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EC132

Freeze Injury to Nebraska Wheat[1]

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Nebraska's adverse weather conditions affect winter wheat during much of its growth. While the introduction of newer wheat varieties with good winter hardiness and the use of better management practices have reduced winter injury of winter wheat, low temperature injury during winter and spring can still be destructive.

Wheat has little resistance to low temperatures after it begins rapid growth in the spring; injury from freezes at this time can occur in any part of the state. This publication describes temperature conditions that cause winter injury, symptoms of injury at different spring growth stages, and management practices to use when wheat is injured.

Winter Injury

Low temperatures kill winter wheat plants by injuring the crown. The hardening process is the key to a plant's ability to withstand low temperatures. When adequately hardened, crowns can tolerate temperatures down to -9° to -11°F. Plants in the three-leaf to four-leaf stage with good root systems are in the best position to survive the winter in the Central Great Plains. Plants that develop numerous tillers because of early seeding remain more vulnerable to low temperatures than those seeded later. Larger plants are more subject to desiccation due to cold, dry winds or an open winter with a lack of adequate snow cover. Good stands and dense canopies provide insulation from cold temperatures so the temperatures in the winter canopy can be much higher than the air temperature. Also, moist soil cools off much slower than dry soil. Soil and seed-inhabiting fungi parasitize weakened plants and cause root and crown rot.

Plants killed by low temperatures normally will fail to green up in the spring and will have a bleached tan color. Typically, these symptoms will be most apparent on exposed ridges or hilltops. Very dry conditions in the fall through winter can prevent secondary root development, often predisposing the plants to direct low temperature winter kill or a combination of winter injury and root/crown rot.

Wheat that has suffered winter injury will often green up in the spring only to decline and eventually die. The crown tissue of plants suffering from winter injury will be soft, brown and mushy. Secondary roots will be rotted off. Healthy plants have firm, pale green crowns and white roots. To check for winter injury before spring green-up, carefully dig up wheat plants and soil from the field, place in a pot, add water and bring them indoors. If the crown tissue is still alive, new growth should be visible within three days on plants clipped at 1/2 to 3/4 inch above the crown.

When and Where Spring Freeze Injury Occurs

Significant spring freeze injury to wheat has occurred in many areas of Nebraska over the years. One of the most severe instances of winter wheat injury in Nebraska occurred in 1992. Other significant freezes occurred in 2004 and 2005.

Spring freeze occurs whenever low temperatures coincide with sensitive plant growth stages. Injury can cover large areas or only a few fields or parts of fields. It is often more severe along river bottoms, valleys and depressions in fields where cold air settles.

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[1]This publication is based on *Spring Freeze Injury to Kansas Wheat,* written by James P. Schroyer, Merrel E. Mikesell, and Gary M. Paulsen and published by Agricultural Experiment Station and Cooperative Extension Service, Kansas State University, Manhattan, Kansas, 1995. The University of Nebraska Authors Robert N. Klein and Drew J. Lyon adapted and revised the material for Nebraska growing conditions.

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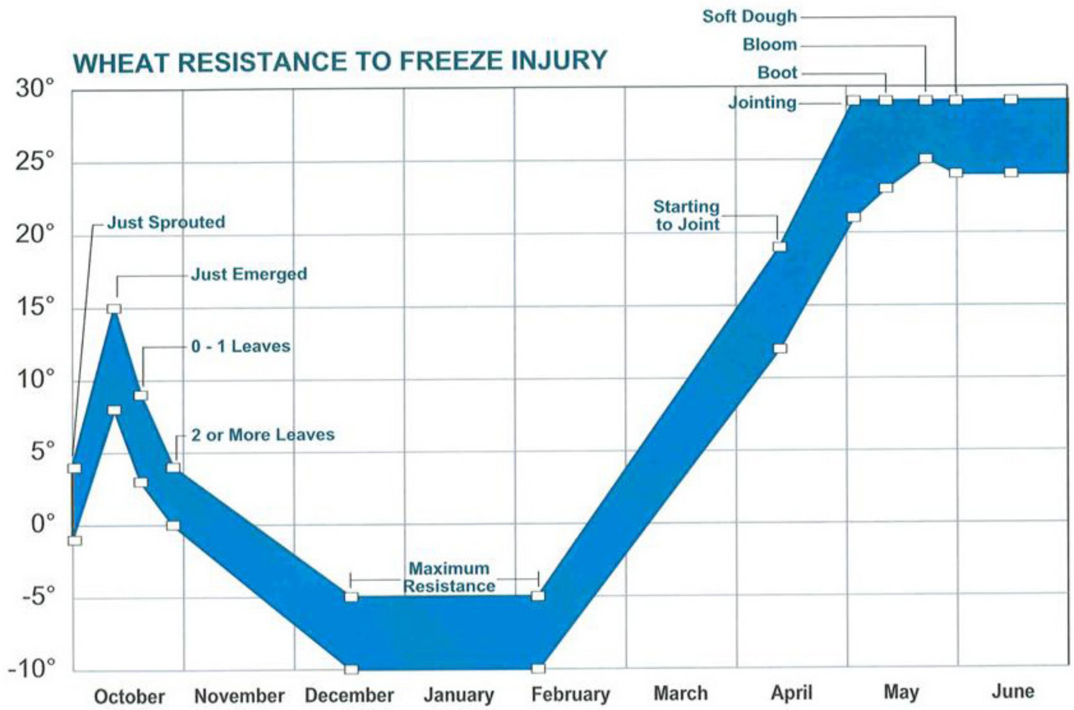

Figure 1. **Temperatures that cause freeze injury to winter wheat at different growth stages. Winter wheat rapidly loses hardiness during spring growth and is easily injured by late freezes. (Graph adapted from A. W. Pauli.)**

Early maturing wheat is more likely to be injured by freezes than late maturing wheat because of its advanced growth. Susceptibility to freezing temperatures steadily increases as maturity of wheat advances during spring *(Figure 1)*. Some varietal difference in resistance to spring freeze injury has been reported, but it is mostly caused by differences in plant growth stages at the time of the freeze. There is little difference among wheat varieties at the same growth stage and, therefore, little opportunity to increase freezing resistance in improved varieties.

When growing conditions are favorable and available soil nitrogen is high, wheat may be less sensitive to freeze injury because of its lush growth and high moisture content. Conversely, drought stress and poor canopy subjects the plants to cold and increases the severity of freeze injury. Ample soil moisture, cool temperatures, and high soil fertility slow plant maturity, so injury is less severe than in plants that have had less favorable growing conditions and are at a more advanced growth stage when freezing occurs.

Temperatures Causing Spring Freeze Injury

Winter wheat goes through a complex process of cold hardening during fall that increases its resistance to cold winter temperatures. Its cold hardiness is quickly lost when growth resumes during spring, leaving little resistance to freezing.

Cold temperatures that cause injury to winter wheat after hardening in the fall and dehardening in the spring are shown in *Figure 1.* Wheat is most sensitive to freeze injury during the reproductive period, which begins with pollination during late boot or heading stages. Temperatures that are only slightly below freezing can severely injure wheat at these stages and greatly reduce grain yields.

The degree of injury to wheat from spring freezes is influenced by both low temperature and the duration of low temperatures. Prolonged exposure to freezing causes much more injury than brief exposure to the same temperature. Temperatures at which injury can be expected are shown in *Figure 1* and *Table I*, and are for two hours of exposure to each temperature. Less injury can be expected from shorter exposure times, while injury might be expected at even somewhat higher temperatures from longer exposure.

The many factors influencing freeze injury to wheat — plant growth stage, plant moisture content, and duration of exposure — make it difficult to predict the extent of the injury. This is complicated further by differences in elevation and topography among wheat fields and between the fields and official weather stations. It is not unusual, for instance, for wheat growers to report markedly lower temperatures than are recorded at the nearest official weather station.

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Table I. Temperatures that cause injury to wheat at spring growth stages and symptoms and yield effect of spring freeze injury.

Growth stage	*Approximate injurious temperature (Two hours)*	*Primary symptoms*	*Yield effect*
Tillering	12°F	Leaf chlorosis; burning of leaf tips; silage odor; blue cast to fields	Slight to moderate
Jointing	24°F	Death of growing point; leaf yellowing or burning; lesions, splitting, or bending of lower stem; odor	Moderate to severe
Boot	28°F	Floret sterility; head trapped in boot; damage to lower stem; leaf discoloration; odor	Moderate to severe
Heading	30°F	Floret sterility; white awns or white heads; damage to lower stem; leaf discoloration	Severe
Flowering	30°F	Floret sterility; white awns or white heads; damage to lower stem; leaf discoloration	Severe
Milk	28°F	White awns or white heads; damage to lower stems; leaf discoloration; shrunken, roughened, or discolored kernels	Moderate to severe
Dough	28°F	Shriveled, discolored kernels; poor germination	Slight to moderate

Symptoms of Spring Freeze Injury

Knowing the symptoms of freeze injury and doing an early injury assessment can improve earlier management decisions. Waiting until harvest to learn that wheat has been damaged by freezing decreases the value of the damaged crop for some uses and limits management choices.

Assessment of freeze injury is aided by several characteristic symptoms that develop at each growth stage. Cold temperatures after spring freezes might delay development of injury symptoms, but injury to vital plant parts can be detected by careful examination. It is important to know which plant parts are most vulnerable at each growth stage, where they are located on the plant, and their normal appearance as well as their appearance after injury.

Figure 2 illustrates several growth stages of the wheat plant. *Figure 3* shows the wheat inflorescence and *Figure 4,* a portion of the spike of common wheat.

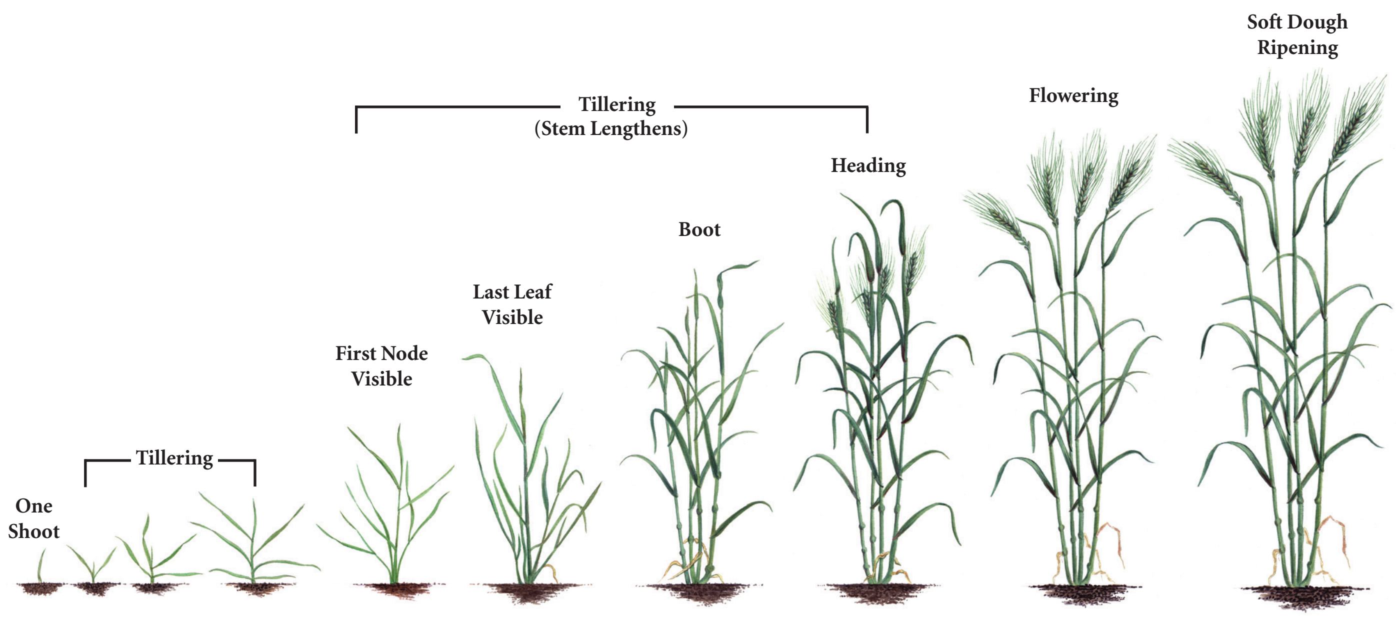

Figure 2. Physiological growth stages in winter wheat.

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3.1

3.2

3.3

3.4

Figure 3. The wheat inflorescence.

3.1. A wheat spikelet. There are usually 2 to 5 florets in each spikelet that have the potential to develop kernels. The two outside structures (one on each side) with the short barbs or horns are called glumes, which protect the florets.

3.2. The glumes are pulled down and the lemma and palea are exposed. The lemma is on the left and has the long barb, which is called the awn. On the right is a papery structure called the palea. At the base of the lemma and palea are the floral parts. The lemma, palea and floral parts make up the floret.

3.3. The inside of the floret before pollination. The three lime green, tri-lobed structures are the anthers and the pollen is inside them. The white, fuzzy structure is the stigma. The round, greenish-white object with a greenish crease is the ovule. When the pollen from the anthers is released and the grains attach to the stigma, pollination has occurred. The pollen then moves from the stigma through the style to the ovule where it is fertilized.

3.4. A time course photo showing the maturation of an individual floret. On the left is the young floret with immature floral parts. In the middle is a more mature floret where the anthers have turned yellow, the filaments (the threadlike structures attached to each anther) have elongated (the anthers will soon be visible outside the floret), and the stigma has expanded and is ready for pollen. Pollen grains are everywhere. On the right is the fertilized embryo, which will soon develop into a recognizable kernel. The anthers are gone and the stigma is drying up.

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Figure 4. Portion of spike of common wheat.

Tillering Stage

Spring tillering of wheat in Nebraska usually begins in March and continues through mid April. The growing point is just below the soil surface during this stage and is protected against injury. Most damage occurs to leaves, which become twisted and light green to yellow in color and are necrotic ("burned") at the tip within one or two days after freezing (*Figures 5* and *6*). A strong odor of dehydrating vegetation may be present after several days.

Injury at this stage slows growth and may reduce tiller numbers, but growth of new leaves and tillers usually resumes with warmer temperatures.

Figure 5. Burned and yellowing leaf tips are common spring freeze symptoms at the tillering stage.

Figure 6. More severe freeze damage causes the entire leaf to turn yellowish-white and the plants to be limp or flaccid. A silage odor may be detected after several days.

Jointing Stage

The jointing stage is when the internodes (stem segments between joints or nodes) are elongating in the wheat stem and the embryonic head is moving up through the stems. This usually occurs from early April through early May. Leaves of freeze-injured plants show the same symptoms as the tillering stage (*Figures 5* and *6*), but the most serious injury occurs to the growing points (*Figure 7*).

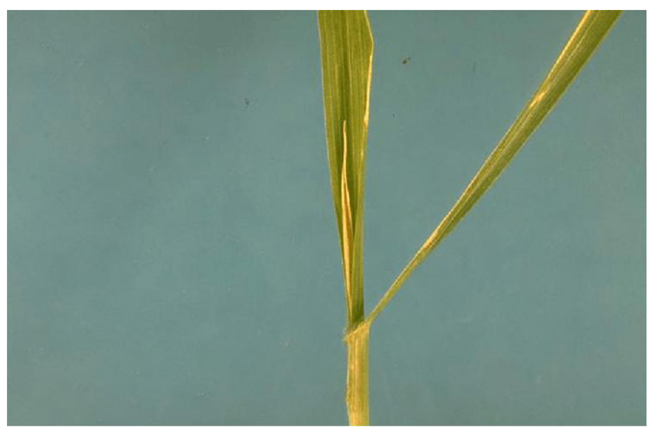

Figure 7. A yellow or necrotic leaf emerging from the whorl indicates the growing point may be damaged.

The growing points can be located by splitting stems lengthwise with a sharp knife. A normal, uninjured growing point is bright yellow-green and turgid; freeze injury causes it to become white or brown and water-soaked in appearance (*Figure 8*). This injury can occur even in plants that appear otherwise normal because the growing point is more sensitive to cold than other plant parts.

Stem growth stops immediately when the growing points are injured, but growth from later tillers may

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Figure 8. A healthy growing point has a crisp whitish-green appearance (left). A growing point that has been damaged loses its turgidity and greenish color within several days after a freeze. A hand lens will help detect subtle freeze damage symptoms (right).

obscure damage. Partial injury at this stage may cause a mixture of normal tillers and late tillers and result in uneven maturity and some decrease in grain yield.

Injury to the lower stems in the form of discoloration, roughness, lesions, splitting, collapse of internodes, and enlargement of nodes frequently occurs at the jointing stage and the following stages after freezing (*Figures 9* and *10*). Injured plants often break over at the affected areas of the lower stem so that one or two internodes are parallel to the soil surface.

Stem injury does not appear to seriously interfere with the ability of wheat plants to take up nutrients from the soil and translocate them to the developing grain. Injured areas might become infected by microorganisms, however, which can cause further stem deterioration. Lodging, or falling over, of plants is the most serious problem following stem injury. Wind or hard rain will easily lodge the plants, decreasing grain yields and slowing harvest.

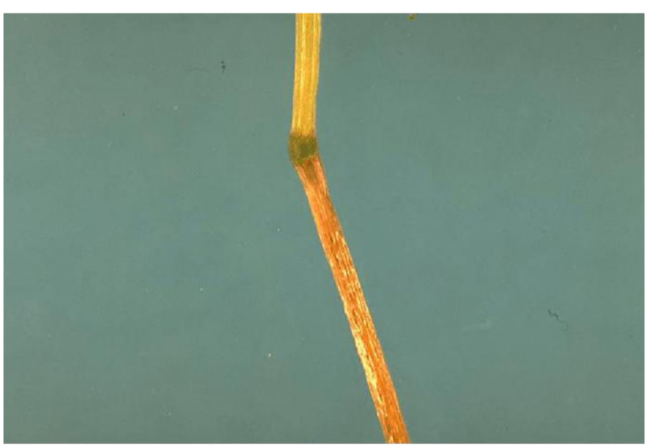

Figure 9. Discoloring and roughening of the lower stem are symptoms of spring freeze damage.

Figure 10. Splitting of stem occurs with severe freeze damage.

Boot Stage

The boot stage is the stage of growth from the time the head passes the third joint or node until the head emerges through the flag leaf.

Freeze injury at this stage, when the head is enclosed in the sheath of the flag leaf, causes a number of symptoms. Freezing may trap the head inside the flag leaf (boot) so that it doesn't emerge normally. When this happens, the head remains in the boot, splits out the sides of the boot, or emerges base first from the boot (*Figure 11*).

Sometimes a head can emerge normally from the boot after freezing, but remain yellow or even white instead of its usual green color. When this happens, the head has been killed (*Figure 12*).

Frequently, only the male parts (anthers) of the flower in the head are killed. Since wheat is mostly self-

Figure 11. The twisted spike on the right was trapped in the boot and split out the sheath. The awns of the middle spike were damaged while it was still in the boot stage. The spike on the left had partially emerged when freezing occurred so only the upper portion of the spike was damaged.

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Figure 12. This spike is emerging normally, but the yellow, water-soaked appearance, instead of the normal crisp, green spike indicates it is damaged.

Figure 13. Healthy wheat anthers are trilobed, light green and turgid before pollen is shed. Each wheat floret contains three anthers. Healthy stigmas are white and have a feathery appearance.

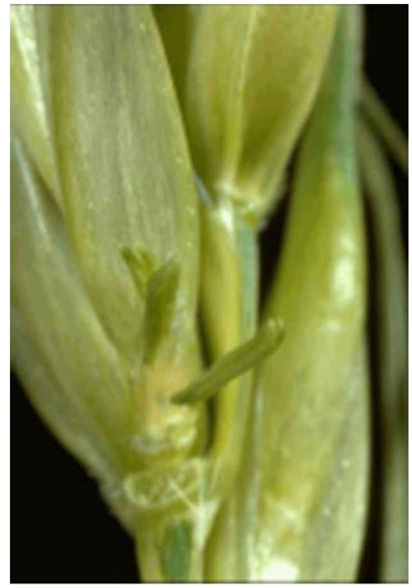

Figure 14. Anthers become twisted and shriveled, yet they are still their normal color within 24 to 48 hours after a freeze. A hand lens is necessary to detect these symptoms.

Figure 15. Close-up of twisted anthers and unopened whitish stigma shown in Figure 14.

Figure 16. If damaged, anthers become white after three to five days and eventually turn whitish-brown. The anthers will not shed pollen or extrude from the florets.

pollinated, sterility caused by freeze injury causes poor kernel set and a low grain yield. Injury can be detected soon after freezing by examining the anthers inside each floret. Anthers are normally light green and turgid when young and become yellow about the time they are extruded from the florets after flowering (anthesis) (*Figure 13*). Freeze injury causes anthers to become white and shriveled and might prevent them from being extruded from the florets (*Figures 14, 15, 16*).

Many symptoms of freeze injury that occur at early stages also may be present at the boot stage (*Figure 17*). Leaves and lower stems might exhibit symptoms described for the jointing stage, but these plant parts

Figure 17. Damage to the lower stem and nodes can occur at the boot and heading stages. Freeze damage causes nodes to become enlarged and the stem to bend or have a crooked appearance.

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Figure 18. Symptoms of slight freeze damage may occur only on the awns as the spike is emerging from the boot or after heading. Awns become twisted and bleached or white instead of their normal green color. There may be no other damage to the rest of the plant.

Figure 19. Freeze damage at heading causes glumes to become yellow and have a water-soaked appearance instead of being green and turgid. The rachilla, the short stem that connects the floret to the spike, may become purplish-brown, indicating damage.

are less sensitive to injury than the male flower parts. It is important, for this reason, to examine the anthers. Freezing temperatures that are severe enough to injure leaves and lower stems are nearly always fatal to male flower parts. Less severe freezing may cause male sterility

Figure 20. A whitish frost ring encircles the stem at the juncture of the stem and flag leaf at the time of the freeze.

Figure 21. Damage may occur in different areas of the spike because flowering, which is the stage most sensitive to freeze, does not occur at the same time in all florets.

without any symptoms appearing on the vegetative parts (leaves and stems).

Heading Stage

Wheat heads usually emerge from the boots during mid May to early June. Most symptoms of freeze injury at this stage — sterility, leaf desiccation or drying and lesions on the lower stems — are similar to symptoms at earlier growth stages. The most apparent symptom, however, is usually chlorosis or bleaching of the awns ("Beard") so that they are usually white instead of the normal green color *(Figure 18)*. Freezing temperatures that injure the awns also usually kill the male flower parts *(Figure 19)*.

A light green or white "frosting ring" may encircle the stems one to two inches below the heads several days after exposure to freezing temperatures *(Figure 20)*. This area of yellowed chlorotic tissue marks the juncture of the stems and the flag leaves when the freeze occurred. The frost ring may be present on injured plants as well as on plants that show no other symptom of injury. It does not seem to

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Figure 22. Shortly after pollination healthy greenish-white kernels begin to develop.

Figure 23. As healthy kernels continue to develop, they will contain a clear liquid.

interfere with the movement of nutrients from the plant to the developing grain. As the plants mature, however, the heads may break over at the frost ring. This is most likely to happen to heads that are well filled, particularly during windy conditions.

Flowering (Anthesis) Stage

Wheat usually flowers about one week after the heads appear. Symptoms of freeze injury at the flowering and heading stages are similar.

The flowering stage is the most freeze-sensitive stage in wheat. Small differences in temperature, duration of exposure, or other conditions can cause large differences in the amount of injury.

Exposure to freezing temperatures at the flowering stage kills the male parts of the flowers and causes sterility as described for the boot and heading stages. After freezing, the anthers are white and desiccated or shriveled instead of their normal yellow color *(Figure 21)*.

Freeze injury at the flowering stage causes either complete or partial sterility and void or partially filled heads because of the extreme sensitivity of the flower parts.

Flowering proceeds from florets near the center of the wheat heads to florets at the top and bottom of the heads over a two- to four-day period. This small difference in the flowering stage when freezing occurs produces effects shown in *Figure 21*. The center, or one or both ends of the heads, might be void of grain because the male flowers in those florets were at a sensitive stage when they were frozen. Grain might develop in other parts of the heads, however, because flowering hadn't started or was already completed in those florets at the time of the freeze.

Milk Stage

Young developing kernels normally grow to full size (volume) within 12 to 14 days after flowering, but maximum grain weight is not reached for another two weeks (*Figures 22, 23*). If young kernels fail to develop after freezing temperatures occur, they likely have been injured. Injured kernels also may be white or gray and have a rough, shriveled appearance instead of their normal light green, plump appearance (*Figure 24*). Cool weather frequently delays these other symptoms, however, so that failure of the kernels to develop may be the major indication of injury.

Kernels that are slightly injured at the milky ripe stage may grow to normal size, but produce light, shriveled grain at maturity. Examination of these kernels before maturity, as at the early dough stage, may show that their contents are grey and liquid instead of white and viscous as they should be at this stage (*Figure 25*). The interior of the rachilla, the small stems that attach the spikelets to the stems, may also be dark instead of light-colored, so that the spikelets are easily stripped from the stems. These symptoms result from the gradual deterioration of tissues and usually do not show up for a week or more after freezing occurs.

Wheat that has been injured by freezing at the milky-ripe stage often shatters easily at maturity, and the shriveled kernels cause the grain to have a low test weight. Germination percentage of the grain also may be seriously reduced as a result of freeze injury.

Dough Stage

Wheat kernels reach full size and nearly full weight by mid-dough stage in early to late June. Because kernel

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Figure 24. Kernel development stops immediately after freeze damage. Damaged kernels are grayish-white, rough and shriveled.

Figure 25. These healthy kernels at the milk to early dough stage contain a whitish fluid. Damaged kernels contain a gray to brownish liquid that is less viscous than the whitish fluid in the undamaged kernels.

development is nearly complete and kernel moisture content may have decreased, wheat is usually more resistant to freezing temperatures at this stage than at most earlier spring growth stages. The only visible sign of freeze injury at the dough stage may be an unsightly wrinkled appearance of the kernels and a slightly reduced test weight.

The most serious consequence of freeze injury at the dough stage is reduced germination of kernels. The embryo or germ usually has a higher moisture content than other kernel parts, and its complex of cellular contents and structures makes it more vulnerable to freezing.

Management of Freeze-injured Wheat

Harvest for Grain

Freezing frequently injures only part of the wheat head or only plants in certain parts of fields such as depressions and low areas (*Figure 26*). In addition, late tillers that normally would not produce significant grain may develop rapidly after a freeze, particularly when it occurs at early spring growth stages. These late tillers may produce appreciable yields if weather conditions following the freeze are favorable. After freezes at late spring growth stages, however, hot and dry conditions usually prevent later tillers from producing acceptable yields.

When freeze injury is only partial, when alternate management practices might disrupt established rotation systems, or when good alternate uses or crops are not available, the best management practice might be patience. Except in the most severe cases, wheat that has been injured often produces yields that exceed harvesting and hauling costs. However, this might be offset somewhat by increased shattering losses of freeze-injured wheat and the possibility of lodging (usually during the boot and heading stages) caused by lower stem damage.

Grain produced by wheat injured by freezing after the flowering stage frequently is of poorer quality than usual. Test weight may be low, kernels may be shriveled or discolored, and the grain may be a mixture of kernels of different sizes and maturities.

The germination percentage of seed from freeze-injured plants should be checked before planting. Seed of most wheat varieties has a natural dormancy that causes low germination for several weeks after harvest. The seed should be given a cold treatment before testing, or germination tests should be delayed for about four weeks. If germination is slow and germination percentage is low four weeks or more after harvest, the wheat should not be used as seed. Shriveled seed should not be used in any case because field emergence is poor even if germination percentage is high. In addition, shriveled seeds produce less vigorous seedlings that usually yield less grain than seedlings from good quality wheat seed.

Wheat grain that is shriveled or germinates poorly makes excellent cattle feed. It is usually high in protein content (test for protein level), which enables the amount of protein from other sources to be decreased. Wheat grain should be gradually incorporated into the livestock ration over a one-week period. It should never constitute more than one-third to one-half of the total grain in the ration.

Hay or Ensilage

Cutting freeze-injured wheat for hay or ensilage may be the most economic and practical use if the feed is needed and equipment is available. The feed quality of hay or ensilage is good through the soft dough stage. Moreover, it might be necessary to kill the remaining freeze-injured wheat plants with herbicides after haying or ensiling so they will not become weeds if the land is replanted to other crops. It is also usually desirable to

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Figure 26. Low areas in a field are more susceptible to freeze damage.

remove the wheat vegetation instead of directly working it into the soil to prevent excessive moisture loss.

The nitrate content of wheat for hay or ensilage after freezing should be checked to avoid toxicity to livestock. Because late freezing usually injures only certain parts of the wheat head and rarely kills the plant, plants may continue to absorb nitrate from the soil but not have any developing grain to utilize the nitrogen. Nitrate may accumulate under those conditions. High nitrate feed can poison livestock unless the feed is diluted with adequate quantities of low-nitrate feed. The ensiling process decreases nitrate but the grain should still be tested before feeding.

Cattle on wheat hay or ensilage that was cut after the anthesis (flowering) growth stage should be closely observed for development of actinomycosis, commonly known as big jaw or lumpy jaw. The problem occurs when tissues inside the mouth of cattle are punctured by wheat awns and become infected. Actinomycosis is less likely when wheat is cut at young growth stages and when it is fed as ensilage rather than as hay.

Alternate Crops and Management Options

Ample time is usually available after early assessment of spring freeze injury to replant to other crops. The most likely alternate crop possibilities include soybean or sorghum in eastern Nebraska and sorghum, proso millet, or sunflower in western Nebraska. Available soil moisture should be determined when choosing the alternate crop. In many situations summer fallow land will have more soil moisture than the land on which the injured wheat grew and the summer fallow land should be planted to the alternate crop. The land with injured wheat can be summer-fallowed and replanted to wheat in the fall. This strategy requires better than usual moisture conditions for both the alternate crop and for the wheat in the fall.

Freeze-injured wheat might need to be killed with herbicides if it is not cut for hay or ensilage to prevent it from becoming a weed after replanting to another crop. This is necessary because freezing rarely kills the entire plant. If the wheat is not removed or killed with herbicides, it should be chopped or worked thoroughly to prevent rapid drying of the soil.

The injured wheat could contribute to wheat streak mosaic virus the following year if the plants develop late tillers. These late tillers, along with some early volunteer plants, could bridge the gap between crops.

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This publication has been peer reviewed.

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