Texas A&M AgriLife Extension

Wheat Freeze Injury in Texas

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Introduction

Freeze injury is a complex issue that many wheat producers in Texas have faced in recent years. Environmental, cultural, and physiological factors all influence susceptibility of wheat to freezing temperatures. As a result of these factors, variability of freeze damage between fields, and even within fields, can be profound and make injury assessment difficult.

The following information describes when and where to scout for damage, what symptoms to look for, and how to manage an injured crop.

Scouting for Damage

Because official temperatures recorded at nearby weather stations are not completely representative of field temperatures, anticipated damage to a wheat crop is better estimated by placing a thermometer directly in the plant canopy in the early morning hours when temperatures are likely at their minimum. AgriLife data using canopy temperature sensors demonstrate that temperatures may sometimes be 4 to 6°F higher in the

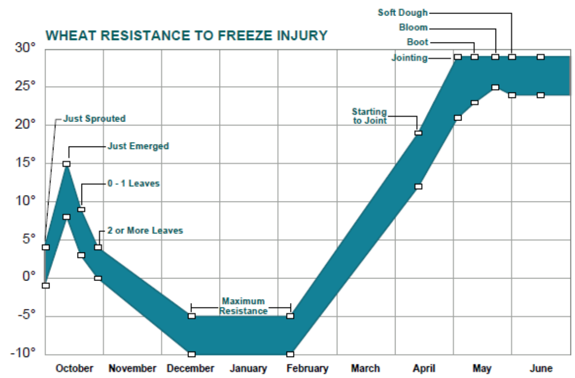

Figure 1. *Wheat is most tolerant to cold temperatures in the vegetative stage (Feekes 2-4) during the winter months. After vernalization, wheat enters into the reproductive phase and becomes progressively more susceptible to cold temperatures as it advances in development (adapted from A.W. Pauli).*

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 two hours.*

Growth Stage	Approximate Injurious Temperature (two 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 lower 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	30 F (-1 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

canopy than the surrounding air temperature, especially on still nights.

If damaging temperatures have been detected or suspected in a wheat field, patience is required as symptoms generally may not appear on the plant for up to a week or more, depending on weather. Appearance of symptoms varies with temperature following the freeze event, with warmer temperatures accelerating the decomposition of dead tissue. Foliage symptoms such as a dark green or "water soaked" appearance may appear quickly, but the determination of a dead growing point or death of the most recently emerged leaf can take time.

When scouting for freeze damage, low lying fields or areas should be checked first, especially if little to no wind occurred during the freezing event. Cold air sinks and will settle in valleys and bottoms on still nights. If these areas are unaffected, then areas at higher elevation are likely unharmed. Necrotic leaf tissue and white awns are two easily visible symptoms that by themselves rarely impact yield significantly, but are often indicative of more serious injury and require further investigation.

Temperature Sensitivity

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

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

Figure 3. *Freeze damaged leaves on wheat turn from yellow to brown in color as tissue turns necrotic.*

At the onset of winter, wheat should be in the tillering phase (Feekes 2-4) of development and most tolerant of cold temperatures. A prolonged period of cold temperatures (between 32 and 45ºF) is required by winter wheat in order to vernalize, though "chilling hour" requirements vary greatly among varieties (120 to 1080 hours). A vernalized wheat

Figure 4. *Brown necrotic region where the stem has collapsed and become soft was caused by freeze injury. 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 left image there is a damaged stem (left) next to a healthy stem (right). Image on the right shows stem damage located in the node (brown) below the growing point.*

plant will initiate jointing (Feekes 6) in the spring with warming temperatures. Jointing can occur as soon as early February in South Texas and as late as the end of March in the Texas Panhandle, though timing can vary up to three weeks at each location due to weather. At this time, the growing point, which has remained below the soil surface throughout the winter, will begin to move upwards 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 observed are likely due to differences in maturity. However, differences among varieties may appear in other small grains species such as triticale or oats, which could have spring-type lineage.

Cold tolerance also varies considerably among small grains species with rye and triticale being equal to or superior to wheat, while barley and oats are less tolerant. Early maturing varieties are more likely to be injured due to more advanced development compared to later maturing wheat.

Impact of soil moisture on freeze injury is unclear. Water helps to 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 throughout the cropping season, 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 and overcome the loss of green tissue. Although leaf damage alone does not normally have a large impact on yield, it is often indicative of more serious injury to other plant parts in later growth stages.

Once wheat is headed out, freeze injury to flag leaves is detrimental to seed quality since up to 85% of the energy required for seed development and ultimately yield comes from the flag leaf.

Leaf burn at any stage of growth can make a field look badly damaged, but as stated previously, it is mostly cosmetic, especially for younger fields.

Stem Damage

Once wheat plants have initiated jointing and the first hollow stem appears, stem damage can occur. Symptoms of stem injury can manifest in several different ways. Obvious injury may appear as brown regions that completely encircle the stem (Figs. 4 and 5) and cut off vertical movement of water and nutrients between the roots and head. Slight discoloration in the stem or “frost rings” also create weak points in the stem, but may or may not significantly impact yield.

In other cases, frozen water in the stem can physically split open the stem (Fig. 6) which can result in lodging (Fig. 7), a disease infection site, or reduced water and nutrient flow along the stem. This is more problematic later in the growing season when temperatures are warmer and the plant requires more water transport to meet evaporative demands.

Vertical splitting of the stem is generally not as damaging to head development because water and nutrient transport is not disrupted (assuming lodging does not occur). Large tillers that lodge can smother out 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

This is often the most critical aspect of assessing freeze injury in wheat. Successfully and quickly splitting many

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

Figure 7. *Stem injury can lead to severe lodging in wheat as seen above.*

stems and recognizing what you find is often the best key to understanding the status of a field.

A healthy growing point is essential for tiller and head development in wheat. As previously stated, growing points begin in the crown of the plant prior to vernalization. As tillers elongate in the late winter and spring, growing points are elevated above the soil and into the crop canopy. The canopy provides some insulating effect against cold temperatures, but provides less protection as the growing point is pushed further upwards towards the top of the canopy.

Healthy, young growing points have a turgid, yellow-green (sometime whitish) appearance (Fig. 8a). When injured by freeze, dead growing points turn white and then brown (Fig. 8b) as cells begin to decompose in the plant. The death of a growing point is not always immediately obvious by visual inspection as seen in Fig. 9. In most cases, the youngest leaf

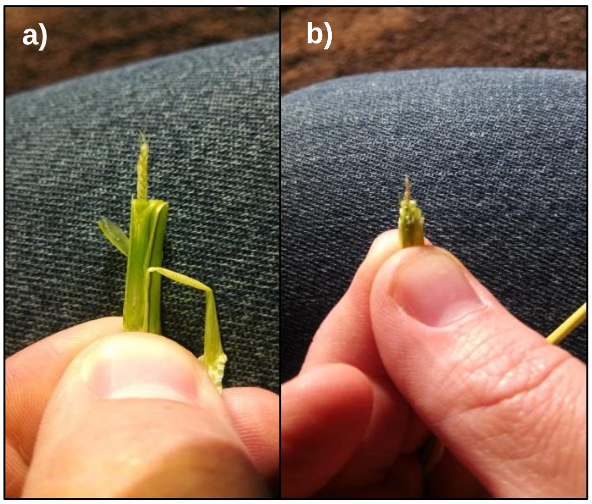

Figure 8. *Example of a healthy (a) and dead (b) growing point.*

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 will die as well. If an emerged leaf such as this (above) is dead, the growing point is likely dead and no further development of the head or forage growth on that tiller will occur.*

exerting from the whorl will also die and turn brown (Fig. 10). However, in some cases this leaf can remain green weeks after the growing point is dead and close inspection of each growing point is necessary. This can be done by splitting the stem with a razor just above the uppermost node.

Once a growing point dies, growth for that tiller will cease immediately. Even though the majority of the tiller remains green, there is no additional stem elongation, head development, or forage accumulation of any sort. If this occurs during the boot stage, the head will remain inside the flag leaf sheath and not emerge. In most cases, the head will also turn white and die (Fig. 11). If the growing point is not killed in the boot stage, freezing

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 while 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 and result in a distorted (hook-like) head.*

temperatures can sometimes lock the auricles around any protruding awns which prevents the head from emerging normally. Instead, the head may split out the side of the boot and create a fish-hooked appearance (Fig. 12). These heads usually can develop normally with minimal to no impact on grain yield.

Head Damage

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

Individual wheat heads flower over the course of 2-4 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 male portion of the flower, the anthers, are particularly sensitive and can be damaged with temperatures as high as 32^{o}F. Damaged anthers can appear twisted, shrivelled, and discolored within 48 hours after a freeze. When anthers are damaged, the pollen is sterilized and cannot fertilize the female portion of the flower. Therefore,

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

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

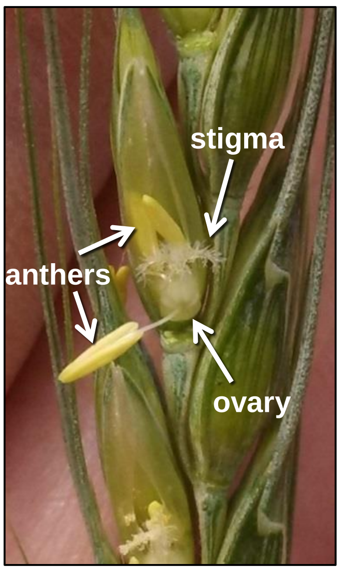

***Figure 15.** At the time of pollination, healthy anthers appear yellow and plump and the stigma is white and feathery in appearance (right). Damaged anthers will appear white and shriveled or twisted.*

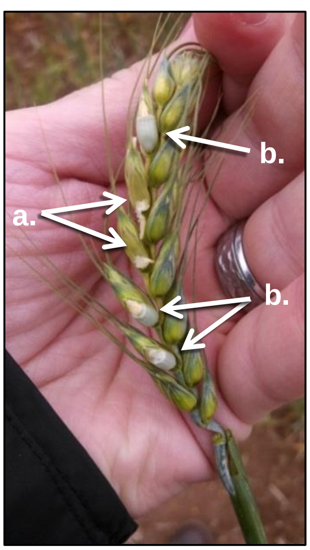

***Figure 16.** In the center portion of this seed head, anthers were damaged (a.) during development and pollination did not occur, resulting in no seed production in those florets. Florets at the top and bottom (b.) of the seed head were unharmed and seed development is proceeding normally.*

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

no seed is produced. Because wheat is self pollinated, chance of pollination from another undamaged floret (even on the same head) is unlikely.

When young, anthers appear green and turgid (Fig. 14) and eventually turn yellow (Fig. 15) as 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. Following fertilization, the seed begins to form and extends upward, elongating from the lower end (Fig. 16).

Once the ovary (lower end) swells to 2-3 mm long, then assume fertilization has occurred and the seed is growing. Afterwards, healthy anthers often are expelled from the floret and are indicative of a succesful pollination (Fig. 17). However, anthers sometimes remain inside the floret even though fertilization has occurred.

Anthers naturally turn white and shrivelled after mature pollen is shed, which mimic symptoms of freeze damaged anthers. Thus, determination of anther sterilization/damage due to freeze injury is perhaps the most difficult step in assessing wheat freeze injury and often confirmation only 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 while unaffected kernels continue to elongate. Even if a freeze does not kill the seed, it may reduce test weight or germination.

Seed that is partially developed at these stages of growth may appear a combination of gray, green, or even bluish, and may have a rubbery, pliable feel even though they appear plump. Though they don't appear normal, these seeds generally develop normally.

After two weeks, the seed should be in the milk stage and over the course of two more weeks will go through the soft dough and hard dough stages. 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; however, injured seeds will contain a clear, watery substance and turn grey in color. Freeze damage during the milk stage also may produce small, shrivelled seed (Fig. 18). Often, these seeds will have poor test weight and low percent germination.

Figure 18. *The kernels above depict two healthy seeds (left) in the dough stage and one shriveled seed (right) damaged during the milk stage. Freeze damaged seed, similar to the one above, will typically have reduced test weight and decreased germination.*

Once seeds have reached the hard dough stage, they are nearly full weight. This typically occurs sometime in mid May in central Texas, while regions of the High Plains may not reach hard dough until early to mid June. At this point, the seed is nearly fully developed and water content is lower; therefore, freeze injury potential is low.

Results from freeze damage in seed at soft or hard dough 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 therefore more susceptible to freeze injury.

Estimating Yield Loss

It is important to distinguish between percent freeze injury and percent yield loss (potential) because one rarely is equal to the other. Freeze injury can be estimated by the number of heads and/or number of tillers impacted. A simple sampling regime of the field can give a rough estimate of initial damage.

Start by picking two opposing areas of the field (i.e. highest and lowest points) and randomly select 20 stems 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. If 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 20-60%, additional areas of the field may need sampled to get a better idea of whether the majority of the crop is damaged or not.

Even after the damage has been assessed, the actual impact freeze injury has on yield is difficult to estimate. Yield loss estimation is difficult because conditions following the freeze greatly impact the ability of wheat to compensate.

Compensatory growth regularly occurs through development of younger tillers, larger seed, or more seeds per spikelet in undamaged portions of the head. Cool weather will facilitate additional growth and yield recovery, while warm, dry weather has the opposite effect. Wheat is productive when temperatures remain below 90ºF, but will struggle to compensate for freeze damage if temperatures are above this threshold, especially when night time 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% freeze injury might only result in 25% yield loss. The earlier damage occurs in the year, the better the chance of lower yield loss as wheat has more growing season left before heat and drought stress impact the crop. For actual yield estimation refer to the Texas A&M 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 wheat is unlikely to make a significant grain crop, harvesting the forage for hay is often a viable alternative.

The quality of wheat hay, particularly protein and fiber content, varies substantially with growth stage, however, freeze injury does not greatly impact

Figure 19. *Unless a wheat crop is substantially damaged, harvesting wheat for grain is generally the most profitable option for producers.*

Figure 20. *Damaged wheat crops are often baled for hay if they fail to make a profitable grain crop.*

Figure 21. *Wheat residue contains nitrogen and other nutrients which 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 response to heavily damaged wheat.*

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 quality is low, the value of the hay may not cover the expense of harvest. In some cases, the standing biomass may be more valuable as a plow down green manure or as a standing cover crop to be chemically terminated for protection of the next crop. Late freeze injury to bearded wheat, which is headed out, may be of low value due to the presence of hard awns that can cause problems in feeding livestock.

Don't overlook the value of nutrients removed from the field when selling freeze-damaged hay: Consider the value of nitrogen and other nutrients present in the forage as a fertilizer source and how much is being removed when hay is baled and transported off the field. At $0.65 per pound, 1.5 ton of wheat forage at 15% crude protein contains $18 per acre worth of nitrogen. Total nitrogen yield of wheat forage can be calculated by multiplying dry forage yield (lbs./A) by percent cude protein (in decimal form) and dividing by 6.25.

The value of nutrients removed from the field, which may need to be replaced, will help producers better understand if hay prices are worth it. Refer to the tables on the following page to estimate crop value based on yield potential, price, and harvest costs. Refer to the *Wheat Crop Budget* developed by Texas A&M AgriLife Extension Agricultural Economics website for a more detailed budget scenario. ■

For further information and up-to-date wheat freeze injury reports and field assessment observations, consult http://wheatfreezinjury.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.

Photo credits: Clark Neely: Figs 5a, 9, 12-17, 18; Calvin Trostle: Figs. 2, 4, 5b, 6-8, 10; Gaylon Morgan: Fig. 11; Qingwu Xue: Fig. 2

The following tables can be used to estimate the net profit value of a wheat crop as a grain, forage, or green manure crop. Harvest costs will vary depending on the end product and need to be considered in addition to the value of the crop.

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	$325	$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† (lbs/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 (lbs/acre)] * [% Protein Content / 6.25]

‡Total cost estimate used in calculating net profit value