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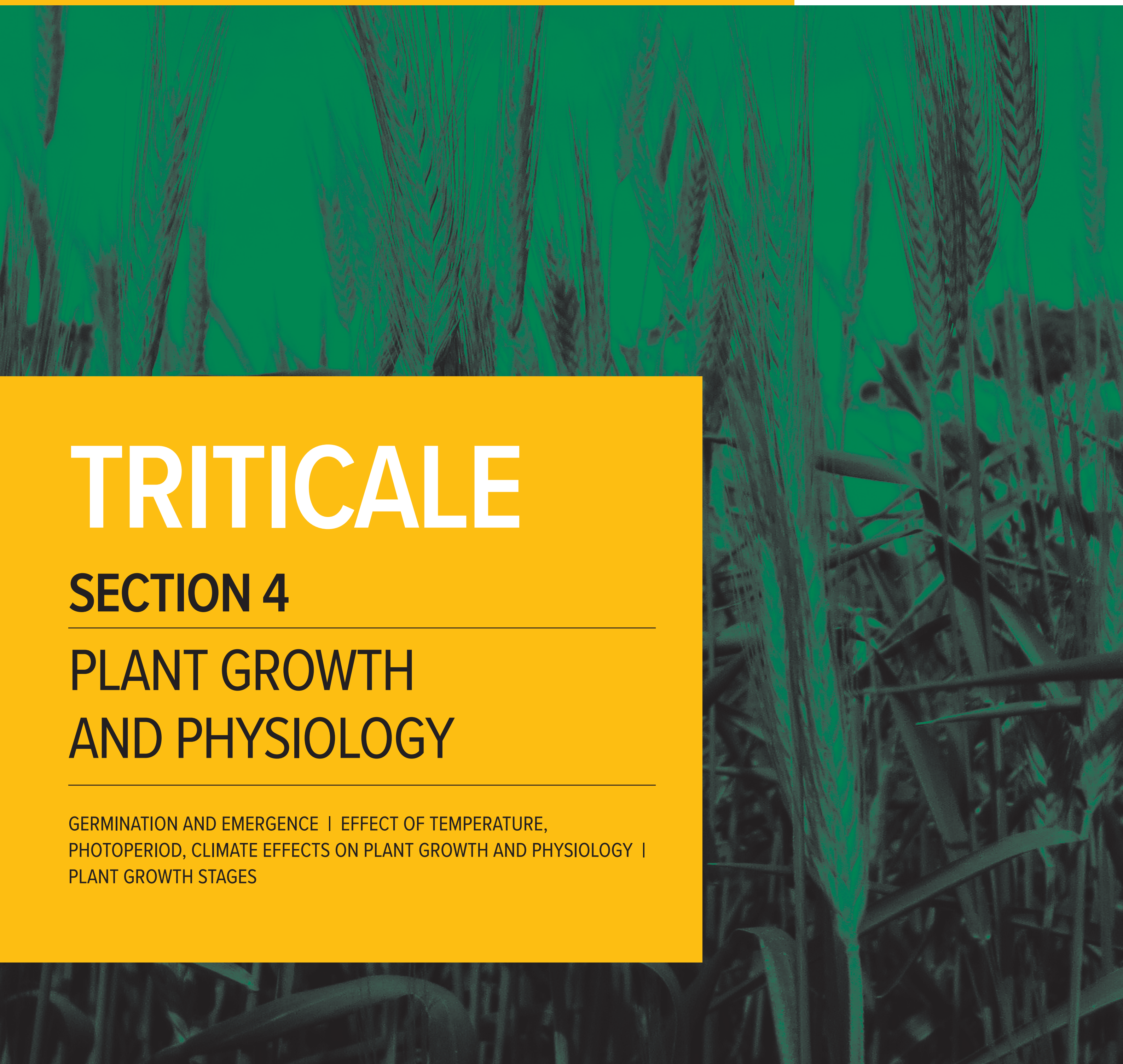

# TRITICALE

## SECTION 4

## PLANT GROWTH AND PHYSIOLOGY

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

# Plant growth and physiology

## Key Messages:

- Triticale is quite similar to wheat except it has spreading growth until stem elongation, when the stems extend in the normal erect growth form of wheat. [1]
- Triticale tillers less than wheat.
- Germination optimum temperature is 20°C
- Growth optimum temperature is 10-24°C
- Maximum temperature of survival is 33°C [2]
- Though triticale is generally considered tolerant to salt stress, studies have found that cultivars are slightly less salt tolerant at germination. [3]
- Since the early development of triticale, its tolerance to drought stress has increased compared to other cereals. [4]

Key Characters of triticale (see Table 1):

- Emerging leaves rolled in the shoot.
- Leaf blade flat with a clockwise twist.
- Short membranous ligule.
- Auricles.
- Seed is a grain like wheat. [5]
- Height is about 1–1.5m.
- Leaves are like wheat but larger and thicker. The spikes are also larger. [6]

**Table 1:** *Main features of triticale.*

| Plant part | Description |
|---|---|
| Cotyledons | 1 |
| First leaves | Single, and similar to later leaves |
| Leaves | Emerging leaves rolled in the shoot |
| | Blade: parallel sided, flat, clockwise twist when viewed from above, 30–300 mm long, 10–20 mm wide |
| | Ligule: short membrane |
| | Auricles: present, occasionally with hairs on the shoulders |
| | Sheath: rolled, prominent veins, often bluish-green at the base |
| Stems | Many, unbranched stems arise from base, erect, up to 1,500 mm tall, hollow with solid nodes |

1 Hill Laboratories. Crop Guide: Triticale. https://www.hill-laboratories.com/crop-guides/

2 Agro Info. Triticale growing. http://agriculture.infoagro.com/crops/triticale-growing/

3 Francois, L. E., Donovan, T. J., Maas, E. V., & Rubenthaler, G. L. (1988). Effect of salinity on grain yield and quality, vegetative growth, and germination of triticale. *Agronomy Journal*, *80*(4), 642–647.

4 Jessop, R. S. (1996). Stress tolerance in newer triticales compared to other cereals. In *Triticale: today and tomorrow* (pp. 419–427). Springer Netherlands.

5 Triticale. Collated by HerbiGuide. http://www.herbiguide.com.au/Descriptions/hg_Triticale.htm or www.herbiguide.com.au for more information.

6 Agro Info. Triticale growing. http://agriculture.infoagro.com/crops/triticale-growing/

| Plant part | Description |
| --- | --- |
| Flower head | Compact spike, squarish in cross-section, awned (Photo 1) [5] |

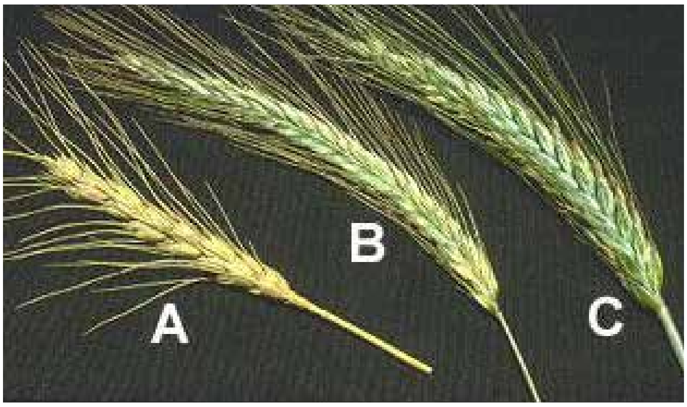


**Photo 1:** *vA comparison of flower heads. A: Bread wheat, B: Cereal rye and C: Triticale.*

Source: Palomar College

| Plant part | Description |
| --- | --- |
| Fruit | Grain |
| Seeds | Pale brown, dull, elongated oval, wrinkled grain, 8–12 mm long × 2.5–4 mm wide, 23–36 grains per gram; easily rubbed from the husks (Figure 1) |

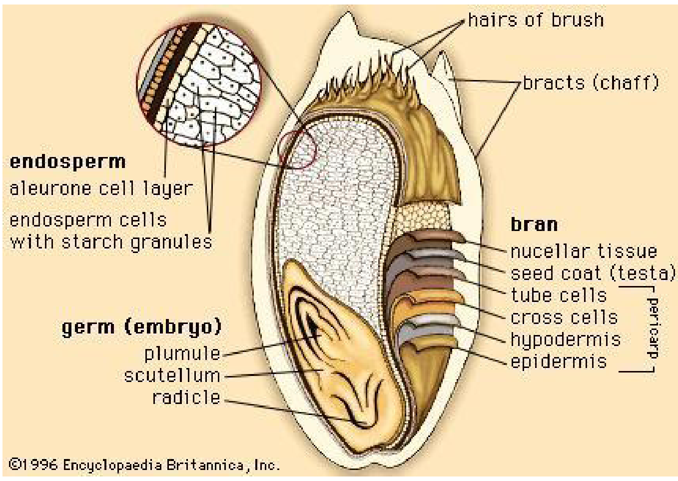


**Figure 1:** *Cross-section of cereal grain seed. This is rye, but triticale is similar.*

Source: Encyclopaedia Britannica

| Plant part | Description |
| --- | --- |
| Roots | Fibrous 2 [7] |

### *Identifying triticale seedlings*

Auricles blunt and hairy, leaf-sheath and blade hairy. Ligule of medium length. Leaf-blades twist clockwise.

Triticale and wheat are difficult to distinguish since their vegetative characters are similar. Removal of the seedling from the soil and observation of the grain shell may be a means of distinguishing wheat from triticale.

7 Triticale. Collated by HerbiGuide. http://www.herbiguide.com.au/Descriptions/hg_Triticale.htm or www.herbiguide.com.au for more information.

Wheat grain shells tend to be lighter in colour than triticale. Wheat shells are oval; triticale grain shells are oblong. [8]

## 4.1 Germination and emergence

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 heading 4. Plant growth stages, for detail on Zadoks Cereal Growth Stage Key)

Phase 1 starts when the seed begins to absorb moisture. Generally, a seed needs to reach a moisture content of around 35–45% of its dry weight to begin germination. Water vapour can begin the germination process as rapidly as liquid can.

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 therefore 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 grow visibly. 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. [9]

Triticale cultivation can be carried out in subtropical, moderately mild and moderately cold climates. Optimal temperatures are:

- Germination optimum temperature is 20°C
- Growth optimum temperature is 10-24°C
- Minimum temperature of survival is -10°C
- Maximum temperature of survival is 33°C [10]

In a study comparing the tolerance of cereal seeds to a range of temperatures, Triticale was more sensitive than wheat and barley to germination temperature. [11]

Thermal time to first seedling emergence for triticale has been recorded at between 113–119 days, and 127–130 days for 95% emergence. This equates to a rate of seedling emergence of 3.3–3.1% seedlings °Cd-1 (thermal time).

Very low temperatures can damage triticale seedling during germination and emergence (Photo 2).

8 Agriculture Victoria. (2012). Identification of cereal seedlings. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/identification-of-cereal-seedlings

9 NSW DPI District Agronomists (2007) *Wheat growth and development.* PROCROP Series, NSW Department of Primary Industries, https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

10 Agro Info. Triticale growing. http://agriculture.infoagro.com/crops/triticale-growing/

11 Buraas, T., & Skinnes, H. (1985). Development of seed dormancy in barley, wheat and triticale under controlled conditions. *Acta Agriculturae Scandinavica*, *35*(3), 233–244.

**Photo 2:** *Cold temperature damage in triticale.*

Source: Alberta Ag

Though triticale is generally considered tolerant to salt stress, studies have found that cultivars are slightly less salt tolerant at germination than they were after the three-leaf stage of growth. [12]

Early research found that saline soils could impair triticale emergence, with the application of Calcium sulphate (CaS04) helping to increase emergence under saline conditions. [13]

One study found that decreases in osmotic potential caused a reduction in germination percentage and seedling growth. Drought conditions had more negative effects on germination and seedling growth than that of Sodium Chloride. Germination and seedling growth were higher in large seeds than in small seeds in control solution and under osmotic stress. In addition, it was observed that seedlings obtained from larger seeds survived even at the low osmotic potential, whereas seedlings obtained from small seeds did not survive under intensive stress conditions. [14]

Excessive herbicide treatments may also limit germination in triticale. The successive effect of five herbicide variants (isoxaben, chlorsulfuron, isoproturon, chlortoluron and control) on the germination and plant growth of triticale cultivars has been explored. Germinative energy and germinating power of winter triticale seeds, obtained from plants treated with herbicide, were generally lower, in particular for the isoproturon and chlorsulfuron variants. [15]

Aeration of seed during storage can help to ensure high seed viability and germination rates. [16]

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

The coleoptile (Photo 3) is well developed in the embryo, forming a thimble-shaped structure covering the seedling tube leaf and the shoot. Once the coleoptile emerges from the seed, it increases in length until it breaks through the soil surface. The fully elongated coleoptile is a tubular structure about 50 mm long and 2 mm in diameter. It is white, except for two strands of tissue that contain chlorophyll. The end of the coleoptile is bullet-shaped and is closed except for a small pore, 0.25 mm long, and a short distance behind the tip.

12 Francois, L. E., Donovan, T. J., Maas, E. V., & Rubenthaler, G. L. (1988). Effect of salinity on grain yield and quality, vegetative growth, and germination of triticale. *Agronomy Journal*, *80*(4), 642–647.

13 Norlyn, J. D., & Epstein, E. (1984). Variability in salt tolerance of four triticale lines at germination and emergence. *Crop science*, *24*(6), 1090–1092.

14 Kaydan, D., & Yagmur, M. (2008). Germination, seedling growth and relative water content of shoot in different seed sizes of triticale under osmotic stress of water and NaCl. *African Journal of Biotechnology*, *7*(16), 2862.

15 Sławomir, S., & Robert, M. (1996). Successive effect of herbicides on triticale seed germination and plant growth. In *Triticale: Today and Tomorrow* (pp. 743–747). Springer Netherlands.

16 Baxter N. (2014). Ground Cover Issue113: Nov-Dec 2014 – Study finds aeration improves seed germination. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-113-NovDec-2014/Study-finds-aeration-improves-seed-germination

**Photo 3:** *Cereal seed germination showing the coleoptile (green) emerging to reach soil surface.*

Source: ICARDA

When the coleoptile senses light it stops growing and the first true leaf pushes through the pore at the tip. Up to this point, the plant is living on reserves within the seed. [17] The difference between the coleoptile and the first true leaf is that the coleoptile knows which way the soil surface is. If it does not reach the surface, the first leaf may emerge under the soil and grow in any direction.

Optimum planting depth varies with planting moisture, soil type, seasonal conditions, climatic conditions, and the rate at which the seedbed dries. The general rule is to plant as shallow as possible, provided the seed is placed in the moisture zone, but deep enough that the drying front will not reach the seedling roots before leaf emergence, or to separate the seed from any pre-emergent herbicides used. [18]

When shallow seeding, the previous crop's residue will have a greater tendency to interfere with good seed-to-soil contact. Even spreading of the previous crop residue is essential for quick emergence (Photo 4). Make sure seed-to-soil contact occurs. [19]

**Photo 4:** *Triticale seedling emergence.*

Source: Kaspar T in MCCC

17 NSW DPI District Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries, https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

18 NSW DPI Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries 2007, https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

19 Alberta Gov. (2016). Fall Rye Production. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf

Seed size influences coleoptile length which is sensitive to sowing depth. Sowing depth influences the rate of emergence and the percentage that emerges. Deeper seed placement slows emergence; this is equivalent to sowing later. Seedlings emerging from greater depth are also weaker, more prone to seedling diseases, and tiller poorly.

Recent research has confirmed the importance of avoiding smaller-sized seed when deep sowing.

Crop emergence is reduced with deeper sowing because the coleoptile may stop growing before it reaches the soil surface, with the first leaf emerging from the coleoptile while it is still below the soil surface. As it is not adapted to pushing through soil (does not know which way is up), the leaf usually buckles and crumples, failing to emerge and eventually dying. [20]

**Photo 5:** *GS11 – 1st unfolded leaf. Deep sown seedling (left) and correctly sown seedling (right).*

Source: GRDC

## 4.1.1 Soil 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. Instead of 5 days at 7°C when there is adequate moisture, germination will take 10 days at 7°C when soil reaches permanent wilting point.

The germination process in a seed may stop and start in response to available moisture. 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 amount of rain that keeps the soil moist for a few days before drying out. When the next rain comes, the seed resumes germinating, taking up water and moving quickly through Phase 2, so that germination is rapid.

20 NSW DPI Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries 2007, https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

This ability to start and stop the germination process (in response to conditions) before the roots and coleoptile have emerged is an important consideration when dry sowing.

If the seedbed dries out before the coleoptile has emerged, the crop needs to be monitored to determine whether it will emerge, so the critical decision to re-sow can be made.

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. In some crusting soils, gypsum and/or lime may improve soil structure and assist seedling emergence.

Stubble reduces the impact of raindrops on the soil surface and helps to prevent formation of soil crusts. 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. [21]

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

### 4.2.1 Temperature

One study explored the effect of high temperatures at different growth stages on triticale. Thermal treatments consistently reduced grain yield ($p<0.05$), the magnitude of the effect ranged between 5 and 52%. The highest effect was found when temperature increased during stem elongation (yield decrease: 46%), lowest when treatments were imposed during heading-anthesis (15%) and intermediate for treatments imposed during booting-anthesis (27%). Greatest yield losses were seen when plants were exposed to high temperatures in the booting-anthesis stage. [22]

Temperature can also affect the photosynthesis and respiration rates of triticale, leading to changes in growth. [23]

High temperatures are known to induce rapid growth which diminishes the cell pool of metabolites (e.g. amino acids, nitrates, carbohydrates) and therefore nutritional quality. [24]

### 4.2.2 Photoperiod

There is limited research into the effects of photoperiod on triticale growth, and results vary between studies.

The developmental responses to temperature and photoperiod of five triticale cultivars and one wheat cultivar were examined in the field in southern Australia in 1974. Six times of sowing and the use of supplemental illumination, providing an 18 hour daylength at one of the two sites, created a range of different photoperiod and temperature treatments. The order in which the varieties reached the various developmental stages changed very little with the successive times of sowing, but differed when the natural daylength was compared with the 18 hour regime. The duration of each phase was shortened by a longer mean daily photoperiod or a higher mean daily temperature, the photoperiod having a greater effect than the temperature. [25]

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21 NSW DPI District Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries, https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

22 Ugarte, C., Calderini, D. F., & Slafer, G. A. (2007). Grain weight and grain number responsiveness to pre-anthesis temperature in wheat, barley and triticale. *Field Crops Research*, *100*(2), 240–248.

23 Winzeler, M., McCullough, D. E., & Hunt, L. A. (1989). Leaf gas exchange and plant growth of winter rye, triticale, and wheat under contrasting temperature regimes. *Crop science*, *29*(5), 1256–1260.

24 McGoverin, C. M., Snyders, F., Muller, N., Botes, W., Fox, G., & Manley, M. (2011). A review of triticale uses and the effect of growth environment on grain quality. *Journal of the Science of Food and Agriculture*, *91*(7), 1155–1165.

25 Brouwer, J. B. (1977). Developmental responses of different hexaploid triticales to temperature and photoperiod. *Animal Production Science*, *17*(88), 826–831.

Spring Triticale is insensitive to photoperiod and have limited tillering. During the early stages of triticale breeding, spring types used in northern latitudes tended to be daylight sensitive, requiring in excess of 12 hours of light to initiate the change from the vegetative state. The development of daylight insensitive types has greatly eliminated this problem for the production of triticale at lower latitudes where day lengths are short. [26]

## IN FOCUS

### Yield determination in triticale as affected by radiation in different development phases

A field experiment was carried out with two triticales, differing in tillering capacity, subjected to shading treatments at five different timings from early tillering to maturity. Results showed that reductions in grain yield were more significant when shading was imposed during 3 weeks before and 1 week after anthesis. Reductions in grain yield by shading treatments were associated with lower number of grains per $m^2$ more than with changes in the average grain weight. Reductions in grains per $m^2$ were due to reductions in the number of fertile florets per spike, affecting grains per spike. The assimilate acquisition by the spikes during the critical period was a key determinant of floret survival. Grain number per $m^2$ was related with photothermal quotient during 30 days before anthesis and spike dry weight at anthesis, though the goodness of the prediction compared with wheat, was lowered by poorer grain setting percentage. [27]

### 4.2.3 Salinity

Research in Europe suggests that triticale is a fairly salt tolerant crop, and recommends its cultivation in saline soils instead of crops that are salt sensitive. [28]

Research in the US found that relative grain yield for triticale cultivars were unaffected by soil salinity up to 7.3 dS/m (electrical conductivity of the saturated-soil extracts in the rootzone). Each unit increase in salinity above 7.3 dS/m reduced grain yield by 2.8%. These results place triticale in the salt-tolerant category. Yield reduction resulted primarily from a reduction in spike number rather than from lower weight per spike or lower weight per individual seed. Cultivars were slightly less salt tolerant at germination than they were after the three-leaf stage of growth. [29]

26 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org.

27 Estrada-Campuzano, G., Miralles, D. J., & Slafer, G. A. (2008). Yield determination in triticale as affected by radiation in different development phases. *European Journal of Agronomy*, *28*(4), 597–605.

28 Koebner, R. M., & Martin, P. K. (1996). High levels of salt tolerance revealed in triticale. In *Triticale: Today and Tomorrow* (pp. 429–436). Springer Netherlands.

29 Francois, L. E., Donovan, T. J., Maas, E. V., & Rubenthaler, G. L. (1988). Effect of salinity on grain yield and quality, vegetative growth, and germination of triticale. *Agronomy Journal*, *80*(4), 642–647.

## IN FOCUS

### The Effect of Salt Stress on Photosynthetic Characteristics and Growth of Various Triticale

Six varieties of triticale cultivars were treated with NaCl in 0,50,100,200,300 mmol/L concentrations. After 15 days the photosynthetic rate, transpiration rate, stomatal conductance, intercellular $CO_2$ concentration, root length, height of seedling and fresh weight were examined. Findings indicate that the 50 mmol/L NaCl process can promote the photosynthetic rate and the growth of the seedlings. With the increase of the concentration of NaCl, the net photosynthetic rate, transpiration rate and stomatal conductance of the seedlings decreased, the intercellular $CO_2$ concentration showed regular changes, with the growth of seedlings impeded. [30]

One study found that germination of triticale under saline soil conditions could be improved by applying Salicylic acid. [31]

### 4.2.4 Drought

Since the early development of triticale, its tolerance to drought stress has increased compared to other cereals. [32]

A wide range of genotypic variability exists within triticale strains/cultivars with respect to drought tolerance. In addition, the usefulness of other parameters, e.g. leaf gaseous exchange and chlorophyll content, for measuring drought tolerance was assessed. Chlorophyll fluorescence and relative loss of intracellular electrolytes from leaf tissues were good indicators of drought resistance. An indication of drought tolerance in triticale has also been given by osmo-regulation capacity, light harvesting capacity and blue fluorescence. [33]

## IN FOCUS

### The role of stomatal conductance for water and radiation use efficiency of durum wheat and triticale in a Mediterranean environment

Stomatal conductance has proven to be important in determining the amount and efficiency with which water is used by cereal crops and the productivity of those crops. Field experiments in Italy compared stomatal conductance and stomatal conductance-related traits (i.e., carbon-isotope discrimination and infrared canopy temperature) of durum wheat and triticale in different environments, to evaluate the impacts on leaf transpiration efficiency and on water- and radiation-use efficiency. A large variation in stomatal conductance was observed between species, although differences decreased as development proceeded. The

30 The effect of salt stress on Photosynthetic characteristics and growth of various triticale. http://en.cnki.com.cn/Article_en/CJFDTOTAL-HSSZ200904022.htm

31 Ghodrat, V., Rousta, M. J., & Zare, N. (2013). Improving germination and growth of Triticale (X Triticosecale Wittmack) by priming with Salicylic acid (SA) under saline conditions. *International Journal of Agriculture and Crop Sciences*, *5*(16), 1832.

32 Jessop, R. S. (1996). Stress tolerance in newer triticales compared to other cereals. In *Triticale: today and tomorrow* (pp. 419–427). Springer Netherlands.

33 McGoverin, C. M., Snyders, F., Muller, N., Botes, W., Fox, G., & Manley, M. (2011). A review of triticale uses and the effect of growth environment on grain quality. *Journal of the Science of Food and Agriculture*, *91*(7), 1155–1165.

greater stomatal conductance of triticale before anthesis did not imply a greater soil water depletion because the good water availability allowed the development of dense canopies exerting a relevant aerodynamic resistance on water vapor fluxes. The greater radiation-use-efficiency of triticale associated with its greater stomatal conductance in pre-anthesis resulted in a greater biomass than durum wheat in correspondence with similar amounts of radiation intercepted and of water used. Transpiration efficiency of triticale was also higher at the crop level, despite similar transpiration efficiency at the leaf level. The greater stomatal conductance of triticale confers an advantage to this species in terms of both water and radiation use-efficiency despite the typical terminal drought affecting winter cereal crops in Mediterranean environments. [34]

In one experiment, triticale cultivars were subjected to drought during the tillering phase and heading phase, and maintained osmotic regulation (high osmotic potential). Consequently, these cultivars were able to maintain better leaf hydration and photosynthetic functioning. It is suggested that these are adaptation mechanisms, acting during drought, which can involve the inhibition of the utilization of carbohydrates in the growth processes of leaves and to maintain high osmotic potential of the cell sap. [35]

### Water stress

## IN FOCUS

#### Triticale grain yield and physiological response to water stress

Water availability in semi-arid regions is increasingly becoming threatened by erratic rains and frequent droughts leading to over-reliance on irrigation to meet food demand. Improving crop Water Use Efficiency (WUE) has become a priority. A two-year study was carried out with four moisture levels, ranging from well-watered (430–450 mm) to severe stress (SS) (220–250 mm), combined with four commercial triticale genotypes grown under field conditions in a hot, arid, steppe climate in South Africa. The results showed that moisture level significantly influenced grain yield and intrinsic WUE in triticale. Well-watered conditions increased grain yield, which ranged from 3.5 to 0.8 t ha−1and4.9–1.8 t ha−1in 2013 and 2014 respectively. Intrinsic WUE increased with decreasing moisture level. Flag leaf photosynthesis and pre-anthesis assimilates contribute much less carbon to grain filling under water stress than previously thought. [36]

34 Motzo, R., Pruneddu, G., & Giunta, F. (2013). The role of stomatal conductance for water and radiation use efficiency of durum wheat and triticale in a Mediterranean environment. *European Journal of Agronomy*, *44*, 87–97.

35 Hura, T., Hura, K., & Grzesiak, M. (2011). Soil drought applied during the vegetative growth of triticale modifies the physiological and biochemical adaptation to drought during the generative development. *Journal of Agronomy and Crop Science*, *197*(2), 113–123.

36 Munjonji, L., Ayisi, K. K., Vandewalle, B., Haesaert, G., & Boeckx, P. (2016). Combining carbon-13 and oxygen-18 to unravel triticale grain yield and physiological response to water stress. *Field Crops Research*, *195*, 36–49.

## 4.3 Plant growth stages

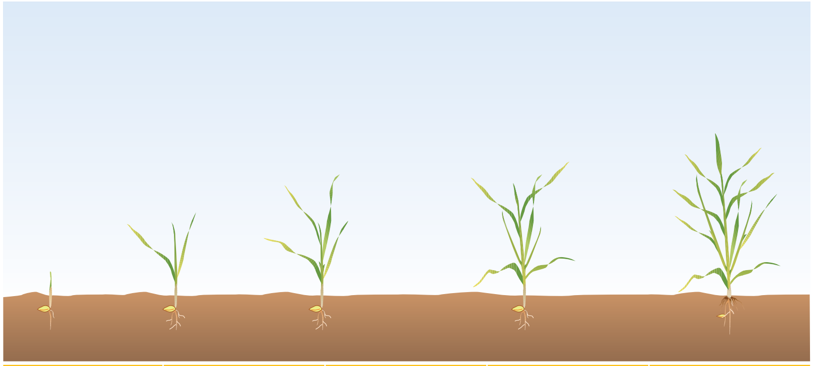
Plant development is divided into several stages: germination and early seedling growth, tillering and vegetative growth, elongation and heading, flowering, and kernel development. Numerical scales have been developed for quantifying growth stages of small grains. A growth stage key provides farmers, advisers and researchers with a common reference for describing the crop's development. Management by growth stage is critical to optimise returns from inputs such as N, herbicides, plant growth regulators and fungicides.

### 4.3.1 Zadoks cereal growth stage key

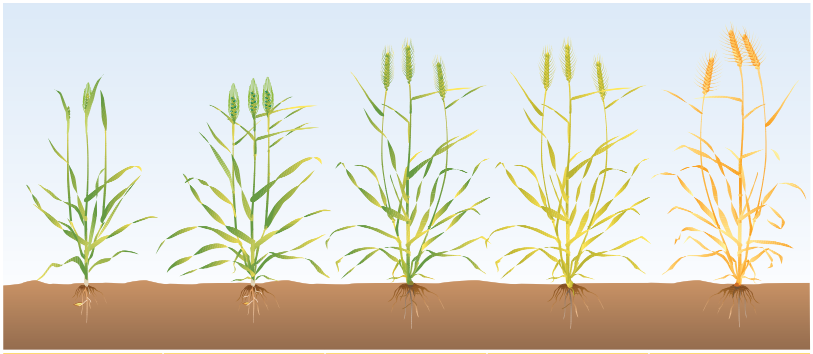
Zadoks growth stages in relation to 10 distinct development phases are depicted in Figure 2 and examples of cereal plants at various growth stages in Figure 3 and described in Table 2.

The Zadoks system uses a 2-digit code to refer to the principal stages of growth from germination (stage 0) through kernel ripening (stage 9). The second digit subdivides each principal growth stage. For instance, '13' indicates that in principal stage 1 (seedling growth) subdivision 3, leaves are at least 50 percent emerged from the main stem; '75' indicates that in principal stage 7 (kernel development) subdivision 5, the grain is at the medium milk stage.

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



| | | | | | |
|---|---|---|---|---|---|
| Zadoks Growth Stage | GS 00-09 | GS10-19 | GS20-29 | GS30-39 | GS40-49 |
| Development phase | Germination | Seedling growth | Tillering | Stem elongation | Booting |



| | | | | | |
|---|---|---|---|---|---|
| Zadoks Growth Stage | GS 50-59 | GS60-69 | GS70-79 | GS80-89 | GS90-99 |
| Development phase | Ear emergence | Flowering | Milk development (grain fill period) | Dough development (grain fill period) | Ripening |

**Figure 2:** *Zadoks cereal growth stages.*

Source: GRDC

**Table 2:** *Cereal Growth Stages.*

| **Crop growth stage** | | | | | |
|---|---|---|---|---|---|
| 2-leaf stage | Start of tillering | Tillering stage | Fully tillered stage | Start of jointing | Early boot stage |
| Two leaves (L) have unfolded; third leaf present, yet to fully expand. | First tiller (T1) appears from between a lower leaf and the main shoot. Usually 3 or 4 leaves are on the main tiller. | Tillers come from the base where leaves join the stem and continue forming, usually until there are 5 leaves on the main shoot. Secondary roots developing. | Usually no more tillers form after the very young head starts forming in the main tiller. Tillering completed when first node detected at base of main stem. | Jointing or node formation starts at the end of tillering. Small swellings – joints – form at the bottom of the main tiller. Heads continue eveloping and can be seen by dissecting a stem. | The last leaf to form – the flag leaf – appears on top of the extended stem. The developing head can be felt as a swelling in the stem |
| Zadoks decimal code | | | | | |
| 2 leaves unfolded (Z12). | 4 leaves unfolded (Z14).<br>Main shoot and 1 tiller (Z21). | 5 leaves on main shoot or stem (Z15).<br>Main shoot and 1 tiller (Z21). | 6 leaves on the main shoot or stem (Z16).<br>Main shoot and three tillers (Z23). | First node formed at base of main tiller (Z31). | Z35–Z45. |

Source: NSW DPI

**Table 3:** *Zadoks growth key – key points:*

- The Zadoks Growth Stage key does not run chronologically from GS00 to 99, for example when the crop reaches 3 fully unfolded leaves (GS13) it begins to tiller (GS20), before it has completed 4, 5, 6 fully unfolded leaves (GS14, 15, 16).
- 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 e.g. GS22 is main stem plus 2 tillers up to GS29 main stem plus 9 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 (2nd node on the main stem) with 3 tillers and 7 leaves on the main stem would be at GS32, 23, 17, yet practically would be regarded as GS32, since this describes the most advanced stage of development.
- NOTE: 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 e.g. GS39 is full flag leaf on the main stem, meaning that not all flag leaves in the crop will be fully emerged. [37]

## 4.3.2 Germination and early seedling growth

The kernel (seed), or caryopsis, consists of a seed coat surrounding an embryo and endosperm. The embryo contains the seedling root (radicle), stem, and growing points of the new grain plant. The endosperm provides nutrients for growth until the first true leaves emerge and the root system is established. When moisture conditions are favorable, the seed germinates with the emergence of the radicle and the coleoptile, the first leaf that forms a protective sheath around the first four leaves.

The primary root system includes the radicle and roots that develop from stem tissue near the kernel (Figure 3). It may penetrate the soil up to 30 cm and provides the developing seedling with water and nutrients. The primary root system supports plant growth until tillering, when the secondary root system becomes the main root system of the plant. The primary roots may persist for the life of the plant and can

37 GRDC (2005). Cereal growth stages – the link to crop management. https://www.researchgate.net/file.PostFileLoader.html?id=5780fa6bf7b67e860b4def31&assetKey=AS%3A381929540079624%401468070506798

support some plant growth through the heading stage. The first secondary roots appear at the tillering node about 2.5 cm below the soil line at the two- or three-leaf stage. These roots are always produced at about the same distance below the soil's surface, regardless of the depth at which the seed is planted. The secondary root system makes up the major part of the fully developed plant's root system.

Root development approaches the maximum at about the boot stage. The 'boot' represents the swollen flag leaf sheath within which the developing spike is located after being pushed up as the stem has elongated.

As the seedling root system is forming, the coleoptile grows upward and ruptures, allowing the first leaf to begin unfolding as soon as the coleoptile tip breaks the soil surface. Emergence usually occurs 6 to 20 days after sowing, depending on temperature and moisture. Emergence can be later than 20 days after sowing under prolonged cold or dry conditions. Initial formation of leaves and stems occurs at the shoot apex, which is located just below the soil surface.

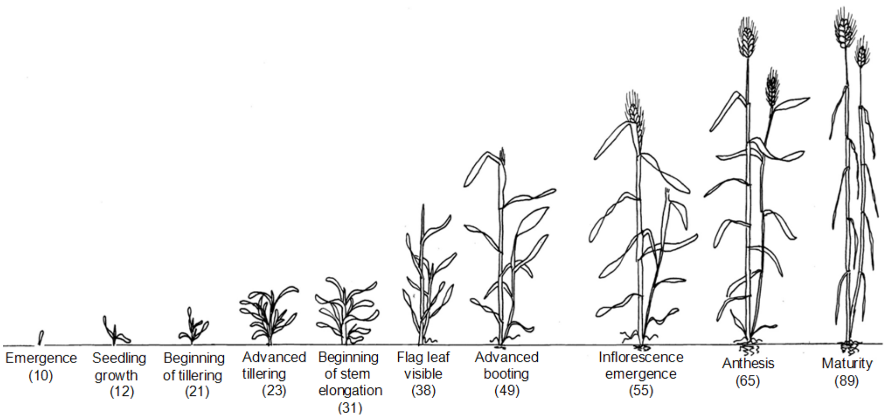



**Figure 3:** *Growth stages of small-grain cereals. Numbers correspond to the Zadoks growth key.* [38]

## 4.3.3 Tillering and vegetative growth

Branching in small grains is called tillering or stooling. Individual branches are called tillers, and the mass of tillers is the stool. Two to four primary tillers develop from buds in the crown area of the main stem. Secondary tillers develop from buds in the axils of leaves at the base of the primary tillers. Tertiary tillers may develop from buds in the axils of leaves at the base of the secondary tillers.

The number of tillers that form is influenced by plant density (more with low plant density), soil moisture and nutrient supply (more with high supply), sowing date (more with early sowing), temperature (more under cooler temperatures), and cultivar. Water stress, nutrient deficiency, low temperatures, weed competition, and pest damage during early development reduce the number of tillers.

The emergence of primary tillers is synchronous with the emergence of leaves on the main stem of the plant (Photo 6). The first primary tiller begins developing as leaf 4 of the main stem emerges; the second primary tiller begins developing as leaf 5 emerges. Subsequent primary tillers begin developing when subsequent leaves emerge.

Successive tillers develop fewer leaves; flowering and grain development is only slightly delayed on later-developing tillers. Before the main stem and tillers begin to elongate, the spikes differentiate. The precursors (primordia) of all florets (flowers with lemma and palea, the outer bracts) or spikelets (units consisting of several florets on a thin axis, subtended at the base by two bracts, or glumes) develop at this time.

38 Royo, C., & Villegas, D. (2011). *Field measurements of canopy spectra for biomass assessment of small-grain cereals*. INTECH Open Access Publisher.

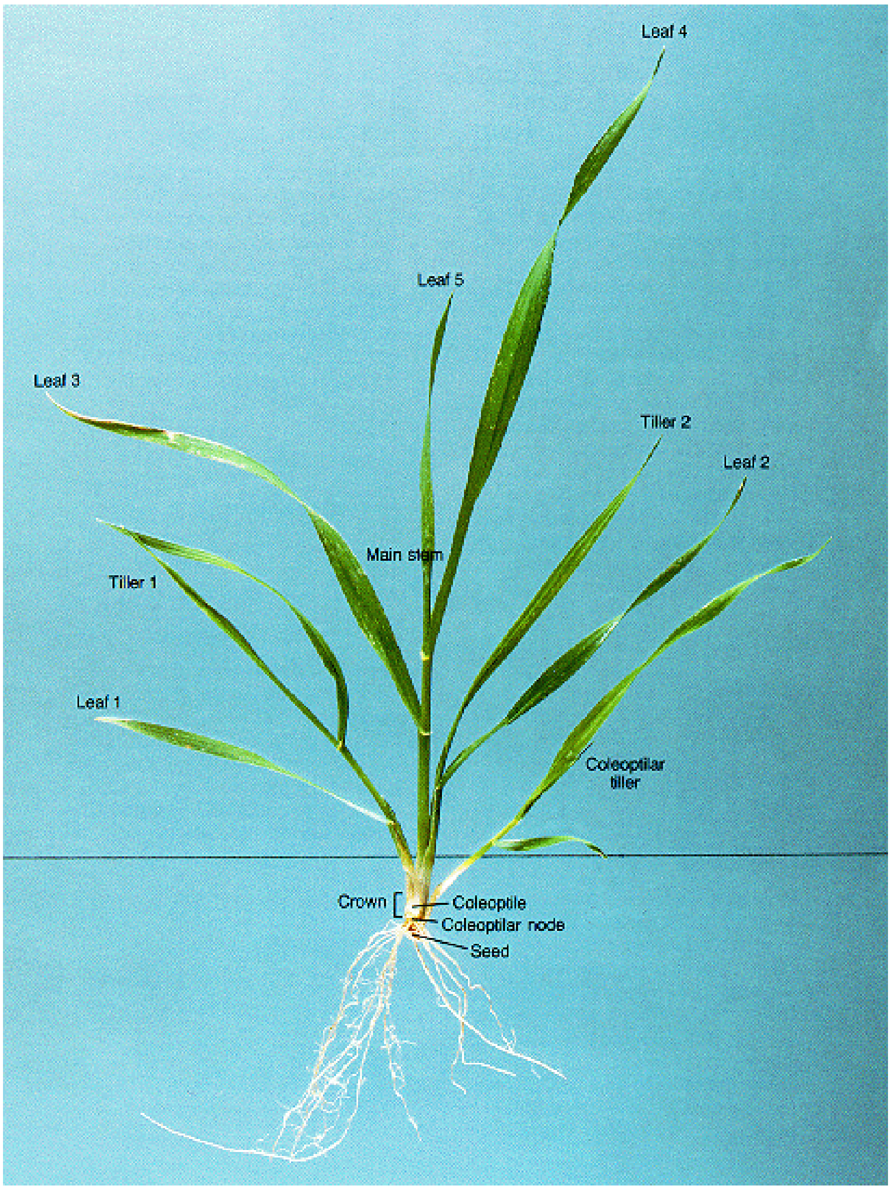



**Photo 6:** *Plant parts in relation to growth stage.*

Source: Wisc Edu

### 4.3.4 Stem elongation and heading

Stem elongation, or jointing, occurs when stem internodes increase in length and bring the nodes above ground. The uppermost five or six internodes elongate, beginning with the lowest of these. The appearance of the first node above ground marks the beginning of jointing. Jointing begins about the time all spikelet primordia have formed. The flowering structure (inflorescence) of triticale, wheat and barley is called a spike. Inflorescences are composed of spikelets, each consisting of one or more flowers, called florets, at nodes along the spike or panicle.

During stem elongation, the spike increases in length from about 3 mm to its final size, and individual florets mature. All stages of spikelet development in triticale, wheat and barley begin near the middle of the spike and proceed toward the base and tip.

The last leaf of the small grain plant to emerge is called the flag leaf. When the flag leaf blade has completely emerged, the appearance of its ligule (a short membrane on the inside of the leaf at the junction of the blade and sheath) marks the beginning of the boot stage. During boot stage the enlarging spike swells and splits the sheath of the flag leaf. Heading begins when the spike begins emerging through the flag leaf collar and is complete when the base of the spike is visible.

### 4.3.5 Flowering and grain filling

The flowers of triticale, wheat, barley, and oat are self-pollinated; most of the pollen is shed before the anthers emerge from the florets. Flowering (anthesis, or pollen shed) usually occurs within 2 to 4 days after spikes have completely emerged from the boot. If emergence occurs during hot weather, flowering may occur while spikes are still in the boot. Most cells of the grain endosperm are formed during a period of rapid cell division following pollination. These cells enlarge and accumulate starch during grain filling. Most of the carbohydrate used for grain filling comes from the photosynthetic output of the flag leaf. Developing spikelets compete for limited supplies of photosynthate and nitrogen. The smallest, slowest-growing florets, which occur at the tip of the spikelet, are often unable to obtain enough nutrients to keep growing. Some spikelets at the base of the cereal spike also may fail to develop.

The stages of grain ripening are called milk, soft dough, hard dough, hard kernel, and harvest ripe (Photo 7). Dry matter begins accumulating in the kernel during the milk stage. During early milk stage, a clear fluid can be squeezed from the kernel. During late milk stage, milky fluid can be squeezed from the kernel. Most of the dry matter accumulates during the soft dough stage. Loss of water gives the kernel a doughy or mealy consistency. At the end of the hard dough stage the kernel reaches physiological maturity, water content drops to about 30 percent, and the plant loses most of its green color. The kernel contents can be divided with a thumbnail. At the hard kernel stage the plant is completely yellow and water content of the kernel is 20 to 25%. The contents of the kernel are difficult to divide with a thumbnail, but its surface can be dented. When kernel moisture content has dropped to 13 to 14%, the grain is harvest ripe. The surface of the kernel cannot be dented with a thumbnail. [39]

39 Jackson L, Williams J. (2006). Small grain production 2 – Growth and developments of Small grains. University of California. http://anrcatalog.ucanr.edu/pdf/8165.pdf

**Photo 7:** *Stages of cereal grain ripening from the milky stage (top) to the harvest ripe stage(bottom),*

Source: UCANR

## 4.3.6 Triticale growth

One of the advantages of triticale compared to wheat and barley is its early vigour, which enables fast crop growth during the first stages of development and a rapid cover of the soil by the crop canopy (Photo 8).


**Photo 8:** *Triticale 50 days after emergence.*

Source: Kaspar T in MCCC

Trials in the UK compared triticale growth to wheat growth. It found a noticeable difference between the species in the length of key growth phases. The growth phase from drilling to growth stage, (GS31 - first node detectable) was, on average, 8.5 days shorter for the triticale, and GS31 to flowering (GS61) 1.75 days shorter than the wheat. The grain filling phase (GS61 to harvest) was considerably (10.6 days) longer in the triticale, though (Figure 4). However, this longer grain filling phase did not confer a greater thousand grain weight (TGW) to the triticale varieties. Instead, this extra time was needed to fill the greater number of grains per ear that triticale has compared to wheat.

Despite having a shorter duration to flowering, triticale formed more biomass during this phase than wheat. Both triticale varieties formed more biomass than both wheats, but only for Benetto were the increases significant. This was associated with both a greater number of stems and a greater biomass per stem. The relative differences between the biomass of the different species at GS61 translated into differences at harvest, where triticale produced greater yield. It can be seen that the yield advantages of triticale come from a combination of a greater number of ears per $m^2$ and more grains per ear that are filled during a longer grain-filling period. These are supported by greater biomass that is evident throughout the season. [40]

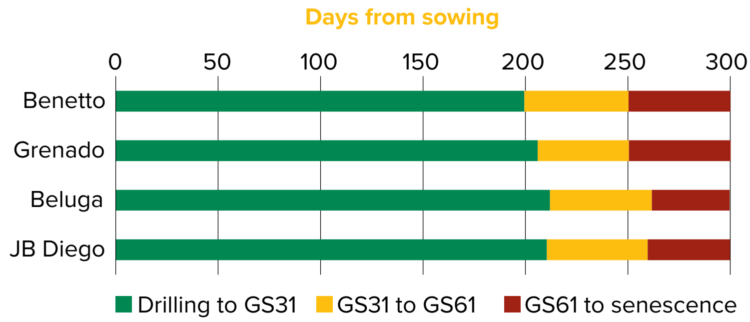



**Figure 4:** *Length of key growth phases of two triticale (Benetto, Grenado) and two wheat (Beluga, JB Diego) varieties: Drilling to GS31, GS31 to GS61, and GS61 to harvest. Results are an average of two experiments. Plots grown at 180 kg N/ha.* [41]

Although triticale has a very large seed and a very robust embryo, in cooler climates it has been observed in the early stages of development to be slow growing compared to other cereal species. This may be due to the early development of a massive

40 Clarke S, Roques S, Weightman R, Kindred D. (2016). Understanding Triticale. https://cereals.ahdb.org.uk/media/897536/pr556-understanding-triticale.pdf

41 Clarke S, Roques S, Weightman R, Kindred D. (2016). Understanding Triticale. https://cereals.ahdb.org.uk/media/897536/pr556-understanding-triticale.pdf

root system versus early top growth, which is in contrast to the general perception that triticale as a species is a very robust and competitive crop during its growth in many of its adapted growing zones. Triticale seed size is generally bigger than that of commonly grown wheat varieties. Consequently spring triticale can be seeded deeper than other small cereals and therefore benefit from stored moisture in the soil, which allows better crop establishment early in the season, particularly in drought-prone areas. Seeding equipment needs to be seed to account for a seed that may be 10 to 20% larger than wheat. [42]

Spring triticale does not require vernalisation to go from vegetative to reproductive stages. These types exhibit upright growth and produce much more forage early in their growth. They are insensitive to photoperiod and have limited tillering. [43]

Triticale cultivars tiller less profusely than wheat cultivars of similar maturity. [44] Significant differences in tillering abilities between triticale and wheat influences management practices, such as seed rate or amount of fertiliser applied. Adding N increased tiller and ear numbers in three cereals (triticale, wheat and rye), however, triticale produced fewer tillers and the response to N was significantly greater than wheat and rye. Triticale compensated for having fewer tillers by producing more spikelets per ear and setting more grains/spikelet, thereby producing more grains/pot than the other two cereals. Average kernel weights of triticale were also greater than those of wheat and rye. Total water use (WUE) of triticale was less than that of the other cereals, particularly at the higher rates of N. This experiment showed that the yield of triticale was not restricted by less profuse tillering and it was able to compensate by producing more grains per ear and heavier kernels. Indeed, Currency's restricted tiller production was associated with lower WU and higher WUE. [45]

Triticale flowers earlier than most wheats, but matures at about the same time.

## IN FOCUS

### Variation in temperate cereals in rainfed environments II. Phasic development and growth

Barley yields more grain and total biomass than does triticale which in turn yields more biomass than do bread wheat, durum wheat and oats when sown at the same time in rainfed environments in southern Australia. To determine reasons for these differences, cultivars of each species were grown at five field sites and variation in their phenology and both pre- and post-anthesis growth was measured. Barley achieved a higher yield of grain and biomass in a shorter duration than the other species. It reached physiological maturity about 10 days (180 thermal units) before the other species, and reached double ridge and anthesis earlier. Triticale was also earlier to reach double ridge and terminal spikelet than the mean for the other species, although it had a similar physiological maturity to the wheats. Barley and triticale developed a greater leaf area and dry mass faster than the wheats and oats. The differences in leaf area was established from the time the first leaf had fully expanded. Barley also developed mainstem leaves and tillers faster than the other species whereas triticale was slower in this respect. Crop growth rate was greatest in barley and triticale up to anthesis, but no differences between species were found in their relative growth rates. The growth rate of individual grains and of total grain per unit ground area were substantially greater in barley than the other species. Oats and durum wheat had the slowest individual grain and total grain

42 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org

43 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

44 I. McDonald, G.K., Sutton, B.G. and Ellison, F.W. (1984). Aust. J. Exp. Agric. Anim. Husb. 24, 236–243.

45 Golding, J. B. Restricted tillering in triticale cv. currency-an impediment to grain yield? http://www.regional.org.au/au/asa/1989/contributed/crop/p1-20.htm

growth rates. Grain growth rate per unit ground area was significantly associated with grain yield at one site where this was examined. The change in stem mass between anthesis and physiological maturity, which was determined to assess the possible contribution of stem reserves to grain, was also positively associated with grain yield at the two sites where it was determined, and more so at the drier site. The change in stem mass averaged 76 g $m^{-2}$ at the two sites and this represented 25% of the total grain yield. However, the range varied from 13 to 39% of grain yield (corrected for husk mass in barley and oats). The loss in leaf sheath mass averaged 68 g $m^{-2}$ at both sites; this was not associated with grain yield. [46]

Anthesis generally occurrs 14 days after apical spikelet emergence for triticale. [47]

Early research explored the physiological maturity in seeds of two triticale cultivars. Maximum germination, dry weight, and seedling vigour were attained 24 to 26 days after anthesis. Some seeds were capable of germination 8 days after anthesis. Moisture content decreased slowly from over 78 to 41% at which time functional maturity was attained. After this stage loss of moisture was accelerated and the seed entered into the ripening phase. [48]

In dry springs triticale yields are 10–15 per cent below wheat, due to triticale's longer grain filling period. Triticale usually flowers earlier than wheat planted at a similar time, however grain filling takes longer and grain size may suffer in a hot dry finish (Photo 9). [49]


**Photo 9:** *Triticale flowering (left) before grain fill (right).*

Source: KT Farmlife and Living Crop Museum

46 López-Castañeda, C., & Richards, R. A. (1994). Variation in temperate cereals in rainfed environments II. Phasic development and growth. *Field Crops Research*, *37*(1), 63–75.

47 Tshewang S. (2011). Frost tolerance in Triticale and other winter cereals at flowering. https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

48 Bishnoi, U. R. (1974). Physiological Maturity of Seeds in Triticale hexaploid L. *Crop Science*, *14*(6), 819–821.

49 Birchip Cropping Group. (2004). Triticale agronomy – 2004. http://www.farmtrials.com.au/trial/13801