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GRAINS RESEARCH
& DEVELOPMENT
CORPORATION

TRITICALE

SECTION 4

PLANT GROWTH AND PHYSIOLOGY

CHARACTERISTICS OF TRITICALE | GERMINATION AND EMERGENCE |
EFFECTS OF TEMPERATURE, PHOTOPERIOD, CLIMATE AND ENVIRONMENT |
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.
- Triticale tillers less than wheat.
- The optimum temperature for germination is 20°C.
- The optimum temperature range for growth is 10–24°C.
- The maximum temperature for 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.
- Since the early development of triticale, its tolerance to drought stress has increased compared to other cereals.

4.1 Characteristics of triticale

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. The key characteristics of triticale are (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.
- The seed is a grain similar to that of wheat.¹
- 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.²

¹ HerbiGuide (n.d.) Triticale. HerbiGuide, http://www.herbiGuide.com.au/Descriptions/hg_Triticale.htm; see also HerbiGuide, www.herbiGuide.com.au


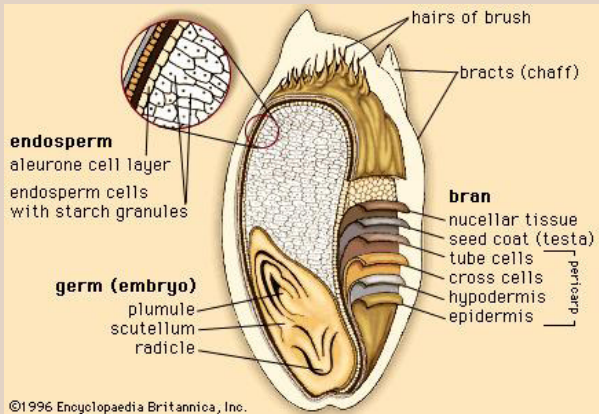
² Infoagro (n.d.) Triticale growing. Infoagro Systems, <http://agriculture.infoagro.com/crops/triticale-growing/>

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Table 1: Main characteristics of triticale.

| Plant part | Description |
|--------------|---|
| Cotyledons | One |
| 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) ³ |
| |  <p>Figure 1: A comparison of flower heads. A: Bread wheat, B: Cereal rye and C: Triticale.</p> <p>Source: Palomar College</p> |
| 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 2) |
| |  <p>Figure 2: Cross-section of cereal grain seed. This is rye, but triticale is similar.</p> <p>Source: Encyclopaedia Britannica</p> |
| Roots | Fibrous ⁴ |

³ Photos of some important cereal grains. Wayne's World. Palomar College, <http://waynesword.palomar.edu/ecoph12.htm>

⁴ HerbiGuide. Triticale. HerbiGuide, http://www.herbiguide.com.au/Descriptions/hg_Triticale.htm; see also HerbiGuide, www.herbiguide.com.au

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 is a means of distinguishing wheat from triticale. Wheat grain shells tend to be lighter in colour than in triticale. Wheat shells are oval; triticale grain shells are oblong.⁵ 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 water 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 it and begin Phase 1, although it takes longer than in moist conditions.

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 reserves, 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.⁶

4.2.1 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

The minimum temperature at which triticale can survive is –10°C, and the maximum is 33°C.⁷

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

5 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>

6 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>

7 Infoagro (n.d.) Triticale growing. Infoagro Systems, <http://agriculture.infoagro.com/crops/triticale-growing/>

SECTION 4 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

temperature.⁸ Very low temperatures can damage triticale seedling during germination and emergence (Photo 1).⁹ For triticale, the thermal time to the emergence of the first seedling has been recorded at 113–119 degree-days, and 127–130 degree-days for 95% emergence.



Photo 1: 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.¹⁰ Early researchers found that saline soils could impair triticale emergence, although the application of calcium sulfate (CaSO₄) (Gypsum) helped to increase emergence in these conditions.¹¹

In one study researchers 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 did sodium chloride (NaCl). 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.¹²

Herbicide treatments may also limit germination in triticale, as in other cereals. The successive effect of four herbicides (isoxaben, chlorsulfuron, isoproturon and chlortoluron) and a control on the germination and plant growth of triticale cultivars has been explored. Germination rate of winter triticale seeds obtained from plants treated with herbicide were generally lower, in particular for the isoproturon and chlorsulfuron variants.¹³

As the first primary roots appear, the coleoptile (Photo 2) 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. Fully elongated, it 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.

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

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

10 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. See also Hill Laboratories (n.d.) Crop guide: Triticale. KB item 28750v1. Hill Laboratories, https://www.researchgate.net/publication/250102346_Effect_of_Salinity_on_Grain_Yield_and_Quality_Vegetative_Growth_and_Germination_of_Triticale

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

12 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), 2862–2868.

13 S Slawomir, 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.

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 2: 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.¹⁴ A 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, which can't sense which way is up, may emerge under the soil and grow in any direction, resulting in crinkled leaves beneath the surface. 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 (Photo 3), and to separate the seed from any pre-emergent herbicides used.¹⁵



Photo 3: Emerged triticale seedlings.

¹⁴ 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>

¹⁵ 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>

Source: Midwest Cover Crops Council

Sowing depth also influences the rate of emergence and the percentage of seedlings that emerge. 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 (Photo 4).¹⁶ 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 (i.e. does not 'know' which way is up), the leaf usually buckles and crumples, failing to emerge and eventually dying.¹⁷ Soil bulk density can also influence crop emergence at different sowing depths. Research has confirmed the importance of avoiding smaller-sized seed when deep sowing.



Photo 4: By the stage of the first unfolded leaf, GS11, there is a noticeable difference in vigour between a seedling sown too deep (left) and correctly sown seedling (right).

Source: GRDC

4.2.2 Soil moisture

Soil moisture influences the speed of germination. Germination is rapid if the soil is moist and warm. 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.

Germination 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.

Sowing into hard-setting or crusting soils that dry out after sowing may result in poor emergence. Hard soil makes it difficult for the coleoptile to push through to the

¹⁶ N Poole (2005) Cereal growth stages. GRDC, <https://www.researchgate.net/file/PostFileLoader.html?id=5780fa6bf7b67e860b4def31&assetKey=AS%3A381929540079624%401468070506798>

¹⁷ 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>

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.¹⁸

4.3 Effects of temperature, photoperiod, climate and environment

4.3.1 Temperature

Temperature, photoperiod, environment and climate affect plant growth and physiology.

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.¹⁹

Temperature can also affect the photosynthesis and respiration rates of triticale, leading to changes in growth.²⁰

High temperatures (e.g. above 33°C) are known to induce rapid growth which diminishes the cell pool of metabolites (e.g. amino acids, nitrates and carbohydrates) and therefore nutritional quality.²¹

4.3.2 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 at Werribee, Victoria, in 1974. Researchers created a range of 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 the photoperiod had a greater effect than the temperature.²²

4.3.3 Salinity

In Australia, data is limited on the salt tolerance of triticale. However, it can be inferred that triticale has similar high salt tolerance as wheat and cereal rye (Table 2). Crops in this high salinity tolerance rating can grow in saline soils up to 10 dS/m (Saturated extract ECe).

18 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>

19 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.

20 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.

21 CM McGovern, 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.

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

SECTION 4 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 2: *Tolerance of some common crops to salinity.*

| High tolerance | Moderate tolerance | Low tolerance |
|----------------|--------------------|---------------|
| Wheat | Lucerne | Maize |
| Barley | Peas | Sugar cane |
| Canola | Sweetcorn | Red clover |
| Cotton | | Sub. clover |
| Ryegrass | | |
| Sorghum | | |
| Soybeans | | |

Source: Australian Soil Fertility manual, JS Glendinning 1999

Trials conducted in the Northern region between 2002–2007 explored various options to manage subsoil constraints including; plant adaptation through breeding of tolerant cultivars, agronomic decisions, and chemical, mechanical and biological treatments. Triticale was found to have high tolerance to saline soils. The trial found that different crop species showed differences in sensitivity to increasing subsoil Chlorine (Cl) concentration (a measure of salinity). Grain yield of most species declined with increasing subsoil Cl. Barley and triticale yielded better than bread wheat at sites high in subsoil Cl.²³

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.²⁴

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 results primarily from a reduction in spike number rather than from lower weight per spike or lower weight per individual seed. Cultivars are slightly less salt tolerant at germination than they are after the three-leaf stage of growth.²⁵

IN FOCUS

The effect of salt stress on photosynthesis 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 (CO₂) 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 CO₂ concentration showed regular changes, and the growth of seedlings was impeded.²⁶

23 R Dalal (2007) GRDC Final reports: DNR00004–SIP08 (north) Combating subsoil constraints. <http://finalreports.grdc.com.au/DNR00004>

24 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.

25 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.

26 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

4.3.4 Drought

Since the early development of triticale, its tolerance to drought stress has increased compared to other cereals.²⁷

A wide range of genotypic variability exists within triticale strains and cultivars show a wide range of tolerances to drought. In addition, the usefulness of other parameters, e.g. leaf gaseous exchange and chlorophyll content, for measuring drought tolerance have been assessed.

Stomatal conductance has proven to be important in determining the amount of water used and how efficiently it is used by cereal crops; it therefore affects productivity. Stomatal conductance is a measure of the rate at which carbon dioxide enters the stomata and water vapour exits. One study explored stomatal conductance in durum wheat and triticale in different environments. It was found that the greater stomatal conductance of triticale confers an advantage to this crop in both water- and radiation-use efficiency.²⁸

Water stress

Water availability in semi-arid regions is becoming increasingly threatened as rains become more erratic and droughts more frequent. Improving crop Water Use Efficiency (WUE) has become a priority. One study found that moisture level significantly influences 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. Flag-leaf photosynthesis and pre-anthesis assimilates contribute much less carbon to grainfilling under water stress than previously thought.²⁹

4.4 Plant growth stages

Plant development is divided into five general 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 optimising returns from inputs such as nitrogen (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 3).³⁰ Table 2 relates the main features of the earlier stages of growth with the Zadoks scale.³¹

The Zadoks system uses a two-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

27 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.

28 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.

29 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.

30 N Poole (2005) Cereal growth stages. GRDC, <https://www.researchgate.net/file/PostFileLoader.html?id=5780fa6bf7b67e860b4def31&assetKey=AS%3A381929540079624%401468070506798>

31 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW DPI, <https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide>

SECTION 4 TRITICALE

[TABLE OF CONTENTS](#)

[FEEDBACK](#)

50% emerged from the main stem; 75 indicates that in principal stage 7 (kernel development), the plant has reached subdivision 5, where the grain is at the medium milk stage. The Zadoks system is often differentiated from other similar systems by the use of the letter Z before the number of the growth stage; in GrowNotes and other GRDC publications, the Z is converted to GS, for growth 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.

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK

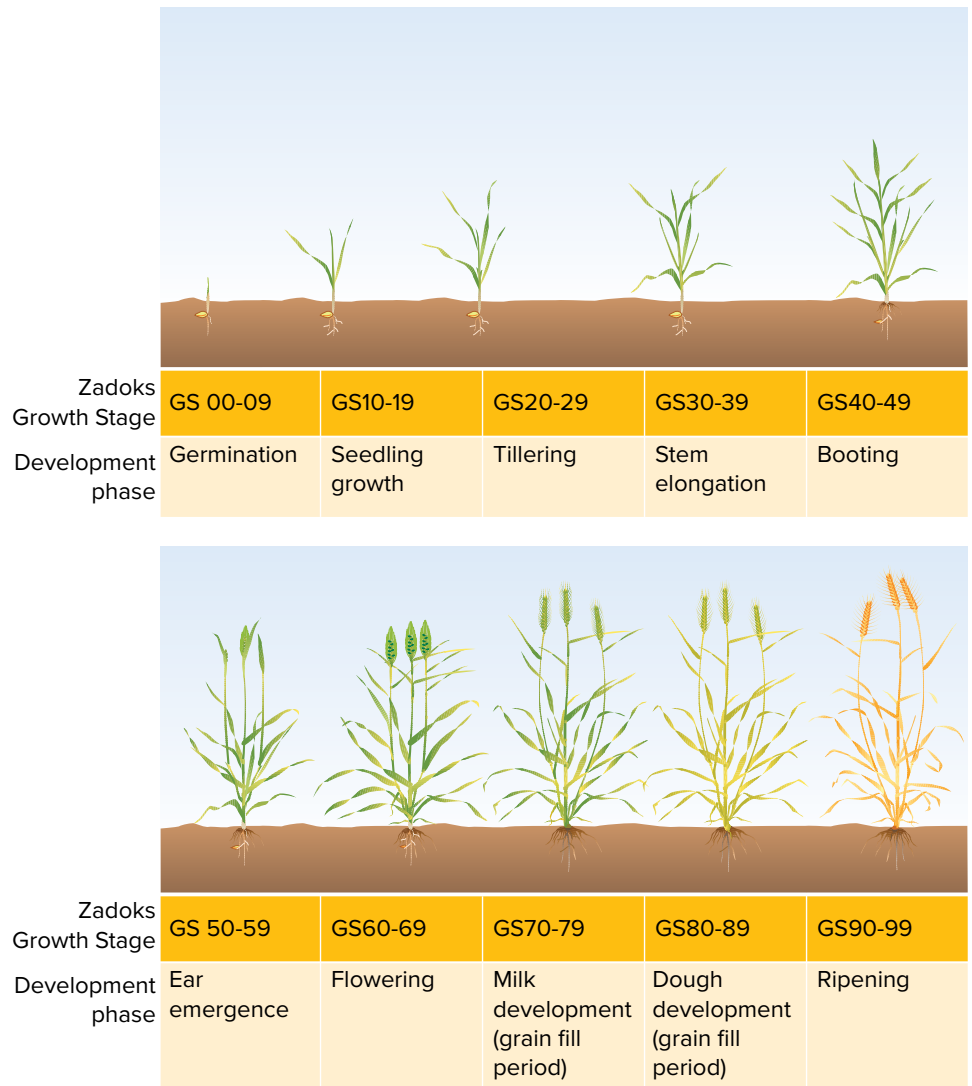


Figure 3: The Zadoks cereal-growth stages.

Source: GRDC

SECTION 4 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 3: 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) | 5 leaves on main shoot or stem (Z15) | 6 leaves on the main shoot or stem (Z16) | First node formed at base of main tiller (Z31) | Z35–Z45 |
| | Main shoot and 1 tiller (Z21) | Main shoot and 1 tiller (Z21) | Main shoot and three tillers (Z23) | | |

Source: NSW DPI

Reading the Zadoks growth key

The main points to understanding the use of the Zadoks scale 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 usually reach GS29 before the main stem starts to stem elongate (GS30), dependent on variety and plant available nitrogen.
- 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.³²

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

³² N Poole (2005) Cereal growth stages. GRDC, <https://www.researchgate.net/file/PostFileLoader.html?id=5780fa6bf7b67e860b4def31&assetKey=AS%3A381929540079624%401468070506798>

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 (Figure 4). 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.

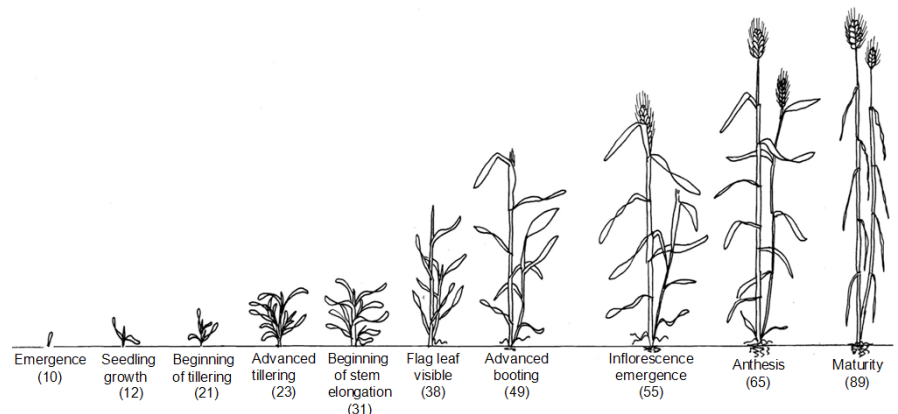


Figure 4: Growth stages of small-grain cereals. Numbers correspond to the Zadoks growth key.

Source: Royo and Villegas 2011

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 5).³³ 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

³³ University of Wisconsin (2013) Wheat growth and development. University of Wisconsin, <http://corn.agronomy.wisc.edu/Crops/Wheat/L007.aspx>

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.

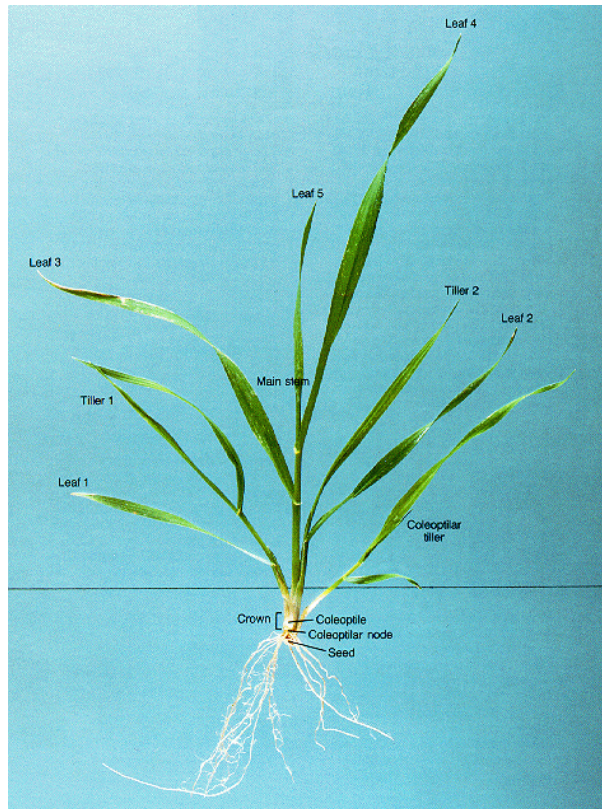


Photo 5: Plant parts in relation to growth stage.

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

Anthesis generally occurs 14 days after apical spikelet emergence for triticale.³⁴

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 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 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 6). 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.³⁵

34 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>

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

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 6: 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

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 7).

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 7: *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 species in the length of key growth phases. The growth phase from sowing 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 considerably longer—10.6 days—in the triticale (Figure 5).³⁶ 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. 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 heads per square metre and more grains per head that are filled during a longer grainfilling period. These are supported by greater biomass that is evident throughout the season.³⁷

³⁶ S Clarke, S Roques, R Weightman, D Kindred (2016) Understanding triticale. AHDB, <https://cereals.ahdb.org.uk/media/897536/pr556-understanding-triticale.pdf>

³⁷ S Clarke, S Roques, R Weightman, D Kindred (2016) Understanding triticale. AHDB, <https://cereals.ahdb.org.uk/media/897536/pr556-understanding-triticale.pdf>

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK

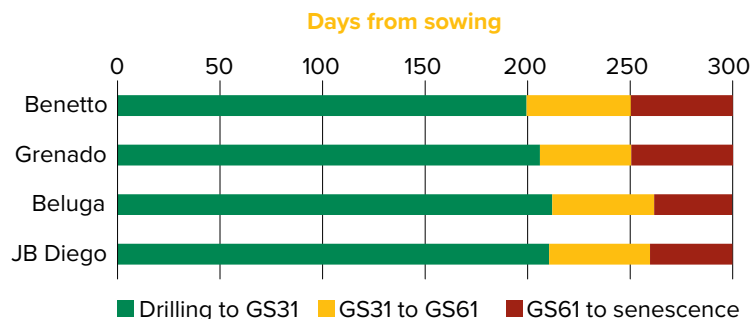


Figure 5: Length of key growth phases of two triticale varieties (Benetto and Grenado) and two wheat varieties (Beluga and JB Diego). Results are an average of two experiments. Plots grown at 180 kg N/ha.

Triticale cultivars tiller less profusely than wheat cultivars of similar maturity.³⁸ Significant differences in tillering abilities between triticale and wheat influences management practices. Triticale can compensate for having fewer tillers by producing more spikelets per head 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. In one trial, total Water Use Efficiency (WUE) of triticale was less than that of the other cereals, particularly at the higher rates 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.³⁹

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

38 GK McDonald, BG Sutton, FW Ellison (1983) The effect of time of sowing on the grain yield of irrigated wheat in the Namoi Valley, New South Wales. *Australian Journal of Experimental Agriculture and Animal Husbandry*, 24, 236–243.

39 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/pt-20.htm>

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK

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.⁴⁰

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 8).⁴¹



Photo 8: *Triticale flowering (left) before grainfill (right).*

Sources: left, [KT Farmlife](#); right, [Living Crop Museum](#)

40 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.

41 Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, <http://www.farmtrials.com.au/trial/13801>