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Wheat Freeze Injury in Texas

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Freeze injury in wheat is a complex issue involving environmental, cultural, and physiological factors that can cause freeze damage to vary between and even within fields, making it difficult to assess crop injury. Knowing when and where to scout for damage, what symptoms to look for, and how to manage an injured crop is critical in evaluating damaged wheat.

Scouting for Damage

Because official temperatures recorded at nearby weather stations do not always represent temperatures in individual fields, estimate anticipated damage more accurately by placing a thermometer directly in the plant canopy in the early morning when temperatures are likely at their minimum. Texas A&M AgriLife Extension Service data using canopy temperature sensors demonstrate that temperatures may sometimes be 4°F to 6°F higher in the canopy than in the surrounding air temperature, especially on still nights.

If damaging temperatures occur or are suspected in a wheat field, symptoms may not appear on the plant for up to a week or more, depending on the weather. Temperatures following the freeze affect how quickly symptoms develop, since warmer temperatures accelerate the decomposition of dead tissue. A dark green or "water soaked" appearance in foliage may be evident quickly, but determining a dead growing point or the death of the most recently emerged leaf can take time.

When scouting for freeze damage, check low-lying fields or areas first, especially if little to no wind occurred during the freeze. Cold air sinks and settles in valleys and bottoms on still nights.

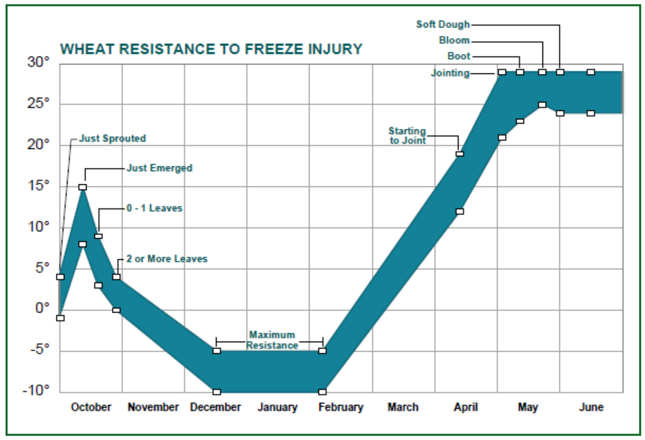

Figure 1. Winter wheat is most tolerant to cold temperatures in the vegetative stage (Feekes 2-4) during the winter months. After vernalization, wheat enters into the reproductive phase and becomes progressively more susceptible to cold temperatures as it develops (adapted from A. W. Pauli).

Table 1. Temperatures at which freeze injury can potentially occur in wheat. Injury generally does not begin until temperatures remain below the critical temperature threshold for at least 2 hours.

Growth Stage	Approximate injurious temperature (2 hours)	Primary symptoms	Impact on yield
Tillering	12°F (-11°C)	Leaf chlorosis; burning of leaf tips; silage odor; blue cast to fields	Slight to moderate
Jointing	24°F (-4°C)	Death of growing point; leaf yellowing or burning; lesions, splitting, or bending of lowe stem; odor	Moderate to severe
Boot	28°F (-2°C)	Floret sterility; spike trapped in boot; damage to lower stem; leaf discoloration; odor	Moderate to severe
Heading	30°F (-1°C)	Floret sterility; white awns or white spikes; damage to lower stem; leaf discoloration	Severe
Flowering	32°F (0°C)	Floret sterility; white awns or white spikes; damage to lower stem; leaf discoloration	Severe
Milk	28°F (-2°C)	White awns or white spikes; damage to lower stems; leaf discoloration; shrunken, roughened, or discolored kernels	Moderate to severe
Dough	28°F (-2°C)	Shriveled, discolored kernels; poor germination	Slight to moderate

If these areas are unaffected, areas at higher elevations are likely unharmed. Symptoms such as necrotic leaf tissue and white awns are easily visible, but, by themselves, rarely impact yield significantly. But, they can indicate more serious injury and require further investigation.

Temperature Sensitivity

Table 1 and Figure 1 show critical temperatures at which potential freeze injury may occur in wheat during different growth stages. For a more detailed discussion of wheat growth stages (Feekes scale) refer to AgriLife Extension publication *Growth Stages of Wheat* (Miller, 1999). Generally, plant parts need a minimum of 2 hours of exposure to freezing temperatures before injury occurs.

At the onset of winter, wheat should be in the tillering phase (Feekes 2-4) of development and most tolerant of cold temperatures. Winter wheat requires a prolonged period of cold temperatures (between 32°F and 45°F) in order to vernalize, though "chilling hour" requirements vary greatly among varieties (120 to 1080 hours). With warming temperatures in the spring, a vernalized wheat plant will initiate jointing (Feekes 6) as soon as early February in South Texas and as late as the end of March in the Texas Panhandle. Timing can vary up to 3 weeks at each location due to weather. At this time, the growing point, which remains below the soil surface throughout the winter, begins to move upward in the stem and is exposed to fluctuations in air temperature.

Temperature, duration of exposure, soil moisture, and wind speed all impact the severity of freeze injury. Susceptibility to freeze injury does not generally change among winter wheat varieties, and any differences are likely due to variations in maturity. However, differences can occur among varieties in other small grains species such as triticale or oats that can have spring-type lineage.

Cold tolerance also varies considerably among small grains species. Rye and triticale are equal to or superior to wheat, while barley and oats are less tolerant. Because of their more advanced development, early-maturing varieties are more sensitive to injury compared to later-maturing wheat.

The impact of soil moisture on freeze injury is unclear. Water helps buffer temperature change and maintains higher field temperatures in the canopy at night. However, available soil moisture generally increases water content in wheat plants, which can increase susceptibility to freeze injury.

Leaf Burn

Leaf burn from freezing temperatures (Figs. 2 and 3) can occur at any growth stage, but generally has limited impact on yield potential, especially during tillering. At the tillering stage, the growing point is protected below the soil surface and the young plant can readily develop new leaves to overcome the loss of green tissue. Although leaf

Figure 2. Leaf freeze injury ("burn") on upper leaves and leaf tips at early jointing gives the appearance of significant damage. However, in this field, only 1 to 2 percent of the growing points were damaged.

Figure 3. Freeze-damaged leaves on wheat turn from yellow to brown as tissue desiccates.

damage alone does not normally have a large impact on yield, it often indicates a more serious injury to other plant parts in later growth stages.

Once the wheat is headed, freeze injury to flag leaves reduces seed quality, since up to 85 percent of the energy for seed development and yield comes from the flag leaf.

Leaf burn at any growth stage can make a field appear badly damaged, but this is mostly cosmetic, especially for younger fields.

Figure 4. Brown, necrotic region (caused by freeze injury) where the stem has collapsed and becomes soft. Stem injury this severe cuts off water and nutrients from the roots to the growing point or head and will likely terminate head development on affected tillers.

Figure 5. More examples of freeze injury to wheat stems. In the image on the left, a damaged stem (left) is next to a healthy stem (right). The image on the right shows stem damage located in the node (brown) below the growing point.

Stem Damage

Once wheat plants begin jointing and the first hollow stem appears, a hard freeze can cause stem damage. Obvious injury may appear as brown regions that completely encircle the stem (Figs. 4 and 5) and cut off the vertical movement of water and nutrients between the roots and the head. Slight discoloration in the stem or "frost rings" also create weak points, but may or may not cause lodging or significantly impact yield.

Frozen water in the stem can physically split the stem open (Fig. 6) and cause lodging (Fig. 7), create a disease infection site, or reduce water and nutrient flow along the stem. This is a greater problem later in the growing season when tempera-

Figure 6. Lower canopy freeze injury due to water freezing in the stem can split the stem open, lead to lodging, create a point of infection for disease, and interrupt water and nutrient transport.

Figure 7. Stem injury can lead to severe lodging in wheat.

tures are warmer and the plant requires more water transport to meet evaporative demands.

Vertical splitting of the stem is not as damaging to head development because it does not disrupt water and nutrient transport (assuming that lodging does not occur). Large tillers that lodge can smother younger tillers that might otherwise develop normally and contribute to compensatory yield. In some cases, flash grazing may be a good management strategy to improve compensatory growth.

Damage to Growing Points

Splitting and checking stems for damage to growing points and recognizing what you find is the best key to assessing freeze injury and understanding the status of a field.

Located in the crown of the plant, a healthy growing point is essential for tiller and head development in wheat. Upon vernalization, this growing point changes from a vegetative to a reproductive role. The development of the spike begins here and, as the stem elongates, the growing point is pushed above the soil surface. As stems elongate in the late winter and spring, growing points grow above the soil and into the crop canopy. Although the canopy gives some insulating effect against cold temperatures, it provides less protection as the growing point is pushed further upwards toward the top of the canopy.

Healthy, young growing points have a turgid, yellow-green (sometimes whitish) appearance (Fig. 8a). When injured by freeze, dead growing points turn white and then brown (Fig. 8b) as cells decompose. The death of a growing point is not always immediately obvious (Fig. 9). In most cases, the youngest leaf emerging from the whorl also dies and turns brown (Fig. 10). However, in some cases,

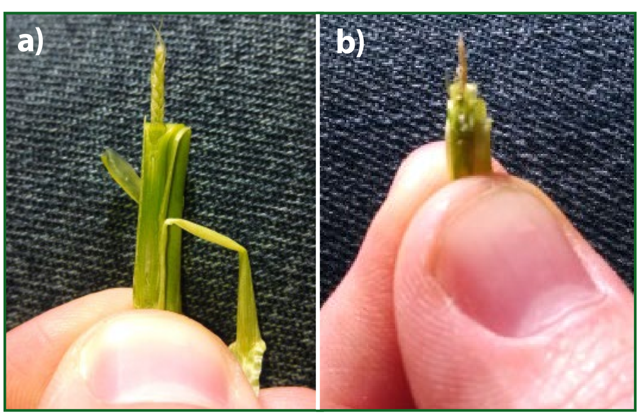

Figure 8. Example of a healthy (a) and dead (b) growing point.

Figure 9. Examples of healthy (left), questionable (center), and dead (right) growing points.

Figure 10. When the growing point dies from freeze injury, the youngest leaf emerging from the whorl often dies as well. If an emerged leaf (above) is dead, the growing point is probably dead and no further development of the head or forage growth on that tiller will occur.

this leaf can remain green for weeks after the growing point dies. Inspect growing points by splitting the stem with a razor just above the uppermost node.

Once a growing point dies, growth for that tiller stops immediately. Even though most of the tiller can remain green, there is no additional stem elongation, head development, or forage accumulation. If this occurs during the boot stage, the head remains inside the flag leaf sheath and does not emerge, turns white, and dies (Fig. 11). If the growing point is not killed in the boot stage, freezing temperatures can sometimes lock the auricles around any protruding awns, preventing the head from emerging normally. Instead, the head may split out of the side of the boot and create a fish-hooked appearance (Fig. 12). These heads can develop normally with minimal to no impact on grain yield.

Figure 11. The growing point was killed in this wheat tiller during the boot stage. As a result, the head turned white inside the plant, died, and never emerged from the boot. The most recently emerged leaf is also dead.

Figure 12. If freezing occurs in the boot stage, sometimes awns become entangled in the flag leaf sheath, resulting in a distorted (hook-like) head.

Head Damage

Freeze injury to wheat heads can be both the most obvious and most difficult damage to assess. If severe, damaged portions of the seed head look bleached or have small and withered spikelets. In less pronounced cases, heads turn light green or appear water-soaked. In certain cases, only portions of the seed head are injured (Fig. 13).

Individual wheat heads flower over the course of 2 to 4 days. Florets in the center of the head flower first and flowering proceeds towards the top and bottom of the head. Wheat is most susceptible to freeze injury during flowering. The anthers, or male portion of the flower, are particularly sensitive and can be damaged with temperatures as high as 32°F. Damaged anthers can become twisted, shrivelled, and discolored within 48 hours after a freeze. When the anthers are damaged, the pollen is sterilized and cannot fertilize the female portion of the flower to

Figure 13. Freeze injury to wheat heads can vary depending on the stage of maturity of each head during a freeze. Heads or portions of heads (usually the top) that are white, tan, or brown are dead.

produce seed. Because wheat is self-pollinated, the chance of pollination from another undamaged floret, even on the same head, is unlikely.

When young, anthers appear green and turgid (Fig. 14), eventually turning yellow (Fig. 15) as the pollen matures. Pollen is then released and deposited on the stigma, which eventually fertilizes the egg inside the ovary at the base of the stigma. After fertilization, the seed begins to form and extends from the bottom upwards (Fig. 16).

Once the ovary (lower end) swells to 2 to 3 mm long, assume that fertilization has occurred and the seed is growing. After fertilization, healthy anthers often are expelled from the floret, indicating a successful pollination (Fig. 17). Anthers can cling to the outside of the spike when normal fertilization has occurred. Freeze-damaged anthers are not expelled from the floret because the damage from the freeze prevents the turgor that causes them to "spring" out when the floret opens during the normal pollination process.

Anthers naturally turn white and dry out after shedding mature pollen. This can mimic the symptoms of freeze-damaged anthers so it may become difficult to determine whether anthers became sterile before or after pollination. Confirmation comes from later observations of seed development.

Kernel Damage

Once the seed begins to develop (visually observable in 2 to 3 days after pollination), it generally takes another 5 to 7 days to reach maximum length. During this time, any freeze injury to the developing embryo may terminate kernel development. Injury may become obvious after a few days when damaged kernels fail to develop and begin to shrivel and discolor, while unaffected kernels continue to elongate (Fig. 18). Even if a freeze does not kill the seed, it may reduce its test weight or germination.

Partially developed seed at these growth stages may be a combination of gray, green, or even blue and have a rubbery, pliable feel even though they appear plump. Though they don't look normal, these seeds generally develop normally.

After 2 weeks, the seed should be in the milk stage and, over the course of 2 more weeks, goes through the soft dough and hard dough stages.

Figure 14. These healthy, young anthers appear green, turgid, and are a few days away from pollination. There are typically three anthers per floret.

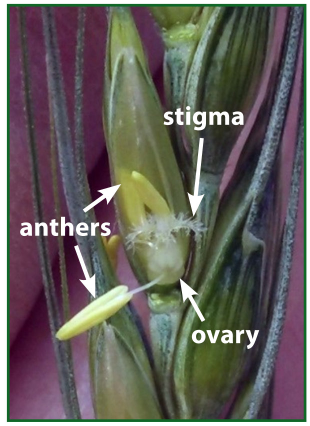

Figure 15. At the time of pollination, healthy anthers appear yellow and plump and the stigma is white and feathery (right). Damaged anthers will be white and shriveled or twisted.

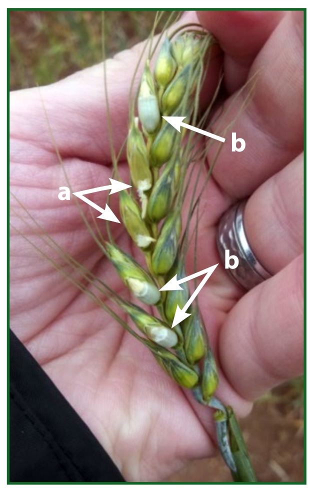

Figure 16. In the center of this seed head, anthers were damaged (a) during development and pollination did not occur, resulting in no seed production in those florets. Florets at the top and bottom (b) of the seed head were unharmed and seed development is proceeding normally.

Figure 17. Healthy anthers are commonly expelled from the floret after pollination and are easily visible on seed heads.

During the milk stage, kernels should be plump and light green. In the soft dough stage, kernels should be filled with a white, viscous liquid. Injured seeds contain a clear, watery substance and turn gray. Freeze damage during the milk stage can produce small, shrivelled seed with poor test weight and low percent germination (Fig. 19).

Figure 18. This photo shows the contrast between healthy, plump kernels (top) and dead, shriveled kernels (bottom) that were freeze-damaged during elongation and development.

Figure 19. These kernels depict two healthy seed (left) in the dough stage and one shriveled seed (right) damaged during the milk stage. Freeze-damaged seed will typically have reduced test weight and decreased germination.

Seeds that have reached the hard dough stage are nearly full weight. In central Texas, this typically occurs in mid-May. Regions of the High Plains may not reach hard dough until early to mid-June. At this point, the seed is almost fully developed, the water content is lower, and the potential for freeze injury is low.

Results from freeze damage in seed at the soft or hard dough stage are similar to seed in the milk stage, though typically less severe. Impacts can include reduced test weight, shrivelled seed, and decreased germination. Decreased seed germination is more of a concern at this stage because the embryo contains more water than the endosperm and is more susceptible to freeze injury.

Estimating Yield Loss

It is important to distinguish between percent freeze injury and percent yield loss (potential) because one is rarely equal to the other. Estimate freeze injury by the number of heads and/or tillers impacted. For a rough estimate of initial damage, use a simple sampling regime of the field.

- Start by picking two opposing areas of the field (the highest and lowest points) and collect all stems within a 1 to 2 foot section of row at each location. Do not include very small tillers, which are likely to have minimal impact on grain yield.
- Count the number of damaged stems and/or dead growing points in each sample. If the plants are past boot stage, consider the number of heads damaged and the percent of damage on each head.
- Divide the number of damaged stems (and/or heads) by the total stem number to get a rough idea of percent damage. If the estimated percent damage is between 20 to 60 percent, you may need to sample additional areas of the field to get a better idea of whether the majority of the crop is damaged.

Even after assessing the damage, it is difficult to estimate the actual impact freeze injury has on yield because conditions following the freeze greatly impact the ability of wheat to compensate.

Compensatory growth regularly occurs through the development of younger tillers, larger seed, or more seeds per spikelet in undamaged portions of the head. Cool weather facilitates additional growth and yield recovery, while warm, dry weather has the opposite effect. Wheat is productive when temperatures remain below 90°F, but will struggle to compensate for freeze damage if temperatures are above this threshold, especially when nighttime temperatures are warm.

On average, percent yield loss (especially if assessed as percent dead growing points) is only half of the initial estimated freeze injury. For example, 50 percent freeze injury might only result in 25 percent yield loss. The earlier in the year that damage occurs, the better the chance of lower yield loss because the wheat has more growing season left before heat and drought stress impact the crop. For actual yield estimation, refer to the AgriLife Extension publication *Estimating Wheat Yield Potential* (Miller and Bean, 1999).

Economic Assessment

Once you have an estimate of yield loss, consider alternative management options for badly damaged crops. If the wheat is unlikely to make a significant grain crop (Fig. 20), harvesting the forage for hay is often a viable alternative (Fig. 21).

The quality of wheat hay, particularly the protein and fiber content, varies substantially with the growth stage. However, freeze injury does not greatly impact the forage quality of wheat. Crude protein remains relatively high until the boot stage, but drops off quickly as the crop heads out and begins filling grain.

If the crop is too mature and the quality is low, the value of the hay may not cover the expense of harvesting it. In some cases, the standing biomass may be more valuable as a plow-down green manure (Fig. 22) or as a standing cover crop to be chemically terminated for protection of the next crop. Late freeze injury to bearded wheat that is headed out may be of low value because of hard awns that can cause problems in feeding livestock.

Figure 20. Unless a wheat crop is substantially damaged, harvesting wheat for grain is generally the most profitable option for producers.

Figure 21. Damaged wheat crops are often baled for hay if they fail to make a profitable grain crop.

Figure 22. Wheat residue contains nitrogen and other nutrients that are removed from fields when forage is baled and transported off-site. Sometimes incorporating wheat biomass as a green manure crop is the most economical use for heavily damaged wheat.

When selling freeze-damaged hay, don't overlook the value of nutrients removed from the field.

- Consider the value of the fertilizer source of nitrogen and other nutrients in the forage lost when hay is baled and transported off the field. At $0.65 per pound, 1.5 tons of wheat forage at 15 percent crude protein contains $18 per acre worth of nitrogen.
- Calculate the total nitrogen yield of wheat forage by multiplying dry forage yield (pounds per acre) by the percent of crude protein (in decimal form) and divide by 6.25.
- Compare the value of removed nutrients in the forage and hay-making expenses to current forage prices to better understand if hay prices are worth it.

The following tables can help estimate crop value based on yield potential, price, and harvest costs. Also refer to the *Wheat Crop Budget* at the AgriLife Extension Service Agricultural Economics website for a more detailed budget scenario.

Summary

Patience and correct scouting are critical when evaluating freeze-damaged wheat. Though some symptoms such as foliar burn and shriveled anthers may appear quickly, reliable symptoms typically require a week or more after a freeze for significant damage to be apparent. Severity can vary greatly between and even within wheat fields.

Always keep a razor or sharp knife and a magnifying glass handy for sampling freeze-damaged plants. Remember that initial freeze damage normally appears to be worse than the actual final yield loss, due to compensatory growth. However, the amount of compensatory growth depends on the growth stage of the crop during the freeze as well as the subsequent spring weather as the crop matures.

Use the following tables to estimate the net profit value of a wheat crop as a grain, forage, or green manure crop. In addition to the value of the crop, consider that harvest costs will vary depending on the end product.

Grain Price	Grain Yield (bu/a)					
	10	20	30	40	50	60
$4.00	-$10	$30	$70	$110	$150	$190
$4.50	-$5	$40	$85	$130	$175	$220
$5.00	$0	$50	$100	$150	$200	$250
$5.50	$5	$60	$115	$170	$225	$280
$6.00	$10	$70	$130	$190	$250	$310
$6.50	$15	$80	$145	$210	$275	$340
$7.00	$20	$90	$160	$230	$300	$370
$7.50	$25	$100	$175	$250	$345	$400
$8.00	$30	$110	$190	$270	$350	$430

Costs‡	$/acre
Fungicide	$7
Water (2 applic.)	$18
Combine	$20
Transport	$5
Total	$50

‡Total cost estimate used in calculating net profit value

Forage Price	Forage Yield (ton/acre)					
	0.25	0.50	0.75	1.00	1.25	1.50
$80	-$9	$11	$31	$51	$71	$91
$90	-$7	$16	$39	$61	$84	$106
$100	-$4	$21	$46	$71	$96	$121
$110	-$2	$26	$54	$81	$109	$136
$120	$1	$31	$61	$91	$121	$151
$130	$4	$36	$69	$101	$134	$166
$140	$6	$41	$76	$111	$146	$181

Costs‡	$/acre
Swath	$7
Rake	$5
Bale	$12
Transport	$5
Total	$29

‡Total cost estimate used in calculating net profit value

Nitrogen Price	Total Forage Nitrogen Yield† (lb/acre)					
	10	20	30	40	50	60
$0.50	$0	$5	$10	$15	$20	$25
$0.55	$1	$6	$12	$17	$23	$28
$0.60	$1	$7	$13	$19	$25	$31
$0.65	$2	$8	$15	$21	$28	$34
$0.70	$2	$9	$16	$23	$30	$37
$0.75	$3	$10	$18	$25	$33	$40
$0.80	$3	$11	$19	$27	$35	$43

Costs‡	$/acre
Plow	$5
Total	$5

†TFNY = [Forage Yield (lb/acre)] * [% Protein Content / 6.25]
‡Total cost estimate used in calculating net profit value

References

Miller, Travis D. 1999. *Growth Stages of Wheat.* http://varietytesting.tamu.edu/wheat/docs/mime-5.pdf

Miller, Travis D. and Brent Bean. 1999. *Estimating Wheat Yield Potential.* http://varietytesting.tamu.edu/wheat/docs/mime-6.pdf

Texas A&M AgriLife Extension Service Agricultural Economics. *Wheat Crop Budget.* http://agecoext.tamu.edu/resources/crop-livestock-budgets/budgets-by-commodity/wheat/

For More Information

For up-to-date wheat freeze injury reports and field assessment observations, consult http://wheat-freezeinjury.tamu.edu, including the additional "Pictures of Wheat Freeze Injury" for more examples of freeze injury.

For additional information about wheat and small grains production practices in Texas, consult http://varietytesting.tamu.edu/wheat.

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