SOUTHERN
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GRDC GROWNOTES™

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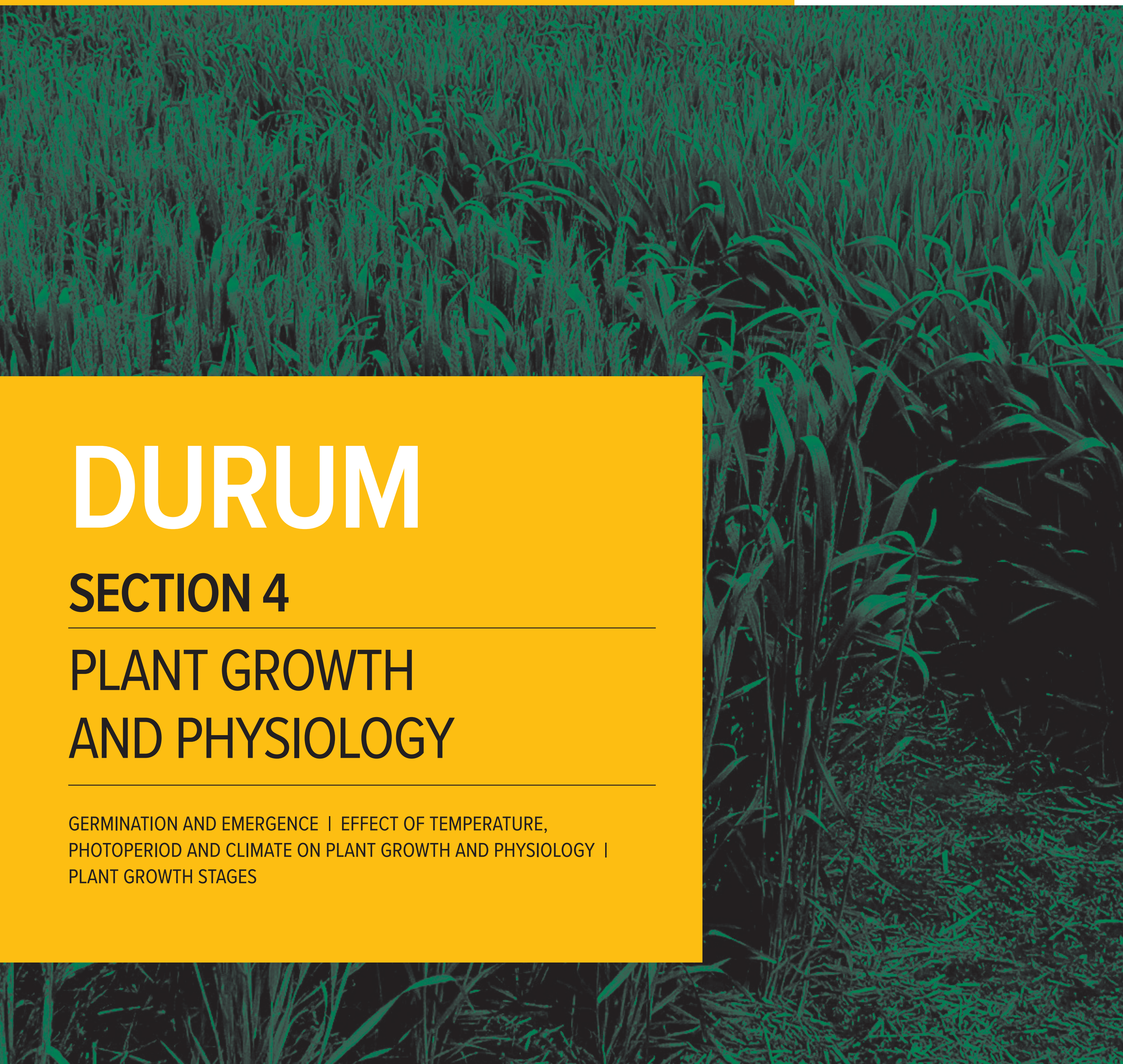

DURUM

SECTION 4

PLANT GROWTH AND PHYSIOLOGY

GERMINATION AND EMERGENCE | EFFECT OF TEMPERATURE, PHOTOPERIOD AND CLIMATE ON PLANT GROWTH AND PHYSIOLOGY | PLANT GROWTH STAGES

Plant growth and physiology

Key messages

- Crop growth stages need to be considered carefully to maximise yield and to ensure the appropriate timing for in crop treatments such as growth regulants, herbicides, fertilisers and insecticides.
- Genetics, planting practices and environmental factors will affect durum differently at different growth stages.
- High nitrogen is required for plant growth and to ensure durum reaches 13% protein levels.
- Durum is relatively sensitive to saline soils.
- Take time to learn and understand growth stage keys to make informed decisions and to be able to communicate about your crop.

4.1 Germination and emergence

Wheat germination begins when the seed absorbs water and ends with the appearance of the radicle. Germination has three phases:

- water absorption (imbibition)
- activation
- visible germination.

Phase 1: Water absorption (GS01*)

See Section 4.3.1 Zadoks Cereal Growth Stage Key, below, for more details.

Phase 1 of cereal growth starts when the seed begins to absorb moisture. Generally, a wheat seed needs to reach a moisture content of 35–45% of its dry weight to begin germination. Water vapour can begin the germination process as rapidly as liquid can. Wheat seeds begin to germinate at a relative humidity of 97.7%. Soil so dry that roots cannot extract water still has a relative humidity of 99%, much higher than that of a dry seed. So even in dry conditions, there can be enough moisture for the seed to absorb and begin Phase 1, but it takes longer than in moist conditions.

Phase 2: Activation (GS03)

Once the embryo has swollen it produces hormones that stimulate enzyme activity. The enzymes break down starch and protein stored in the seed to sugars and amino acids, providing energy to the growing embryo. The larger the seed, the more starch and, consequently, energy it will have. If the seed dries out before the embryo starts to grow, it remains viable. Phase 2 continues until the rupture of the seed coat, the first visible sign of germination.

Phase 3: Visible germination (GS05–GS09)

In Phase 3 the embryo starts to visibly grow. The radicle emerges, followed soon after by other primary roots and the coleoptile. The enzymes produced in Phase 2 mobilise sugars and amino acids stored in the seed and enable their transfer to the growing embryo. [1]

Emergence (GS07)

As the first primary roots appear, the coleoptile bursts through the seed coat and begins pushing towards the surface (Photo 1). Emergence is when the coleoptile or the first leaf becomes visible above the soil surface.

1 NSW DPI (2007) Wheat growth and development. PROCROP Series (Eds. J White, J Edwards). NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

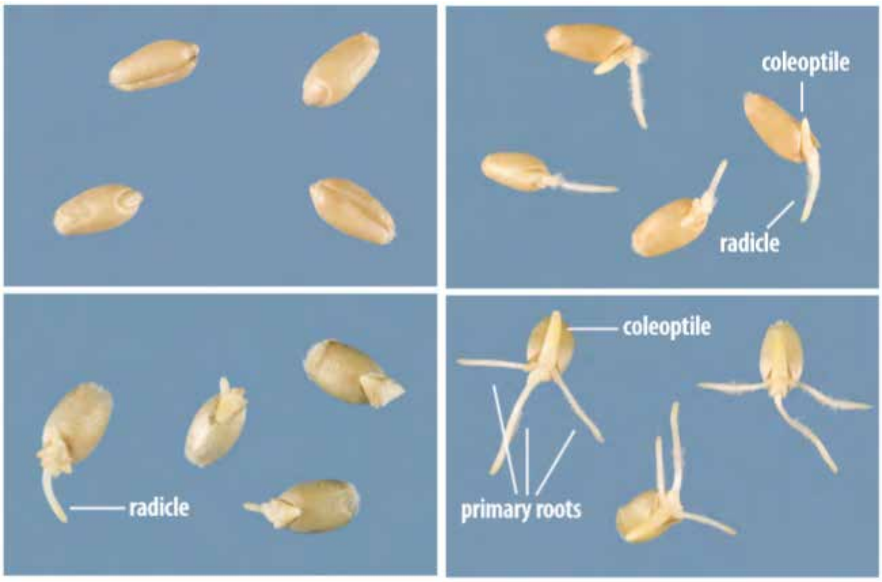

Photo 1: *Germinating wheat seed (with stages progressing from top left, bottom left, top right, bottom right). The radicle emerges followed by the coleoptile and the primary roots.*

Photo: L Turton, Source: NSW DPI

4.1.1 Factors affecting germination and emergence

Temperature

Germination is dependent on temperature. The ideal temperature range for wheat germination is 12–25°C, but germination will occur between 4°C and 37°C.The speed of germination is driven by accumulated temperature, or degree-days. Degree-days are the sum of the average daily maximum and minimum temperatures over consecutive days.

Extension of the coleoptile is directly related to soil temperature. Soils that are too cold or too hot shorten the coleoptile length. Research shows that coleoptiles are longest when soil temperatures are between 10°C and 15°C. This is one reason why there is variation in emergence and establishment in the different wheat growing areas.

Moisture

Soil moisture influences the speed of germination. Germination is rapid if the soil is moist. When the soil dries to near the permanent wilting point, the speed of germination slows. Therefore, seeds that have taken up water and entered Phase 2, but not reached Phase 3, remain viable if the soil dries out. This can happen when dry sowing is followed by a small fall of rain that keeps the soil moist for a few days before drying out. When the next fall of rain comes, the seed resumes germinating, taking up water and moving quickly through Phase 2.

Soil moisture also affects emergence. Sowing into hard-setting or crusting soils that dry out after sowing may result in poor emergence. The hard soil makes it difficult for the coleoptile to push through to the surface, particularly in varieties with short coleoptiles. Coleoptile length of durum wheat varieties is shown in Table 1. In some crusting soils, gypsum and/or lime may improve soil structure and assist seedling emergence. [2]

2 NSW DPI (2007) Wheat growth and development. PROCROP Series (Eds. J White, J Edwards). NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

Table 1: *Predicted mean coleoptile length for durum wheat varieties at 18 National Variety Trials sites across Australia from 2010–2014.*

Variety	Predicted mean coleoptile length (cm)
Caparoi⫽	7.5
DBA_Aurora⫽	7.5
EGA_Bellaroi⫽	7.7
Hyperno⫽	7.8
Jandaroi⫽	7.0
Kalka⫽	7.4
Saintly⫽	7.2
Tamaroi⫽	7.9
Tjilkuri⫽	7.6
WID802⫽	7.7
Wollaroi⫽	7.2
Yawa⫽	7.6
Check varieties	
Federation⫽ (long)	9.3
Whistler⫽ (short)	6.0

Source: Department of Primary Industries New South Wales

Stubble reduces the impact of raindrops on the soil surface and helps prevent soil crusts from forming. Stubble retention also encourages biological activity and increases the amount of organic matter, which improves the stability of the soil by binding the soil particles together. [3]

Oxygen

Oxygen is essential to the germination process. Seeds absorb oxygen rapidly during germination, and without enough oxygen they die. Germination is slowed when the soil oxygen concentration is <20%. During germination, water softens the seed coat, making it permeable to oxygen. This means that dry seeds absorb almost no oxygen. Seeds planted in waterlogged soils cannot germinate because of a lack of oxygen. It is commonly thought that in very wet conditions seeds 'burst'; in fact, they run out of oxygen and die. [4]

Salinity

There is increasing evidence for the negative effect of sodium chloride (e.g. saline soils or sea water) on the germination and subsequent growth of durum. In many species, salt sensitivity is associated with the accumulation of sodium (Na+) in photosynthetic tissues. [5] The first study below found that durum seeds were less tolerant to salt at germination than after the three-leaf stage. [6] The second study found that moderate stress intensity (22% seawater osmolarity, –0.62 MPa) only delayed mean germination time, whereas higher seawater osmolarity (37% seawater osmolarity, –1.04 MPa) reduced germination percentage as well. [7]

3 NSW DPI (2007) Wheat growth and development. PROCROP Series (Eds. J White, J Edwards). NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

4 NSW DPI (2007) Wheat growth and development. PROCROP Series (Eds. J White, J Edwards). NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

5 R Davenport, RA James, A Zakrisson-Plogander, M Tester, R Munns (2005). Control of sodium transport in durum wheat. Plant Physiology, 137(3), 807–818, http://www.plantphysiol.org/content/137/3/807

6 LE Francois, EV Maas, TJ Donovan, VL Youngs (1986). Effect of salinity on grain yield and quality, vegetative growth, and germination of semi-dwarf and durum wheat. Agronomy Journal, 78(6), 1053–1058, https://dl.sciencesocieties.org/publications/aj/pdfs/78/6/AJ0780061053

7 Z Flagella, D Trono, M Pompa, N Di Fonzo, D Pastore (2006). Seawater stress applied at germination affects mitochondrial function in durum wheat (*Triticum durum*) early seedlings. Functional Plant Biology, 33(4), 357–366, http://dx.doi.org/10.1071/FP05244

IN FOCUS

Effect of salinity on grain yield and quality, vegetative growth and germination of semi-dwarf and durum wheat

Semi-dwarf bread wheat (*Triticum aestivum* L.) and durum wheat (*Triticum turgidum* L., durum group) are often grown on saline soils in the western United States. Because of the lack of information on salinity effects on vegetative growth and seed yield of these two species, a two-year field plot study was conducted. Six salinity treatments were imposed on a Holtville silty clay (clayey over loamy, montmorillonitic [calcareous], hyperthermic Typic Torrifluvent) by irrigating with waters salinised with sodium chloride and calcium chloride (1:1 by weight). Electrical conductivities of the irrigation waters were 1.5, 2.5, 5.0, 7.4, 9.9, and 12.4 dS/m the first year, and 1.5, 4.0, 8.0, 12.0, 16.1, and 20.5 deciSiemens per metre (dS/m) the second year. Grain yield, vegetative growth and germination were measured. Relative grain yields of one semi-dwarf wheat cultivar and two durum cultivars were unaffected by soil salinity up to 8.6 and 5.9 dS/m (electrical conductivity of the saturated-soil extract), respectively. Each unit increase in salinity above the thresholds reduced yield of the semi-dwarf cultivar by 3.0% and the two durum cultivars by 3.8%. These results place both species in the salt-tolerant category. Salinity increased the protein content of both grains but only the quality of the durum grain was improved. Vegetative growth of both species was decreased more by soil salinity than was grain yield. Both species were less salt tolerant at germination than they were after the three-leaf stage of growth. [8]

4.2 Effect of temperature, photoperiod and climate on plant growth and physiology

The major environmental factors affecting development in wheat are photoperiod and temperature. [9] Genes control the plant's growth responses to the accumulation of temperature, day length and cold requirement (vernalisation). Various combinations of genes are present in Australian wheat varieties which result in a wide spectrum of responses to temperature and day length (photoperiod). [10]

4.2.1 Photoperiod/day length

To ensure the crop flowers at the optimal time, an understanding is required of how sowing time, and subsequent photoperiod range, affects flowering time. Variation in photoperiod response plays an important role in adapting crops to agricultural environments. The longer the days, the shorter the thermal time needed to initiate flowering in photoperiod-sensitive wheat varieties. Photoperiod insensitivity in durum wheat is less characterised. [11]

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8 LE Francois, EV Maas, TJ Donovan, VL Youngs (1986). Effect of salinity on grain yield and quality, vegetative growth, and germination of semi-dwarf and durum wheat. Agronomy Journal, 78(6), 1053–1058, https://dl.sciencesocieties.org/publications/aj/pdfs/78/6/AJ0780061053

9 GA Slafer, HM Rawson (1994) Sensitivity of wheat phasic development to major environmental factors: a re-examination of some assumptions made by physiologists and modellers. Australian Journal of Plant Physiology 21(4), 393–426, http://www.publish.csiro.au/paper/PP9940393.htm

10 GRDC (2011) Time of sowing fact sheet. Grains Research and Development Corporation, March 2011, http://www.grdc.com.au/GRDC-FS-TimeOfSowing

11 EP Wilhelm, AS Turner, DA Laurie (2009) Photoperiod insensitive Ppd-A1a mutations in tetraploid wheat (*Triticum durum* Desf.). Theoretical and Applied Genetics, 118(2), 285–294, http://www.ncbi.nlm.nih.gov/pubmed/18839130

In some Australian wheat varieties, photoperiod can also impact the length of time required to reach growth stages. Genetic studies and observations of wheat varieties grown in different latitudes suggest many Australian wheat varieties are day length-sensitive to varying degrees; however, most varieties are not well characterised for responses to day length.

Varieties released before 1973 generally carried a photoperiod-sensitive gene, making them more sensitive to day length. They tended to flower later for a given sowing date when sown before 22 June—on average a week later in the Mallee, compared with current varieties. A photoperiod-sensitive variety will flower four to 12 days later than an insensitive variety when sown early in southern Australia. [12]

4.2.2 Temperature

Heat and/or drought stress during cultivation can affect the processing quality of durum wheat. High temperatures during establishment cause seedling mortality, reducing the number of plants that establish. In hot environments, the maximum temperature in the top 2-3 cm of soil can be 10–15°C higher than the maximum air temperature, especially with a dry, bare soil surface and high radiation intensity. In these conditions, soil temperature can reach 40–45°C, seriously affecting seedling emergence. Brief exposure to extreme soil temperatures can also restrict root growth and tiller initiation. [13]

In the presence of a long period of temperatures in the range of 30–35°C, a dough 'strengthening' effect has been observed, while frequent episodes of daily maximum temperatures above 35°C led to a dough 'weakening' effect, which is not desirable for pasta making. [14]

One study found that plants sown late experienced heat stress in the growth stages after anthesis. Stress tolerance index (STI) and stress susceptibility index (SSI) for grain yield and 1000-grain weight indicated that durum wheat had the lowest STI for grain yield. Barley genotypes had a higher tolerance to post-anthesis heat stress than wheat genotypes. Average grain yield reduction in barley and wheat genotypes exposed to heat stress after anthesis was 17% and 24%, respectively. Higher SSI for 1000-grain weight in late maturity genotypes was related to delay in anthesis and contact of grain growth period with heat stress. [15]

Photoperiod or day length is the number of hours of daylight. Durum wheat is a long-day plant, meaning that it responds to increasing photoperiod. This sensitivity determines whether the plant continues to produce leaves or changes to reproductive development.

Photoperiod can affect the development of wheat by:

causing changes in the rate of leaf area expansion and dry matter production

providing a cue for the start of reproductive development

changing the rate of reproductive development.

Thermal time

Thermal time is a calculation of accumulated temperature. It helps to explain the relationship between plant development and temperature. It is calculated as the mean daily temperature minus a base temperature and is recorded as degree-days (°Cd). The base temperature is the minimum temperature at which the plant grows, and this varies for each crop. For wheat, the base temperature is 0°C during vegetative growth and 3°C in the reproductive phase.

12 GRDC (2011) Time of sowing fact sheet. Grains Research and Development Corporation, March 2011, http://www.grdc.com.au/GRDC-FS-TimeOfSowing

13 GRDC (2014) Durum quality and agronomy fact sheet. Grains Research and Development Corporation, March 2014, https://grdc.com.au/GRDC-FS-Durum

14 B Borghi, M Corbellini, M Ciaffi, D Lafiandra, E Stefanis, D Sgrulletta, FN Di (1995). Effect of heat shock during grain filling on grain quality of bread and durum wheats. Crop and Pasture Science, 46(7), 1365–1380, http://www.publish.csiro.au/paper/AR9951365.htm

15 A Modhej, R Farhoudi, A Afrous (2015) Effect of post-anthesis heat stress on grain yield of barley, durum and bread wheat genotypes. In Proceedings of the 10th International Barley Genetics Symposium. Alexandria, Egypt, 5–10 Apr 2008, (p. 230), ICARDA

Although not commonly used at farm level, thermal time is very important for predicting the growth stages of some crops. It is not always a good predictor for wheat, as development is also influenced by photoperiod and vernalisation. In general, higher temperatures accelerate development between germination and flowering. However, under increasing photoperiod, thermal time has less effect on plant development.

While the rate of development may be controlled by many factors, higher temperatures and increasing photoperiod reduce the number of days in all growth stages. This is particularly important up until the flowering stage. There is a variation in thermal time between seasons. [16]

IN FOCUS

Heat and drought stress on durum wheat—responses of genotypes, yield and quality parameters

This study examined the effects of drought and heat stress conditions on grain yield and quality parameters of nine durum wheat varieties, grown during two years (2008–09 and 2009–10). More precipitation in 2009–10 may account for the large differences in parameters observed between crop cycles (2008–09 and 2009–10). Combined results of the two crop cycles showed that flour protein content and sodium dodecyl sulfate sedimentation volume increased under both stress conditions, but not significantly. In contrast the gluten strength-related parameters lactic acid retention capacity (LARC) and mixograph peak time increased and decreased significantly under drought and heat stress, respectively. Drought and heat stress drastically reduced grain yield but significantly enhanced flour yellowness. LARC and the swelling index of glutenin could be alternative tests to screen for gluten strength. Genotypes and quality parameters performed differently to drought and heat stress, which justifies screening durum wheat for both yield and quality traits under these two abiotic stress conditions. [17]

4.2.3 Water deficit and water stress

Getting the balance right between too much and too little water is essential in durum growing. Durum wheat production in southern Australia is limited when water deficit occurs immediately before and during anthesis. [18] If durum is water stressed, symptoms of fungal disease will be exacerbated, resulting in the appearance of white heads that produce small shrivelled grain, severely affecting yield. [19]

16 NSW DPI (2008) Wheat growth and development (Eds J White, J Edwards). New South Wales Department of Primary Industries, February 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/516185/Procrop-wheat-growth-and-development.pdf

17 YF Li, Y Wu, N Hernandez-Espinosa, RJ Peña (2013) Heat and drought stress on durum wheat: Responses of genotypes, yield, and quality parameters. Journal of Cereal Science, 57(3), 398–404, http://dx.doi.org/10.1016/j.jcs.2013.01.005

18 H Liu, IR Searle, DE Mather, AJ Able, JA Able (2015) Morphological, physiological and yield responses of durum wheat to pre-anthesis water-deficit stress are genotype-dependent. Crop and Pasture Science, 66(10), 1024–1038, http://www.publish.csiro.au/paper/CP15013.htm

19 GRDC (2014) Durum quality and agronomy fact sheet. Grains Research and Development Corporation, March 2014, https://grdc.com.au/GRDC-FS-Durum

IN FOCUS

Morphological, physiological and yield responses of durum wheat to pre-anthesis water-deficit stress are genotype-dependent

This study was conducted to determine the effect of genotypic variation on various yield, morphological and physiological responses to pre-anthesis water-deficit stress by evaluating 20 durum wheat genotypes over two years of glasshouse experiments. Grain number was the major yield component that affected yield under pre-anthesis water-deficit stress. Genotypes with less yield reduction also had less reduction in chlorophyll content, relative water content and leaf water potential, suggesting that durum genotypes tolerant of water-deficit stress maintain a higher photosynthetic rate and leaf water status. Weak to moderate positive correlations of morphological traits, including plant height and fertile tiller number, with grain number and biomass make the evaluation of high-yielding genotypes in rain-fed conditions possible. Morphological traits (such as plant height and tiller number) and physiological traits (such as chlorophyll content, relative water content and leaf water potential) could therefore be considered potential indicators for indirect selection of durum wheat with water-deficit stress tolerance under Mediterranean conditions. [20]

IN FOCUS

Effect of water stress at various growth stages on some quality characteristics of winter wheat

A field experiment has been carried out on winter wheat to analyse the effect of water stress (fully irrigated [FI], rain-fed [R], early water stress [EWS], late water stress [LWS] and continuous water stress [CWS]) at different growth stages on quality characteristics. Water stress had a substantial effect on most of the quality characteristics recorded. CWS, EWS, R and LWS treatments decreased grain yields by 65.5, 40.6, 30.5 and 24.0%, respectively, compared with the FI treatment. CWS increased grain protein content by 18.1%, sedimentation volume by 16.5%, wet gluten content by 21.9% and decreased 1000-kernel weight by 7.5 g compared with FI treatment. LWS caused an increase of 8.3% in grain protein content, 8.7% in sedimentation volume, 10.8% in wet gluten content and a reduction of 3.8 g in 1000-kernel weight compared with FI. EWS and R increased sedimentation volume and wet gluten content, but decreased 1000-kernel weight compared with FI. The effect of LWS on grain quality was more significant than that of EWS. The results suggest that soil moisture conditions increase grain yield and kernel weight of winter wheat but decrease its quality. [21]

20 H Liu, IR Searle, DE Mather, AJ Able, JA Able (2015) Morphological, physiological and yield responses of durum wheat to pre-anthesis water-deficit stress are genotype-dependent. Crop and Pasture Science, 66(10), 1024–1038, http://www.publish.csiro.au/paper/CP15013.htm

21 A Ozturk, F Aydin (2004) Effect of water stress at various growth stages on some quality characteristics of winter wheat. Journal of Agronomy and Crop Science, 190(2), 93–99, http://dx.doi.org/10.1071/FP05244

4.2.4 Salinity

A saline soil is one that contains sufficient soluble salts (most commonly sodium chloride) to adversely affect the growth of plants. Salinity reduces a plant's ability to extract water from the soil and can cause toxicities from specific ions. The susceptibility of various crops, including durum wheat, to yield decline under saline conditions is shown in Table 2.

Table 2: *Susceptibility of various crops to yield decline with saline soil and irrigation water.*

	Electrical conductivity (EC) causing 5% yield reduction (D S/m)			
		EC of water sample (i.e. irrigation salinity)		
Crop	**EC of a soil extract (root zone salinity)**	**Well drained soils**	**Moderate to slow draining soils**	**Very slow draining soils**
Barley-forage	6.0	6.0	4.0	2.0
Barley-grain	8.0	8.0	5.3	2.6
Canola	6.5	6.5	4.3	2.1
Faba Beans	1.8	1.8	1.2	0.6
Oats	5.0	5.0	3.3	1.7
Wheat	6.0	6.0	4.0	2.0
Durum wheat	5.7	5.7	3.8	1.9
Cotton	2.4	Not recorded	1.6	1.8
Maize	1.7	1.7	1.1	0.6
Soybeans	0.8	0.8	0.5	0.3
Sunflowers	5.5	5.5	3.6	Not recorded
Millet	6.0	6.0	4.0	2.0
Sorghum grain	1.5	1.5	1.0	0.5
Rice	3.0	Not recorded	Not recorded	1.0

Source: Soil Quality Pty Ltd

MORE INFORMATION

Salinity training manual

IN FOCUS

Factors affecting CO_2 assimilation, leaf injury and growth in salt-stressed durum wheat

To examine the factors that affect tolerance to high internal salt concentrations, two tetraploid wheat genotypes that differ in the degree of salt-induced leaf injury (Wollaroi⊕ and Line 455) were grown in 150 mM sodium chloride for four weeks. Shoot biomass of both genotypes was substantially reduced by salinity, but genotypic differences appeared only after three weeks, when durum cultivar Wollaroi⊕ showed greater leaf injury and a greater reduction in biomass than Line 455. Salinity caused a large decrease in stomatal conductance of both genotypes. High Na+ and Cl- concentrations in the leaf and chlorophyll degradation, indicates that these later reductions in CO_2 assimilation in Wollaroi⊕ were a consequence of a direct toxic ion effect. The earlier reduction in CO_2 assimilation and greater leaf injury explain why growth of Wollaroi⊕ was less than Line 455. [22]

4.2.5 Effects of nitrogen

Nitrogen (N) is essential to plant growth, with high N levels required to ensure durum reaches its ideal protein potential of 13%. [23] Nitrogen is an essential nutrient required for growth, and impacts on root development which in turn affects shoot growth, access to water and other essential nutrients. In south-eastern Australia, many soils are naturally deficient in N. [24]

N is highly mobile in wheat hence when N is deficient, older leaves yellow as N is mobilised to younger plant parts including grain. Other symptoms of N deficiency are stunting of the plant, a reduction in the number of tillers, grain with a mottled colouring and lower grain yield. [25]

Soil N supply is particularly important in rotations that include legume crops and pastures. Durum is often grown following legumes to benefit from increased available N in the soil. N in the residues of legume crops and pastures is decomposed by microorganisms and will become available to subsequent crops. For example, 20–25% of the N fixed by a medic pasture was converted to mineral forms of N and taken up by the following crop. [26]

N is commonly applied in moderate to high levels during seedbed preparation, with anhydrous ammonia or urea often used. N can be leached from light soil if heavy rain or continuous wet weather delays sowing. Excessive N fertiliser applied close to the seed can also lead to toxicity problems.

For more information on the use of nitrogen in durum growing, see Section 5: Nutrition and fertiliser.

22 RA James, AR Rivelli, R Munns, S von Caemmerer (2002) Factors affecting CO_2 assimilation, leaf injury and growth in salt-stressed durum wheat. Functional Plant Biology, 29(12), 1393–1403, http://www.publish.csiro.au/paper/FP02069.htm

23 GRDC (2014) Durum quality and agronomy fact sheet. Grains Research and Development Corporation, March 2014, https://grdc.com.au/GRDC-FS-Durum

24 CropPro, Nitrogen as a nutrient for wheat in southern Australia, http://www.croppro.com.au/resources/Review%20-%20Nitrogen%20for%20Wheat.pdf

25 NJ Grundon (1987) Hungry crops: a guide to mineral deficiencies in field crops. Queensland Department of Primary Industries, pp 19, ISBN 0724223150

26 JF Angus, MB Peoples (2012) Nitrogen from Australian dryland pastures. Crop and Pasture Science, 63(9), 746–758, http://dx.doi.org/10.1071/CP12161

4.2.6 Effects of phosphorus

Phosphorus (P) is essential for seed germination and early root development. Large amounts are taken up during germination. Phosphorus deficiency at this early stage of growth significantly reduces yield potential. The plant's peak uptake of P is in the first six weeks. P is relatively immobile in the soil (unlike N), so needs to be placed near the seed and cannot be top-dressed. Regardless of soil test results, some P should be applied at sowing in close proximity to the seed.

4.3 Plant growth stages

Plants grow as green leaves intercept energy from the sun and use that energy to capture carbon (from atmospheric carbon dioxide) and manufacture carbohydrates that are used to grow the leaves and other structures of the plant. Over the life cycle of the plant the allocation of carbon changes as the plant moves through a series of developmental stages. In cereals the key developmental stages are associated with changes in the shoot apex as the head is formed and the stems elongate. The latter is a critical developmental phase as potential yield (number of grains and grain size) is determined at this time. Flowering (anthesis) in cereals is another critical developmental stage and post-anthesis growth is allocated almost entirely to grain filling. [27]

Growth in cereals can be thought of in two distinct parts:

1. Pre-flowering (pre-anthesis) growth, which is the growth that goes into leaves, roots and stems before a crop flowers and sets yield potential.
2. Post-flowering growth, the majority of which goes into grain. [28]

Durum crops grow to about 80 cm at maturity (15–20 cm shorter than bread wheat) depending on seasonal conditions and variety. Low density crops tend to have heads flowering over a longer interval. Such a prolonged flowering period may reduce the impact of a frost around flowering. Protracted moist weather at flowering can have an adverse effect on pollination by inhibiting the release of pollen from the anthers. If the female part of the flower (the stigma and ovule) is not fertilised while in its receptive phase, a grain will not develop. Low density crops are likely to use available soil moisture reserves at a slower rate than the higher density crops. Avoidance of moisture stress before and at flowering is critical for satisfactory grain set, as pollen will abort during periods of stress as part of a natural survival mechanism of the plant. Extended flowering could reduce the risk of pollination failure caused by frost or extended moist weather. The time difference in reaching full maturity between early-flowering and late-flowering tillers is usually small; therefore, the early heads are not likely to be ripe for many days ahead of the later heads (Photo 2). Harvesting should not be delayed significantly. [29]

27 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

28 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

29 R Hare (2006) Agronomy of the durum wheats Kamilaroi⟨D, Yallaroi⟨D, Wollaroi⟨D and EGA Bellaroi⟨D. Primefacts 140. NSW Department of Primary Industries, April 2006, http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/winter-cereals/agronomy-durum-wheats

Photo 2: *Early durum heads are not likely to ripen well ahead of later heads.The Zadoks cereal growth stage key provides farmers, advisers and researchers with a common reference for describing the crop's development and allow implementing of agronomic decisions based on a common understanding of which stage the crop has reached. Management by growth stage is critical to optimise returns from inputs such as N, plant growth regulators, fungicides and water.*

Source: Clove Garden

4.3.1 Zadoks Cereal Growth Stage Key

The Zadoks growth stage key provides a common reference to describe the crop's development and the stages at which to apply key inputs. This is the most commonly used key to growth stages for cereals, in which the development of the cereal plant is divided into 10 distinct development phases covering 100 individual growth stages. Individual growth stages are denoted by the prefix GS (growth stage) or Z (Zadoks), for example, GS39 or Z39.

Key growth stages in relation to disease control and canopy management

The principal Zadoks growth stages (Figure 1) used in relation to disease control and N management are those from the start of stem elongation through to early flowering: GS30–GS61. [30]

Early stem elongation GS30–GS33 (pseudo stem erect—third node on the main stem)

This period is important for N timing, growth regulants and protection of key leaves. In order to ensure the correct identification of these growth stages, plant stems are cut longitudinally, so that internal movement of the nodes (joints in the stem) and lengths of internodes (hollow cavities in the stem) can be measured.

30 GRDC (2005) Cereal growth stages. Grains Research and Development Corporation, September 2005, https://grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf

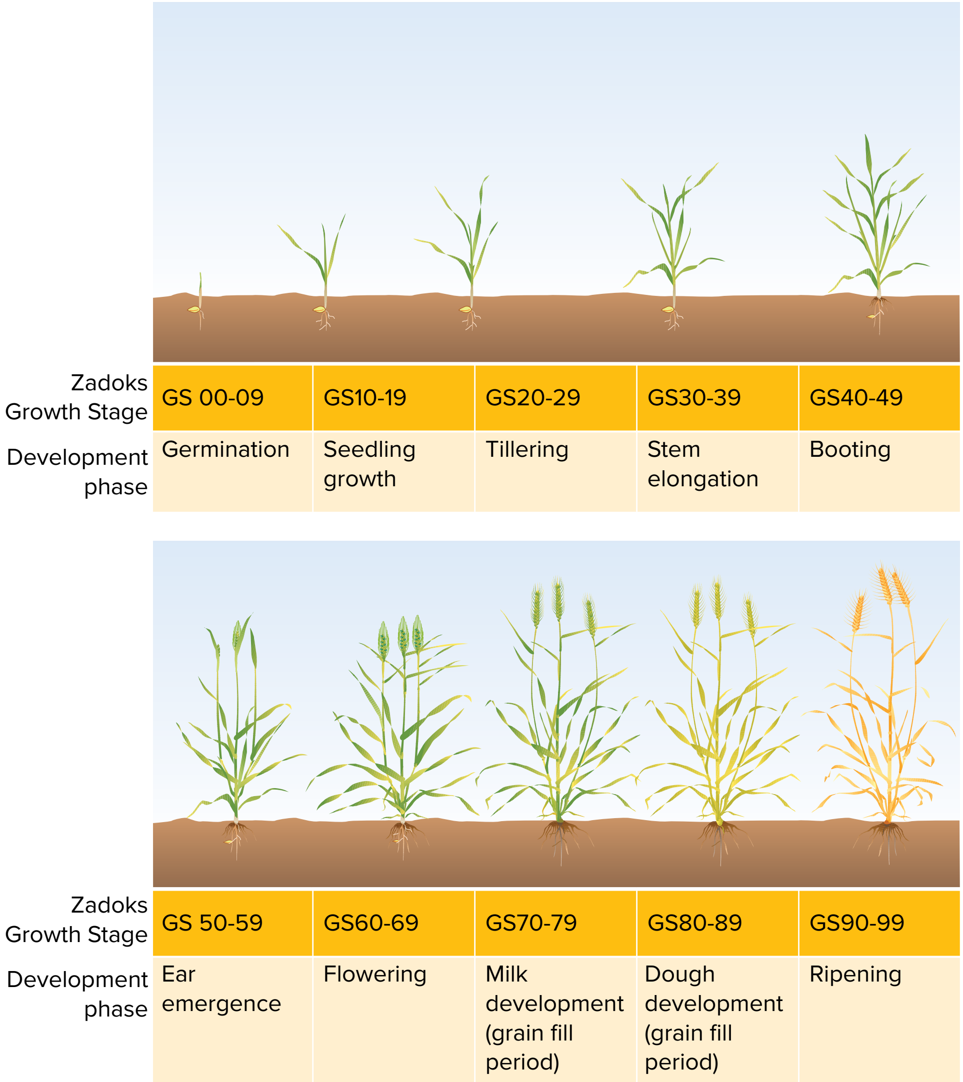


Figure 1: *Zadoks growth stages.* .

Key points: Zadoks growth stage key

- The Zadoks growth stage key does not run chronologically from GS00 to GS99, for example when the crop reaches three fully unfolded leaves (GS13) it begins to tiller (GS20), before it has completed four, five and six fully unfolded leaves (GS14, GS15, GS16).
- It is easier to assess main stem and number of tillers than it is the number of leaves (due to leaf senescence) during tillering. The plant growth stage is determined by main stem and number of tillers per plant, for example GS22 is main stem plus two tillers up to GS29 main stem plus nine or more tillers.
- In Australian cereal crops plants rarely reach GS29 before the main stem starts to stem elongate (GS30).
- As a consequence of growth stages overlapping it is possible to describe a plant with several growth stages at the same point in time. For example, a cereal plant at GS32 (second node on the main stem) with three tillers and seven leaves on the main stem would be at GS32, GS23 and GS17, yet practically would be regarded as GS32, since this describes the most advanced stage of development.
- After stem elongation (GS30) the growth stage describes the stage of the main stem, it is not an average of all the tillers. This is particularly important with

fungicide timing, for example GS39 is full-flag leaf on the main stem, meaning that not all flag leaves in the crop will be fully emerged.

- Use a ruler to measure node movement in the main stem to define early stem elongation growth stages.
- Take care not to confuse the basal node at the stem base with the first true node. Basal nodes are usually signified by a constriction of the stem below the node with an incompletely formed internode space, it is the point where the lowest leaves attach to the stem. Further, basal nodes will often grow small root tips. This is not the first node.
- Nodal growth stage can give an approximate guide to which leaf is emerging from the main stem, this can save time with leaf dissection when it comes to making decisions on fungicide application pre-flag leaf (when all leaves are emerged).
- The rate of development influences the time between growth stages—later sowings spend less time in each development phase including grainfill.
- Though it will vary between varieties and regions (due to temperature), stem elongation leaves emerge approximately five to 10 days apart (10 under cooler temperatures at the start of stem elongation and nearer five to seven days as the flag comes out.)
- The period of time between leaf emergences is referred to as the phyllochron and is approximately 100–120 degree-days, though it can be longer or shorter depending on variety. [31]

4.3.2 Why is growth stage important in making fungicide, nitrogen application and growth regulant decisions?

The start of stem elongation is particularly important for decisions on fungicide and nitrogen inputs, as it marks the emergence of the first of the important yield-contributing leaves and the point at which N uptake in the plant strongly increases. [32]

To correctly identify these growth stages, main stems of the cereal plants are cut longitudinally and the position of nodes (joints in the stem) and the length of internodes (cavity in the stem between nodes) are measured with a ruler (Figure 2).

31 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

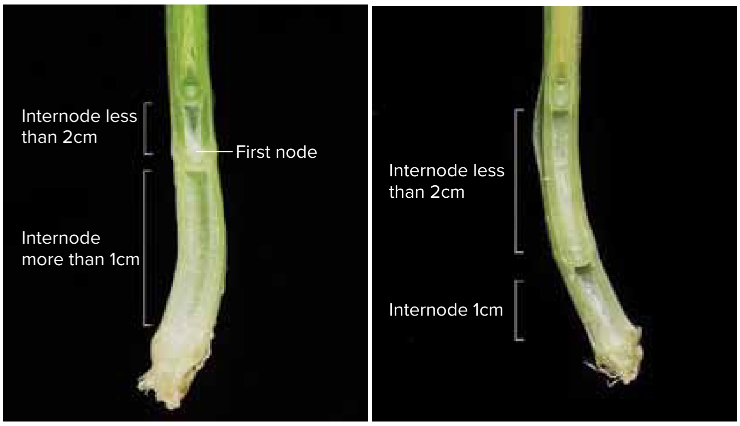
32 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

GS30 The tip of the developing ear is one centimetre of more from the base of the stem where the lowest leaves attach to the shoot apex.

Preparation of main stem for measurement

GS30 - Main stem with embryo ear at 1cm.

GS31 The first node can be seen 1cm or more above the base of the shoot (with clear internode space below it) and the internode above it is less than 2cm



GS31 - Early first node formation

GS31 - second node as less than 2cm from first node

Figure 2: *Dimensions defining stem elongation with internal stem base dimensions.*

Source: Grains Research and Development Corporation