowers will fall off just prior to physiological maturity.

Head type becomes more important at this stage as those which remain upright after the end of flowering are more prone to sunburn. Many commercial varieties have semi-pendulous heads to avoid this.

There are several factors which can impact on pollination and subsequent fertilisation. These can include rain which may wash the pollen off the head, cool weather to the point of near freezing, particularly when the plants are not conditioned to these colder temperatures, drought stress and high temperatures.

Typically drought or moistures stress is most commonly seen as the centre seeds in the head not filling. Whereas the effects of wet or cold weather will often appear as empty hulls in various rings of the head depending on the location of the flowering disc flowers in relation to the impacting event.

Sunflowers will adequately compensate for small reductions in seed set but increasing seed size of neighbouring seeds.

The combination of high temperatures and moisture stress can drastically reduce yields and oil contents during flowering and seed fill. Conversely, frost at flowering will also damage the flowers and reduce seed set. Heads will commonly turn a purple black colour and die if severely affected.

It is important to note that hulls may continue to form and grow to full size even when fertilisation has not occurred, but upon closer inspection these will be found to be empty, i.e. no kernel will be present.

Anecdotal observations have suggested that it is normal for up to 20% of seeds to not be fertilised under normal conditions in a sunflower head, but these are typically not noticed as surrounding seeds fill to compensate for this area in the head. [11]

11 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

4.2.6 Seed filling

The seed is borne in the capitulum or head. Each disc flower has the potential to produce one seed, if fertilised. Each sunflower seed is comprised of a hull (pericarp), true seed coat and a kernel (mainly embryo). Usually the hull averages between 20–26% of the total seed mass.

Figure 4 outlines the development of the sunflower seed (or achene) as determined in work conducted by Mantese et al. (2006). The growth patterns of achene components (pericarp, embryo, oil) were broadly similar across three cultivars of sunflower, with the pericarp growing first and rapid increases of embryo and oil mass taking place later. The pericarp stops growing before the embryo and oil components reached their maximum values. As such, seed development can be split into two stages:

1. Hull (pericarp) development – which typically stops developing 14 days after anthesis.
2. Kernel development – which starts around 8 days after anthesis and is approximately 1/3 of its final weight when the hull development ceases.

The formation of oil in the embryo begins several days after the start of the embryo development. As a result very little oil is deposited during the first third of the seed filling period.

The final oil content also has an interesting relationship with the ability to dehull seed. Seeds with higher oil content are usually more difficult to dehull. Hectolitre weight is also often an indication of ease of dehulling. Seeds with a hectolitre weight above 40 kg/hl are more difficult to dehull.

Head diameter is also often a useful indicator of the likely grain yield. White (1980) described that an ideal head diameter was considered to be in the range of 16–22 cm, as smaller head sizes are usually indicative of a lower seed number per head or poor centre seed fill which cannot be fully compensated by higher plant populations. In contrast, large heads were usually found on plants with excessive leaf areas, fleshy backs of the head and often associated with slow drydown, large seeds with thick hulls and a reduced concentration of seeds per unit area of the head.

Hladni et al. (2008) found that seed yield was most positively correlated with thousand seed weight, total seed number, head diameter and leaf area. The number of seeds present in a head is also usually positively correlated with oil content (White 1980). However, White also demonstrated that oil content is usually negatively correlated with seed yield, 1000 grain weight and head diameter. [12]

12 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

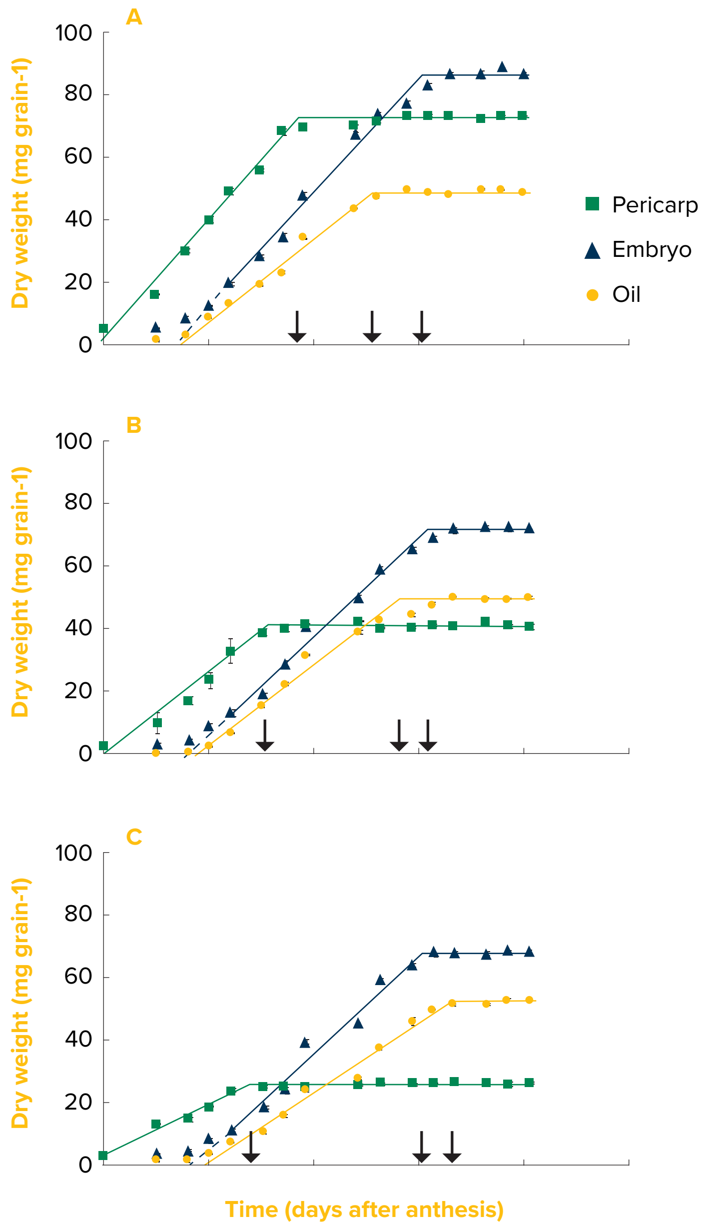

Figure 4: *Dynamics of pericarp, embryo and oil weights per achene for three sunflower cultivars 'Dakar' (A), '11051' (B) and 'Prosol 35' (C). Each point represents the mean of three replicates, vertical bars are ± 1 s.e. The continuous lines show the adjusted bi- linear functions (r2 range 0·89–0·99) and the dashed lines show the extrapolations used to estimate the start of the effective filling. The arrows indicate the end of the oil growth periods for the three achene components. (Mantese, Medan and Hall, 2006).*

4.2.7 Physiological maturity

Physiological maturity signifies when the maximum seed weight has been reached. The crop can then be harvested at any time. However, sufficient dry down needs to occur to reach a moisture content suitable for storage or delivery.

Heads reach physiological maturity approximately 30 days after anthesis, hence seeds on the inner part of the head have a shorter length of time for seed filling and also a lower rate of filling than the outside seeds. As a result, seed size decreases progressively from the outside of the head moving in towards the centre.

In early developmental stages, the receptacle and capitulum are a strong green colour, which is strongly related to the high concentration of chlorophyll in their tissues. As the plant matures, chlorophyll degradation, and the predominance of xanthophylls and other carotenoid pigments are the reason for the colour changing from green to yellow and eventually to brown (Hernandez, 2008). Sunflowers reach physiological maturity when the bracts (termed phyllaries) around the outside of the sunflower head turn brown and brittle and the receptacle base becomes a buttery yellow (Hernandez et al. 2008). This is usually 4 to 6 weeks after flowering.

At this point the sunflower seeds have completed filling and their moisture content is approximately 38% (Rondanini, 2007). It is at this time (30 days after flowering) that maximum dry matter content is usually observed (Dusanic, 2008). From physiological maturity to harvest, the sunflower plant and seeds lose moisture (dry down). Physiological maturity is the appropriate time to apply a desiccant if using one to aid in crop dry down. [13]

4.2.8 Crop desiccation

Crop desiccation is not a common practice in sunflowers. However, it has been used in some seasons to speed up or even out maturity of a crop. Desiccation of a sunflower crop should only commence once the crop has reached physiological maturity. A sunflower plant has reached physiological maturity when the bracts surrounding the head have turned brown. At this point the seed should be mature and the moisture content around 35%. Research in Serbia has shown that the accumulation of protein in sunflower hybrid varies between genotypes, however maximum protein content is reached approximately 21 days after flowering when moisture content is about 45% (Canak et al. 2011). Desiccation after this stage would not affect protein levels in the grain which are important for germination and early seedling growth. [14]

Refer to the weed control section for additional information on crop desiccation.

4.3 Sunflower phenology

Days to critical growth stages, such as flowering, for several commercial sunflower hybrids have been recorded in northern NSW. This information assists in matching hybrid maturity to sowing time.

The exact number of days required to reach specific growth stages can vary depending on temperature, day length, moisture and hybrid, so Tables 2 and 3 should only be used as a guide. The accumulation of growing degree days (GDD), also known as day degrees (DD), can also be used to predict phenological changes in crops and help plan in crop operations. See Table 4 for more information. Day degrees are calculated by taking the mean daily temperature and subtracting the base temperature of 6.7°C for sunflower. Each growing season day is added together cumulatively to give DD at particular growth stages of the crop, as each plant growth stage has defined heat units it must reach to proceed to the next stage.

The critical time for heat stress is 12–15 days after flowering on a spring plant. It is recommended to try and choose hybrid maturity so that it can be matched to avoid these high risk periods. [15]

13 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

14 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

15 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

Table 2: *Development times for a sunflower hybrid at Gunnedah when planted in early October and late December.*

Crop stage	Time for each stage (days) when planting in: Early October	Late December
Planting to emergence	8	4
Emergence to head visible	45	37
Head visible to start of flowering	27	24
Flowering to physiological maturity (PM)	40	42
Stage length		
Planting to start of flowering	80	65
Planting to PM; – slow maturity hybrid – medium maturity hybrid	 120 110	 100 107
PM to harvest	20–30	30–40

Source: NSW DPI, Sunflower Agfact

Table 3: *Days to critical growth stages of various sunflower hybrids.*

Hybrid	Region	Days to 4 cm bud	Days to mid flower	Days to petal drop
Hyoleic 41	Moree	74	86	101
	Gunnedah – Early	78	n.d.	n.d.
Ausigold 61	Moree	71	84	109
	Gunnedah – Early	75	90	n.d.
	Gunnedah – Late	n.d.	74	82
Ausigold 62	Moree	71	83	95
	Gunnedah – Early	73	90	n.d.
	Gunnedah – Late	n.d.	70	78
Sunoleic 06	Moree	71	84	97
	Gunnedah – Early	75	92	n.d.
	Gunnedah – Late	n.d.	67	78
Sunbird 7	Moree	65	83	109
	Gunnedah – Early	72	n.d.	n.d.
Hysun 39	Moree	70	82	100
	Gunnedah – Early	76	90	n.d.
	Gunnedah – Late	n.d.	70	n.d.
Advantage	Moree	72	87	97
	Gunnedah– Early	76	n.d.	n.d.
	Gunnedah – Late	n.d.	69	n.d.
Ausigold 4	Moree	72	84	109
	Gunnedah– Early	74	90	n.d.
	Gunnedah – Late	n.d.	67	n.d.

Source: Belfield and Serafin, pers. comm.

Table 4: *Cumulative day degrees for sunflower.*

Growth Stage	Description	GDD °C
Emergence	Cotyledons completely unfolded	138–191
Leaf stages	2 leaves unfolded	249–313
	4 leaves unfolded	359–435
	6 leaves unfolded	470–558
Flowering	Flowering begins. At least one open disc floret on 50% or more plants	935–1077
	Flowering 50% complete	1081–1232
Seed fill	Seed fill begins. 10% of seeds have reached final size	1255–1417
Maturity	Seeds begin to mature. 10% of seed has changed colour	1547–1725
Maturity complete	90% seed has changed colour. Await completion of dry down for direct heading.	1780–1972

Source: Miller, Lanier and Brandt, 2001

4.4 Drivers of growth and development

4.4.1 Genetic

Genotype has a major impact on the yield and oil content of hybrids. It is the foremost factor in influencing fatty acid composition of sunflower oil (Knowles 1988). However, oil content is ultimately highly varied by environmental factors during seed filling, as is the composition of unsaturated fatty acids (linoleic/oleic acid) (Petcu et al. 2001). Over time, Australian sunflower breeders have worked towards releasing hybrids with higher oil contents through using conventional breeding. Certainly one of the major advances in yield were achieved when hybrid sunflowers became commercially available in the early 1970s as opposed to the traditional open pollinated types.

Radford (1977) commented that sunflowers with large achenes exhibit a slightly higher germination percentage and greater mean hypocotyl length than small achenes, which resulted in higher field emergence percentages when sown below 6 cm. However, the size of achenes had no effect on final yield. [16]

4.4.2 Environment

The environment can have a major impact on sunflower growth and development. Flowering time, for example can be increased by up to 15 days due to day length. Shading can also have an impact by reducing leaf area and crop height. More importantly shading from bud initiation onwards can reduce seed and oil production by as much as 60% (Warmington, 1981). Several of the major environmental factors influencing sunflower growth and development are discussed below.

Day length

Sunflower development is affected by day length with the plants moving through growth stages quicker when days are longer. Sunflower development can be affected by day length in the emergence to bud visible stages, but hybrids vary in their response. See the phenology section for information on hybrid variation in response to day length.

Sunflowers have the ability to orientate their leaves towards the sun so carbon dioxide fixation is fairly constant (0.5 mg per sq cm per hour) during daylight hours. Hence longer days result in greater photosynthesis.

16 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

Photoperiod can affect the length of time between the start of floral initiation to the bud visible stage as well as the start and finish of floral initiation. However, some hybrids show a reverse response to photoperiod, depending on whether they have been sown in spring or summer. (Hall 2004, p 29)

Temperature

Sunflower growth is driven largely by temperature. Temperature may vary the time taken to reach physiological maturity by as much as 25–30 days.

Spring sown crops are generally growing during milder temperatures, which prolong vegetative growth, favouring production of a larger plant and thus higher yield potential. Generally spring sown sunflowers are also taller as a result.

Higher temperatures during vegetative growth will cause plant development to proceed at a faster rate. The optimum temperatures for sunflower growth are between 25–28°C. While hot temperatures (>35°C) have adverse effects, as discussed in the heat stress section of this section.

High oleic sunflowers are recommended to be sown in the spring as warm temperatures during grain fill are needed to produce oleic acid. Studies in controlled temperatures have shown oleic acid percentages are decreased by low night temperatures.

Conversely polyunsaturated sunflowers need to fill seed during lower temperatures to achieve linoleic acid contents above 62%. Filling during high temperatures will reduce the linoleic acid content to below these receival standards. Hence, there is an inverse relationship between temperature and linoleic acid content.

Temperature influences the length of flowering, with the duration of flowering shorter under higher temperatures. However, the range is usually 5–10 days. Temperature during flowering is critical. Excessive temperatures during flowering and seed fill affect oil quality and quantity, as well as reducing seed yield.

Maximum seed dry weight is reached approximately 650 day degrees after pollination. At pollination the moisture content of the developing seed is about 78% which declines to around 38% at physiological maturity. Oil production starts soon after pollination (detectable 3 days after). However, there is a lag of around 150 day degrees before significant oil production occurs.

Linoleic acid levels increase at a regular rate during seed development, meaning there is not one critical phase during seed fill when linoleic acid contents can be affected, but the whole period is important. Oleic acid content declines throughthe period of seed filling. [17]

17 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

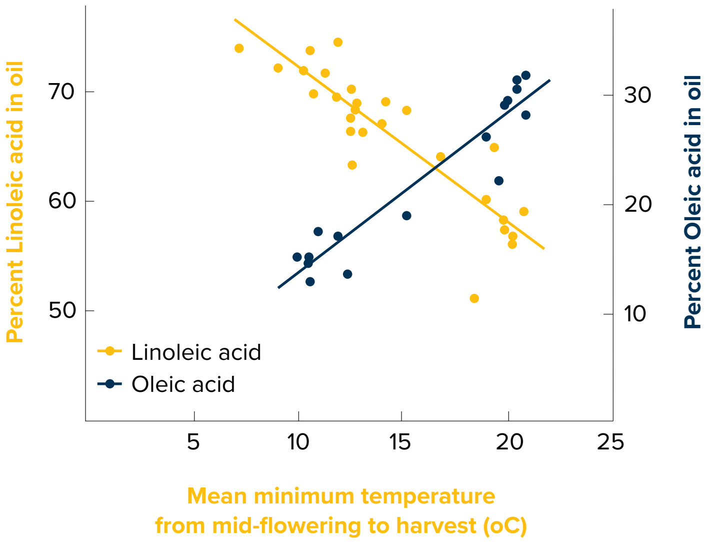

Figure 5: *Relationship between mean minimum temperature from mid flowering to harvest and the linoleic and oleic acid content of sunflower oil.*

Source: Harris, McWilliam, English and Mason, 1977.

As illustrated in Figure 5, oleic acid percentage is higher with higher night temperatures and is not related to daily minimum temperature. Night time temperatures have the greatest effect on oil quality.

Temperature can regulate the rate and duration of grain fill.

Moisture

Moisture stress can reduce yields from the late bud through to seed fill stage. Additional information on moisture and water use is contained in the water use section in the agronomy module.

Sunflowers have several mechanisms which help them respond to moisture stress. The major mechanism is that, in response to less water, the plants produce smaller leaves to conserve water. Leaves produced under water stress are often 25–35% smaller in size.

Transpiration is the process of water vapour loss from plant leaves with 90% of losses occurring from the stomata and 10% from plant cuticles. It is thought that only 1% of water taken up by plants is utilised for biochemical processe within the plant (Evans online). Each square centimetre of leaf transpires about 12 mg of water per hour, so a smaller leaf results in less water loss. In the heat of the day, 85 mg of water can be lost for the same carbon dioxide gain.

Moisture stress is important at two main growth stages, head formation to the start of flowering (which affects seed yield) and post flowering when oil content will be reduced. A study in Romania found that in 5 hybrids evaluated, under moisture stress conditions oleic acid content decreased by up to 14% and linoleic acid contents increased equivalently. However the saturated fatty acids (palmitic and stearic acid) which are a minor component of sunflower oil, were not significantly altered by water stress (Petcu et al. 2001). This decrease in oleic acid levels could be detrimental to Australian monounsaturated hybrids if moisture stress reduced content below the threshold receival standard. [18]

18 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

4.4.3 Nutrition

Crop nutrition is a key driver of sunflower growth and development. Nitrogen is the principal nutrient required as it influences leaf number and size, which relates to yield. Nitrogen has the greatest influence from 4 leaf stage onwards. However several other nutrients have important roles in crop growth and development. Information on specific nutrients is contained in the crop nutrition section in the agronomy module. [19]

4.5 Adverse effects on growth and development

There are many factors which can have an adverse effect on sunflower growth and development. These factors can influence yield by reducing the number of seeds set, the weight of each seed, the ratio of kernel to hull, as well as influencing oil content and quality. Several of these factors are discussed below.

4.5.1 Frost

Sunflowers are reasonably tolerant of frost at certain stages. Newly emerged seedlings are frost tolerant (down to –5°C) until the 6 to 8 leaf stage but are frost sensitive from the 6 leaf stage until the seed ripening stage. Sunflower buds are susceptible to frost damage and also a significant drop in air temperature can be detrimental at this stage.

Frosting during the bud development stage can result in distortion of the bud, failure to set seed and even a complete lack of flower production. This may also be seen as blackening or purpling around the edges of the head. Frosts of 2°C prevent flowers opening and subsequently reduce the seed set. Frosts of –2 to 0°C during grain fill can significantly reduce yield. [20]

4.5.2 Hail

Hail may damage sunflowers in several ways, including plant death, physical injury to the stem, head and leaf defoliation. All of these may reduce yield.

The growth stage when hail damage occurs has a major impact on the effect on yield. Hail in the early vegetative stages can greatly reduce yield if the terminal bud is damaged, generally plants with damaged terminals will tiller and these tillers produce small heads. Defoliation from the stages of R1–R6 appear to be most sensitive, since much of the photosynthate produced at this time is directed to head development.

Plant death is a common occurrence when plants are small. If the plant population is reduced significantly, the remaining plants will compensate if the damage occurs early in the growth stages (e.g 2–8 leaf stage). However beyond this stage the plants cannot compensate enough and yields may be reduced.

Injured plants may also suffer terminal bud damage or stem breakage or bruising. If plants are injured but unable to contribute to yield, they will still use water and nutrients, an unfavourable situation. [21]

Table 5 gives indications of the likely yield reduction should hail damage occur in a sunflower crop.

19 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

20 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

21 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

Table 5: *Approximate percent yield reduction due to hail damage at various growth stages.*

Growth Stage	Percent leaf area destroyed					Percent stand reduction				
	60	70	80	90	100	40	50	60	70	80
VE – V3	3	4	7	10	15	11	12	14	18	32
V6-V8	5	6	10	16	22	11	12	14	18	33
V12- VN	7	12	18	26	35	12	13	15	21	35
R1	9	16	24	34	47	16	18	21	29	43
R3	32	44	59	78	99	24	29	34	41	53
R5	25	37	49	67	90	31	39	45	54	66
R6	24	35	46	63	80	35	44	52	62	73
R7	13	16	18	20	22	-	-	-	-	-
R8	7	8	9	10	11	-	-	-	-	-

Source: Table information formed by extracting data from Berglund, D.R. 1994. Sunflower Production, North Dakota State University, Fargo, North Dakota, USA.

4.5.3 Drought

Dryland sunflowers have reasonable drought tolerance, particularly if planted into a full profile of moisture. Extreme drought will reduce the plant height, leaf area and head diameters, resulting in reduced yields. Additional information on drought can be found under moisture stress in the water use section in the agronomy module. [22]

4.5.4 Heat stress

High temperatures during flowering and seed set will reduce yields and oil contents. Head and seed temperatures usually are 5 to 10°C higher than the air temperature. Yield is generally reduced due to a reduction in seed number and increase in small grains. In addition, sunscald can affect heads which are erect or semi erect as the angle of head inclination is directed at the sun, receiving high heat intensity under hot conditions. This causes brownish red seed hulls and undeveloped seeds.

The effect of temperature on fatty acid composition is most important during early stages of seed fill. Rondanini et al. (2005), found that high alternating day/night temperatures for 4 days or longer with a mean daily grain temperature greater than 35°C produced significant reductions in grain yield and quality. Yield was reduced due to lower seed weights resulting in an increase in the percentage of half full grains in all sections of the head (outside, inter, middle sections). Reductions were highest during early grain fill (10–12 days after anthesis) with reduced yield of 6%/°C above a mean grain temperature of 29°C. Later heat stress (18–24 days after anthesis) resulted in yield reductions of 4%/°C above 33°C, demonstrating that the timing of heat stress is critical to yield and quality responses.

This experiment also found that heat stress 10–18 days after anthesis resulted in lower final pericarp weight due to thinner cell walls in the schlerenchyma and less cell layers. High temperatures (especially 10–12 days after anthesis) reduce both the rate and duration of oil deposition in the developing seed (Rondanini et al. 2005). Constantly higher temperatures reduce oil content when occurring in the grain fill oil deposition period, when compared to alternating high/low temperatures (Rondanini & Mantese, 2004). Temperatures greater than 35°C also affect other grain properties including fatty acid composition and hull to kernel ratio. Additional information on the effect of temperature is contained in Section 2. [23]

22 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

23 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/

4.5.5 Waterlogging

Waterlogging can have an impact on plant growth and development. Waterlogging involved the rapid reduction in the amount of oxygen available in the soil. This has a direct impact water and nutrient uptake and also on physiological processes such as photosynthesis, respiration and leaf senescence.

The effects of waterlogging will vary depending on a number of factors including soil type, e.g. slow draining, length of inundation and crop growth stage. [24]

4.6 Photos of stages of sunflower development

VE

V2

24 Australian Oilseeds Federation (2012), Better Sunflowers Agronomy Training Package (Big Yellow Sunflower Pack), https://bettersunflowers.com.au/


V4


V6



R1


R3


R4


R5.5

R5.8

R6

R9

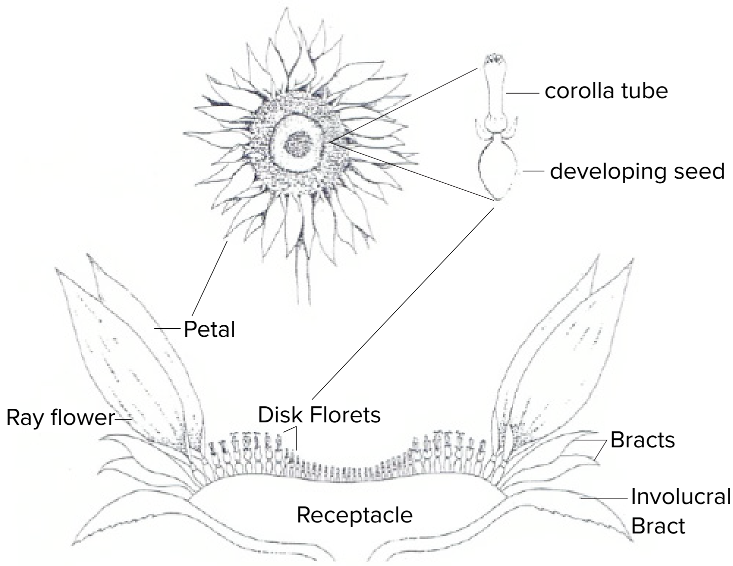

Figure 6: *Parts of the flower – sunflower.*

Photos: Loretta Serafin and Stephanie Belfield, NSW DPI

Source: Sunflower Production and Pest Management Extension Bulletin 25, December 1985, NDSU

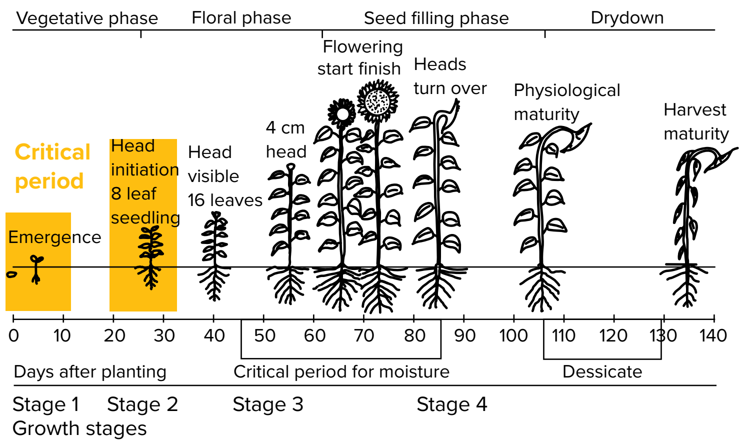

Figure 7: *Sunflower growth stages from a December planting.*

Source: Pacific Seeds Cropping Yearbook 2009/2010 – Sunflower, Pg 7

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