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TRITICALE

SECTION 4

PLANT GROWTH AND PHYSIOLOGY

IDENTIFYING TRITICALE | GERMINATION AND EMERGENCE | EFFECT OF TEMPERATURE, PHOTOPERIOD AND CLIMATE 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.
- Though triticale is generally considered tolerant to salt stress, studies have found that cultivars are slightly less salt tolerant at germination. [2]
- Since the early development of triticale, its tolerance to drought stress has increased compared to other cereals.

4.1 Identifying triticale

The key characters of triticale are (see Table 1):

- Emerging leaves are rolled in the shoot.
- The leaf blade is flat with a clockwise twist.
- It has a short, membranous ligule.
- It has auricles.
- Seed is a grain similar to that of wheat. [3]
- It grows to a height of about 1–1.5 m.
- The leaves are like those of wheat, but larger and thicker. The spikes are also larger. [4]

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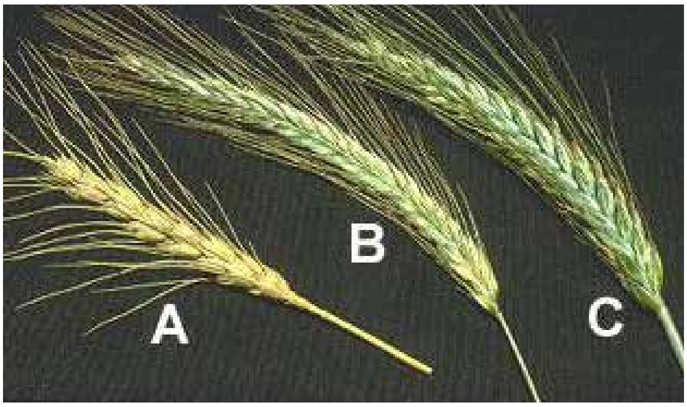
[1] Hill Laboratories. Crop guide: Triticale. KB item 28750v1. Hill Laboratories, http://www.hill-laboratories.com/file/fileid/34912

[2] LE Francois, TJ Donovan, EV Maas, GL Rubenthaler (1988) Effect of salinity on grain yield and quality, vegetative growth, and germination of triticale. Agronomy Journal, 80 (4), 642–647.

[3] HerbiGuide. Triticale. HerbiGuide, http://www.herbiguide.com.au/Descriptions/hg_Triticale.htm; see also HerbiGuide, www.herbiguide.com.au

[4] Infoagro (n.d.) Triticale growing. Infoagro Systems, http://agriculture.infoagro.com/crops/triticale-growing/

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
Flower head	Compact spike, squarish in cross-section, awned (Figure 1) [5]  **Photo 1:** *vA comparison of flower heads. A: Bread wheat, B: Cereal rye and C: Triticale.* Source: Palomar College
Fruit	Grain

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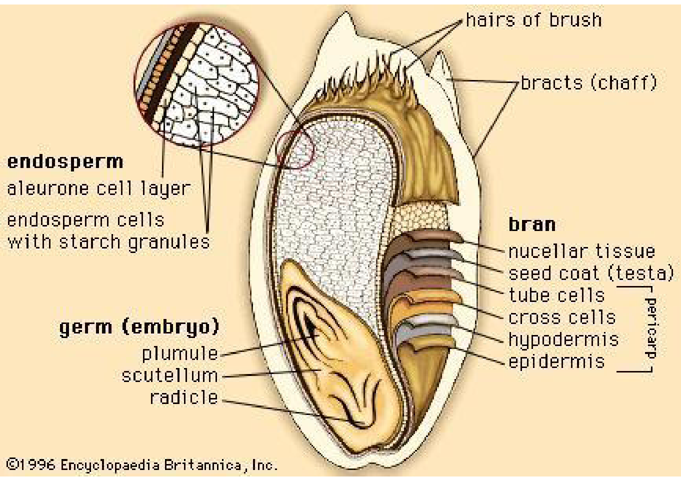
[5] Photos of some important cereal grains. Wayne's World. Palomar College, http://waynesword.palomar.edu/ecoph12.htm

Plant part	Description
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 2)  **Figure 1:** *Cross-section of cereal grain seed. This is rye, but triticale is similar.* Source: Encyclopaedia Britannica
Roots	Fibrous 2 [6]

Source: Wheat and triticale are difficult to distinguish, since their vegetative characteristics are similar. Removal of the seedling from the soil and observation of the grain shell may be a means of distinguishing wheat from triticale. Wheat grain shells tend to be lighter in colour than triticale. Wheat shells are oval; triticale grain shells are oblong. [7] In both, the auricles are blunt and hairy, and the leaf sheath and blade hairy too. The ligule is of medium length. Leaf blades twist clockwise.

4.2 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

The growth stages of cereals are numbered according to the Zadoks scale (see section 4.4.1).

Phase 1: Water absorption

Phase 1 starts when the seed begins to absorb moisture. This is growth stage 1 (GS01) in the Zadoks scale. Generally, a seed needs to reach a moisture content of around 35–45% of its dry weight to begin to germinate. Water vapour can trigger germination as rapidly as liquid can.

Seeds begin to germinate at a relative humidity of 97.7%. Soil so dry that roots cannot extract water from it still has a relative humidity of 99%, which is much higher than that of a dry seed. So even in dry conditions there can be enough moisture for the seed to absorb moisture and begin Phase 1, but it takes longer than in moist conditions.

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[6] HerbiGuide. Triticale. HerbiGuide, http://www.herbiguide.com.au/Descriptions/hg_Triticale.htm; see also HerbiGuide, www.herbiguide.com.au

[7] Agriculture Victoria (2012) Identification of cereal seedlings. Note AG0102. Revised. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/identification-of-cereal-seedlings

Phase 2: Activation

Once the embryo has swollen, it produces hormones that stimulate enzyme activity (GS03). This is Phase 2. The enzymes break starch and protein stored in the seed into sugars and amino acids, which provide energy to the embryo. The larger the seed, the more starch, and therefore energy it will have stored. 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

In Phase 3 (GS05–GS09), 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. [8]

Conditions of germination

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

- for germination, 20°C
- for growth, 10–24°C

In a study comparing the tolerance of cereal seeds to a range of temperatures, triticale was found to be more sensitive than wheat and barley to germination temperature. [9] Very low temperatures can damage triticale seedling during germination and emergence (Photo 2). [10]

The minimum temperature at which triticale can survive is –10°C, and the maximum is 33°C. [11]

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

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

Source: Alberta Agriculture and Forestry

Though triticale is generally considered to be tolerant to salt stress, studies have shown that cultivars are slightly less salt tolerant at germination than they became after the three-leaf stage of growth. [12] Early researchers found that saline soils could

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[8] NSW DPI District Agronomists (2007) Wheat growth and development. Procrop Series. NSW DPI, http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/growth-and-development

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

[10] Alberta Agriculture and Forestry (2016) Triticale crop production. Revised. Alberta Agriculture and Forestry, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571

[11] Infoagro (n.d.) Triticale growing. Infoagro Systems, http://agriculture.infoagro.com/crops/triticale-growing/

[12] LE Francois, TJ Donovan, EV Maas, GL Rubenthaler (1988) Effect of salinity on grain yield and quality, vegetative growth, and germination of triticale. Agronomy Journal, 80 (4), 642–647.

impair triticale emergence, although the application of calcium sulfate (CaS04) helped to increase emergence in these conditions. [13]

In one study, researchers found that drought conditions had more negative effects on triticale germination percentage and seedling growth than 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 could survive under more intense conditions than those that grew from small seeds. [14]

Excessive herbicide treatments may also limit germination in triticale. The successive effect of five herbicide variants (isoxaben, chlorsulfuron, isoproturon, chlortoluron and a 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 (Photo 3) 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 is well developed in the embryo, where it forms 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, a short distance behind the tip.

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

Source: Crop Gene Bank

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 has been living on reserves within the seed. [17] A difference between the coleoptile and the first true leaf is that

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[13] JD Norlyn, E Epstein (1984) Variability in salt tolerance of four triticale lines at germination and emergence. Crop Science, 24(6), 1090–1092.

[14] D Kaydan, M Yagmur (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] S Sławomir, M Robert (1996) Successive effect of herbicides on triticale seed germination and plant growth. In H Guedes-Pinto, N Darvey, V Carnide (eds) Triticale: Today and Tomorrow. Springer Netherlands, pp. 743–747.

[16] N Baxter (2014) Study finds aeration improves seed germination. Ground Cover. No. 113, November–December. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-113-NovDec-2014/Study-finds-aeration-improves-seed-germination

[17] NSW DPI District Agronomists (2007) Wheat growth and development. Procrop Series. NSW DPI, http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/growth-and-development

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. This is one reason that planting depth is so important.

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, and 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. To enhance quick emergence, it is important that previous crop residue is evenly spread (Photo 4). Make sure seed-to-soil contact occurs. [19]

Photo 4: *Triticale seedlings emerge.*

Source: Midwest Cover Crops Council

Sowing depth may influence the rate of emergence and the percentage of seedlings that emerge. Deeper seed placement may slow emergence if the soil is dry; this is equivalent to sowing later. Seedlings emerging from greater depth may be weaker and more prone to seedling diseases, however this is more likely due to unsuitable temperature, moisture or nutritional conditions (see Photo 5). [20] Crop emergence can be 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 (i.e. does not 'know' which way is up), the leaf usually buckles and crumples, failing to emerge and eventually dying. [21] Recent research has confirmed the importance of avoiding smaller-sized seed when deep sowing.

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[18] NSW DPI Agronomists (2007) Wheat growth and development. Procrop Series. NSW DPI, http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/growth-and-development

[19] Alberta Agriculture and Forestry (2016) Fall Rye Production. Agdex 117/20-1. Revised. Alberta Agriculture and Forestry, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf

[20] N Poole (2005) Cereal Growth Stages. GRDC, https://grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf

[21] NSW DPI Agronomists (2007) Wheat growth and development. Procrop Series, NSW DPI, http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/growth-and-development

Photo 5: *By the stage of the first unfolded leaf, GS11, there is a noticeable difference in vigour between a deep-sown seedling (left) and correctly sown seedling (right).*

Source: GRDC

4.2.1 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 taking five days at 7°C, the germination speed with adequate moisture, at the point of permanent wilt, the seed will take 10 days at 7°C to germinate.

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. This ability to start and stop the germination process 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. [22]

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

4.3.1 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 ranging between 5% and 52%. The greatest effect (46% yield decrease) was found when temperature increased during stem elongation, and the least (15%) when treatments were imposed during heading–anthesis; an intermediate effect (27%) was found when treatments were imposed during booting–anthesis. Greatest yield losses were seen when plants were exposed to high temperatures in the booting–anthesis stage. [23]

Temperature can also affect the photosynthesis and respiration rates of triticale, leading to changes in growth. [24]

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. [25]

4.3.2 Photoperiod

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

Spring is thought to be triticale is insensitive to photoperiod. During the early stages of triticale breeding, spring types used in northern latitudes tended to be daylight-sensitive, requiring more than 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]

The developmental responses to temperature and photoperiod of five triticale cultivars and one wheat cultivar were examined in the field at Werribee, Victoria, in 1974. Researchers created a range of different photoperiod and temperature treatments by using six times of sowing and supplemental illumination to provide an 18-hour day length at one of the two sites. 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 day length was compared with the 18-hour regime. When the duration of each phase was shortened by a longer mean daily photoperiod or a higher mean daily temperature, they observed that, in this instance, photoperiod had a greater effect than the temperature. [27]

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[22] NSW DPI District Agronomists (2007) Wheat growth and development. Procrop Series. NSW DPI, http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/growth-and-development

[23] C Ugarte, DF Calderini, GA Slafer (2007) Grain weight and grain number responsiveness to pre-anthesis temperature in wheat, barley and triticale. Field Crops Research, 100 (2), 240–248.

[24] M Winzeler, DE McCullough, LA Hunt (1989) Leaf gas exchange and plant growth of winter rye, triticale, and wheat under contrasting temperature regimes. Crop Science, 29 (5), 1256–1260.

[25] CM McGoverin, F Snyders, N Muller, W Botes, G Fox, M Manley (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.

[26] M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/3/a-y5553e/y5553e00.pdf

[27] JB Brouwer (1977) Developmental responses of different hexaploid triticales to temperature and photoperiod. Animal Production Science, 17 (88), 826–831.

4.3.3 Salinity

Triticale has been found to be a salt tolerant crop. [28] Triticale is thought to be less salt tolerant that barley, but more salt tolerant than wheat. Studies in the US found that relative grain yield for triticale cultivars was unaffected by soil salinity up to 7.3 dS/m (electrical conductivity of the saturated-soil extracts in the root zone). Each unit increase in salinity above this reduced grain yield by 2.8%. These results place triticale in the salt-tolerant category. Yield reduction was primarily from a reduction in spike number rather than from lower weight per spike or lower weight per individual seed. These cultivars were slightly less salt tolerant at germination than they were after the three-leaf stage of growth. [29]

IN FOCUS

The affect of salt stress on photosynthetic characteristics and growth of triticale

Researchers treated six triticale cultivars with sodium chloride (NaCl) in concentrations of 0.5, 100, 200, 300 mmol/L. After 15 days, they measured the photosynthetic rate, transpiration rate, stomatal conductance, intercellular carbon dioxide (CO_2) concentration, root length, seedling height and fresh weight. They found that the 50 mmol/L NaCl process promoted the photosynthetic rate and the growth of the seedlings. However, as the concentration of NaCl increased, the net photosynthetic rate, transpiration rate and stomatal conductance of the seedlings decreased, the intercellular CO_2 concentration showed regular changes, and the growth of seedlings impeded. [30]

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

4.3.4 Drought

Triticale shows some drought tolerance due to its early vigour stemming from its cereal rye heritage. In Australia, triticale has often been more adaptable to drought conditions than wheat and barley. In triticale, tolerance to drought stress has increased with breeding compared to other cereals. [32]

A wide range of genotypic variability exists within triticale strains and cultivars show a wide range of tolerances to drought. [33]

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[28] RM Koebner, PK Martin (1996) High levels of salt tolerance revealed in triticale. In H Guedes-Pinto, N Darvey, V Carnide (eds) Triticale: Today and Tomorrow. Springer Netherlands, pp. 429–436.

[29] LE Francois, TJ Donovan, EV Maas, GL Rubenthaler (1988) Effect of salinity on grain yield and quality, vegetative growth, and germination of triticale. Agronomy Journal, 80 (4), 642–647.

[30] LR Shi, XG Cui, YX Zhu (2009) The effect of salt stress on photosynthetic characteristics and growth of various triticale. Journal of Hengshui University 2009–04, http://en.cnki.com.cn/Article_en/CJFDTOTAL-HSSZ200904022.htm

[31] V Ghodrat, MJ Rousta, N Zare (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] RS Jessop (1996) Stress tolerance in newer triticales compared to other cereals. In H Guedes-Pinto, N Darvey, V Carnide (eds) Triticale: Today and Tomorrow. Springer Netherlands, pp. 419–427.

[33] CM McGoverin, F Snyders, N Muller, W Botes, G Fox, M Manley (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.

IN FOCUS

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

Stomatal conductance is important in crop water-use and ultimately affects crop productivity. Researchers in the Mediterranean-type climate of Italy tested the stomatal conductance of durum wheat and triticale in different environments. They compared leaf-transpiration efficiency and water- and radiation-use efficiency between the two species, giving an indication of crop productivity in different environments.

A large variation in stomatal conductance was observed between species. The greater stomatal conductance of triticale before anthesis did not deplete soil water as there was adequate water available for the development of dense canopies. The greater radiation-use efficiency of triticale associated with greater stomatal conductance in pre-anthesis resulted in greater biomass than durum wheat. Transpiration efficiency of triticale was also higher at the crop level, in spite of similar transpiration efficiency at the leaf level.

The greater stomatal conductance of triticale means an advantage in terms of both water and radiation use efficiency despite typical terminal drought affecting winter cereal crops in a Mediterranean-type environment. [34]

In one experiment, triticale cultivars were subjected to drought during the tillering phase and the heading phase. The cultivars were able to maintain better leaf hydration and, therefore, maintain photosynthesis. It is suggested that these are adaptation mechanisms, acting during drought, which can inhibit the use of carbohydrates in leaf growth and maintain high osmotic potential of cell sap. [35]

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[34] R Motzo, G Pruneddu, F Giunta (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] T Hura, K Hura, M Grzesiak (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.

Water stress

IN FOCUS

Triticale grain yield and physiological response to water stress

Water availability in semi-arid regions is becoming increasingly threatened as rains become more erratic and droughts more frequent. This has led to over-reliance on irrigation in order to meet food demand. Improving crop Water Use Efficiency (WUE) has become a priority. A two-year study was carried out four commercial triticale genotypes that were subjected to four moisture levels, ranging from well-watered (430–450 mm) to severely stressed (220–250 mm). The triticales were 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 3.5–0.8 t/ha–1 in 2013 and 4.9–1.8 t/ha–1 in 2014. Intrinsic WUE increased with decreasing moisture level. The researchers found that flag-leaf photosynthesis and pre-anthesis assimilates contribute much less carbon to grainfilling under water stress than previously thought. [36]

4.4 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-grain crops. 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.

4.4.1 Zadoks scale of cereal growth stages

The Zadoks scale marks the growth stages of cereals according to 10 distinct developmental phases (Figure 2). [37] Table 2 relates the main features of the earlier stages of growth with the Zadoks scale. [38]

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 represents a subdivision of the principal growth stages. For instance, 13 indicates that in principal stage 1 (seedling growth) subdivision 3, when leaves are at least 50% 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 nitrogen management are those from the start of stem elongation through to early flowering, GS30–GS61.

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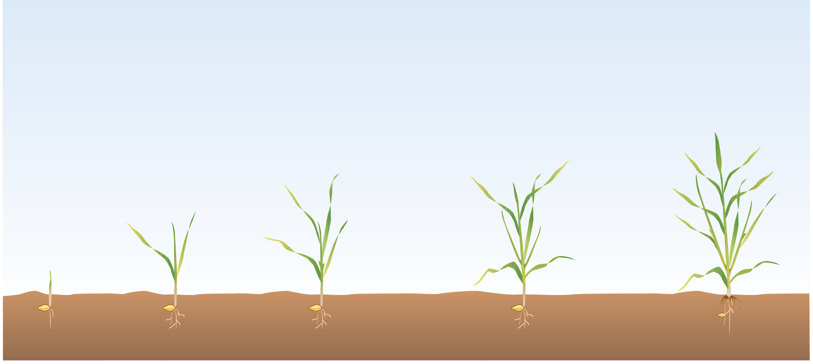
[36] L Munjonji, KK Ayisi, B Vandewalle, G Haesaert, P Boeckx (2016) Combining carbon-13 and oxygen-18 to unravel triticale grain yield and physiological response to water stress. Field Crops Research, 195, 36–49.

[37] N Poole (2005) Cereal Growth Stages. GRDC, https://grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf

[38] P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW DPI, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf



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: *The 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 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 developing 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) Main shoot and 1 tiller (Z21)	5 leaves on main shoot or stem (Z15) Main shoot and 1 tiller (Z21)	6 leaves on the main shoot or stem (Z16) Main shoot and three tillers (Z23)	First node formed at base of main tiller (Z31)	Z35–Z45

Source: NSW DPI

Zadoks growth key

The main points to understanding the use of the Zadoks scale (see Photo 6) [39] are:

- The Zadoks growth stage (GS) key does not run chronologically from GS00 to GS99. For example, when the crop reaches the stage of three fully unfolded leaves (GS13) it begins to tiller (GS20)—before it has completed the stages of four, five or six fully unfolded leaves (GS14, GS15, GS16).
- During tillering, it is easier to assess the main stem and the number of tillers than it is the number of leaves (due to leaf senescence). The growth stage is determined by the main stem and number of tillers per plant, e.g. GS22 is main stem plus two tillers up to GS29, the 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 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 at the same time, yet for practical purposes would be regarded as at GS32, since this describes the most advanced stage of development.
- After stem elongation (GS30) the growth stage describes the stage of the main stem, not an average of all the tillers. This is particularly important when timing the application of fungicides, e.g. GS39 is full flag leaf on the main stem, meaning that not all flag leaves in the crop will be fully emerged, and therefore may harbour infection but not receive spray coverage. [40]

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[39] C Royo, D Villegas (2011) Field measurements of canopy spectra for biomass assessment of small-grain cereals. InTechOpen. DOI 10.5772/17745, http://www.intechopen.com/books/biomass-detection-production-and-usage/field-measurements-of-canopy-spectra-for-biomass-assessment-of-small-grain-cereals

[40] N Poole (2005) Cereal Growth Stages. GRDC, https://grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf

4.4.2 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 favourable, the seed germinates with the emergence of the radicle and the coleoptile, the first shoot, which 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. 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 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 its maximum at about the boot stage. The 'boot' is the swollen flag-leaf sheath, within which the developing spike is located after being pushed up as the stem has elongated.

As the seedling's 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 six to 20 days after sowing, depending on temperature and moisture. Emergence may 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.

4.4.3 Tillering and vegetative growth

Branching in small-grain cereals 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). [41] The first primary tiller begins developing as leaf four of the main stem emerges; the second primary tiller begins developing as leaf five emerges. Subsequent primary tillers begin developing when subsequent leaves emerge.

Successive tillers develop fewer leaves; flowering and grain development is delayed, but only slightly, 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.

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[41] University of Wisconsin (2013) Wheat growth and development. University of Wisconsin, http://corn.agronomy.wisc.edu/Crops/Wheat/L007.aspx

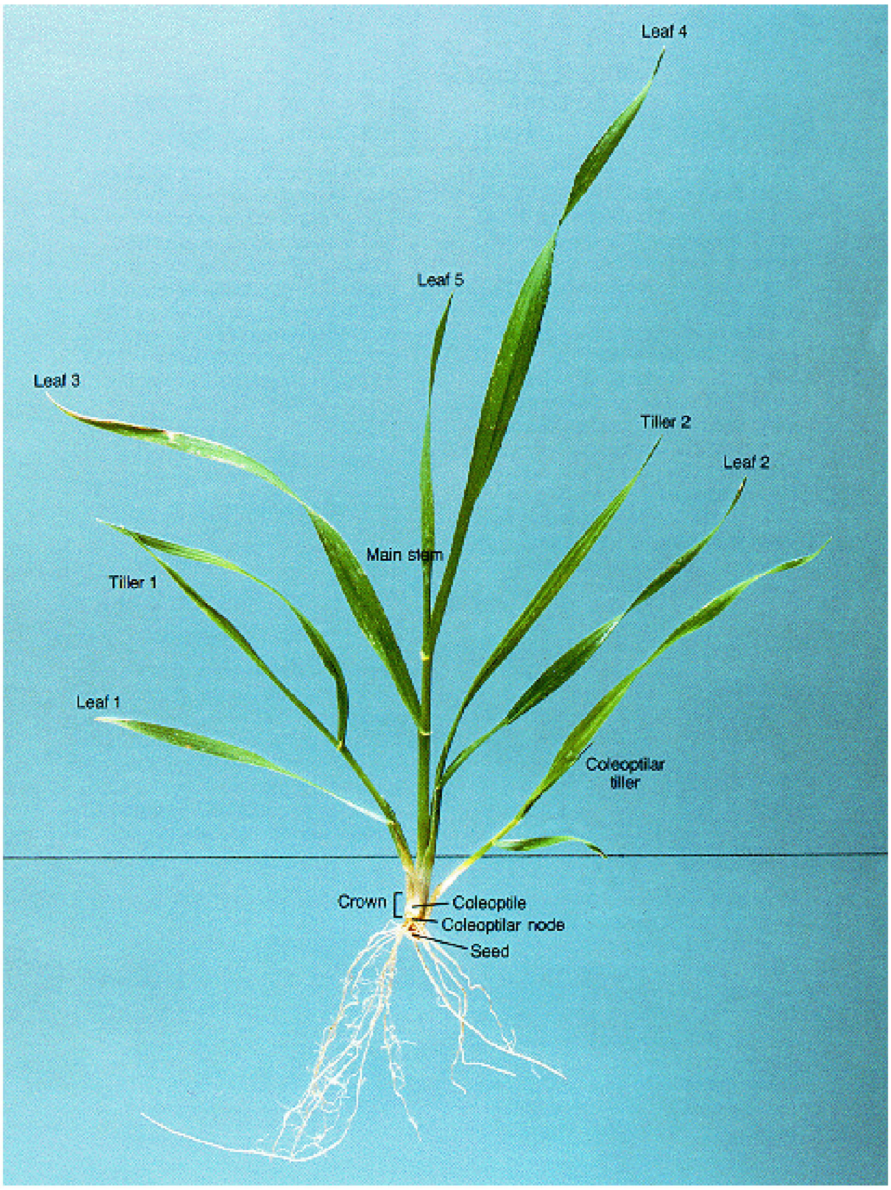

Photo 6: *Plant parts in relation to growth stage.*

Source: University of Wisconsin

4.4.4 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, the lowest ones beginning first. 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 wheat, triticale, 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 wheat, triticale, 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 this stage, the enlarging spike swells and splits the sheath of the flag leaf. Heading begins when the spike begins emerging through the collar of the flag leaf and is complete when the base of the spike is visible.

4.4.5 Flowering and grainfilling

The flowers of wheat, triticale, 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 two to four days of the spikes completely emerging from the boot. If emergence occurs during hot weather, flowering may occur while the 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 grainfilling. Most of the carbohydrate used for grainfilling 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 wheat or barley 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 the early milk stage, a clear fluid can be squeezed from the kernel. By the time the grains reach the late milk stage, the fluid has turned milky (and can still 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%, and the plant loses most of its green colour. 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 20–25%. 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 13–14%, the grain is harvest ripe. The surface cannot be dented with a thumbnail. [42]

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[42] Jackson L, Williams J (2006) Small grain production part 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 milk stage (top) to the harvest-ripe stage (bottom).*

Source: Jackson and Williams 2006

4.4.6 Growth of triticale compared to other cereals

Key points:

- Early stages of growth have been found to be shorter in triticale than wheat. However, the period from grainfilling to harvest in triticale has been found to be considerably longer than wheat, without leading to a greater 1,000 grain weight.

- The yield advantages of triticale come from a combination of a greater number of ears per square metre and more grains per ear that are filled during a longer grainfilling period.
- Triticale seed is generally bigger than wheat seed. Consequently, triticale can be seeded deeper than other small cereals and benefit from stored moisture in the soil, leading to better crop establishment early in the season, particularly in drought-prone areas.
- Differences in tillering between triticale and wheat influences management practices, such as seed rate or amount of fertiliser applied.

One of the advantages of triticale over 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 canopy (Photo 8).

Photo 8: *Triticale 50 days after emergence.*

Source: Midwest Cover Crops Council

Trials in the UK were used to compare triticale and wheat growth. Researchers found a noticeable difference between the crops in the length of key growth phases. The growth phase from drilling to GS31 (first node detectable) was, on average, 8.5 days shorter for the triticale, and from GS31 to GS61 (flowering) 1.75 days shorter for triticale than for wheat. However, from GS61 (grainfilling) to harvest was 10.6 days longer in the triticale (Figure 3). [43] The longer grainfilling phase did not confer a greater 1,000-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.

Despite the 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 triticale were the increases significant. This was associated with both a greater number of stems and greater biomass per stem. The relative differences between the biomass of the different species at GS61 translated into differences at harvest, where triticale produced a greater yield. It can be seen that the yield advantages of triticale come from a combination of a greater number of ears per square metre and more grains per ear that are filled during a longer grainfilling period. These are supported by greater biomass that is evident throughout the season. [44]

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

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

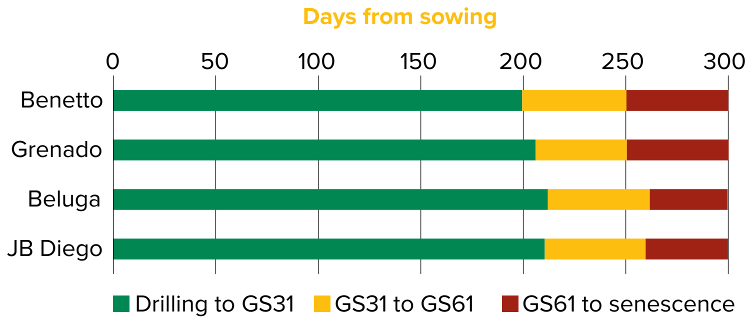

Figure 3: *Length of key growth phases of two triticale varieties (Benetto and Grenado) and two wheat varieties (Beluga and JB Diego). Results are an average of two experiments. Plots grown at 180 kg N/ha.*

Although triticale has a very large seed, 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 root system at the expense of 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 is generally bigger than that of commonly grown wheat varieties. Consequently, spring triticale can be seeded deeper than other small cereals and can therefore benefit from stored moisture in the soil, which translates into 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 10–20% larger than wheat. [45]

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. [46]

Triticale is thought to tiller less profusely than wheat. There are many differences between the tillering capacity between varieties of the same cereal type. However, in general (and assuming a May sowing) barley tillers better than oats, which in turn tillers better than wheat and this in turn tillers better than triticale. Generally, the earlier you sow and the higher the nitrogen fertility, the more tillering and tiller survival to harvest. Varieties with winter habit tend to tiller more, while there are some early maturing types (wheats in particular) which have limited tillering bred into them. Tillering can relate to DM yield; sow low tillering varieties at a higher seeding rate for hay and high tillering types at a lower rate. Similarly, higher sowing rates should be used when sowing late as tillering is reduced by late sowing. [47]

Significant differences in tillering abilities between triticale and wheat influences management practices, such as seed rate or amount of fertiliser applied. In early research, adding nitrogen (N) increased tiller and ear numbers in three cereals (triticale, wheat and rye), although triticale produced fewer tillers and its 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 per spikelet, thereby producing more grains per pot than the other two cereals. The average kernel weights of triticale were also greater than those of wheat and rye. Total water-use of triticale was less than that of the other cereals, particularly at the higher rates

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[45] M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/3/a-y5553e/y5553e00.pdf

[46] M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/3/a-y5553e/y5553e00.pdf

[47] AgVic. Sowing options for autumn: cereal varieties and other alternatives. http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/forage-cereals/sowing-options-for-autumn-cereal-varities-and-other-alternatives

of N. The experiment showed that the yield of triticale was not restricted by less profuse tillering, and that it was able to compensate for this by producing more grains per ear and heavier kernels. Restricted tiller production of the cultivar Currency was associated with lower water use and higher Water Use Efficiency. [48]

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

IN FOCUS

Variation in temperate cereals in rain-fed environments

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 rain-fed environments in southern Australia. Researchers wanted to determine reasons for these differences. They grew cultivars of each species at five field sites, and measured variation in their phenology and both pre- and post-anthesis growth.

Barley achieved a higher yield of grain and biomass in a shorter time than the other species. It reached physiological maturity about 10 days (180 thermal units) before the other species, and also 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 main-stem leaves and tillers faster than the other species, whereas triticale was slower in this respect. The rate of crop growth 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 of ground area were substantially greater in barley than the other species; oats and durum wheat were the slowest. Grain growth rate per unit of 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 13–39% 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. [49]

Anthesis generally occurs 14 days after apical spikelet emergence for triticale. [50]

Early triticale researchers explored the physiological maturity in seeds of two cultivars. Maximum germination, dry weight, and seedling vigour were attained 24 to 26 days after anthesis. Some seeds were capable of germinating eight days after anthesis. Moisture content decreased slowly from over 78% to 41%, at which time

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[48] JB Golding (1989) Restricted tillering in triticale cv. currency: an impediment to grain yield? 5th Australian Agronomy Conference, http://www.regional.org.au/au/asa/1989/contributed/crop/p1-20.htm

[49] C López-Castañeda, RA Richards (1994) Variation in temperate cereals in rainfed environments II. Phasic development and growth. Field Crops Research, 37 (1), 63–75.

[50] S Tshewang (2011) Frost tolerance in Triticale and other winter cereals at flowering. Master's thesis. University of New England, https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

functional maturity was attained. After this stage, the loss of moisture was accelerated and the seed entered into the ripening phase. [51]

In dry springs, triticale yields are 10–15% below wheat, due to triticale's longer grainfilling period. Because of this, grain size may suffer in a hot, dry finish (Photo 9). [52]

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

Sources: left, KT Farmlife; right, Living Crop Museum

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[51] UR Bishnoi (1974) Physiological maturity of seeds in triticale hexaploid L. Crop Science, 14 (6), 819–821.

[52] Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, http://www.farmtrials.com.au/trial/13801