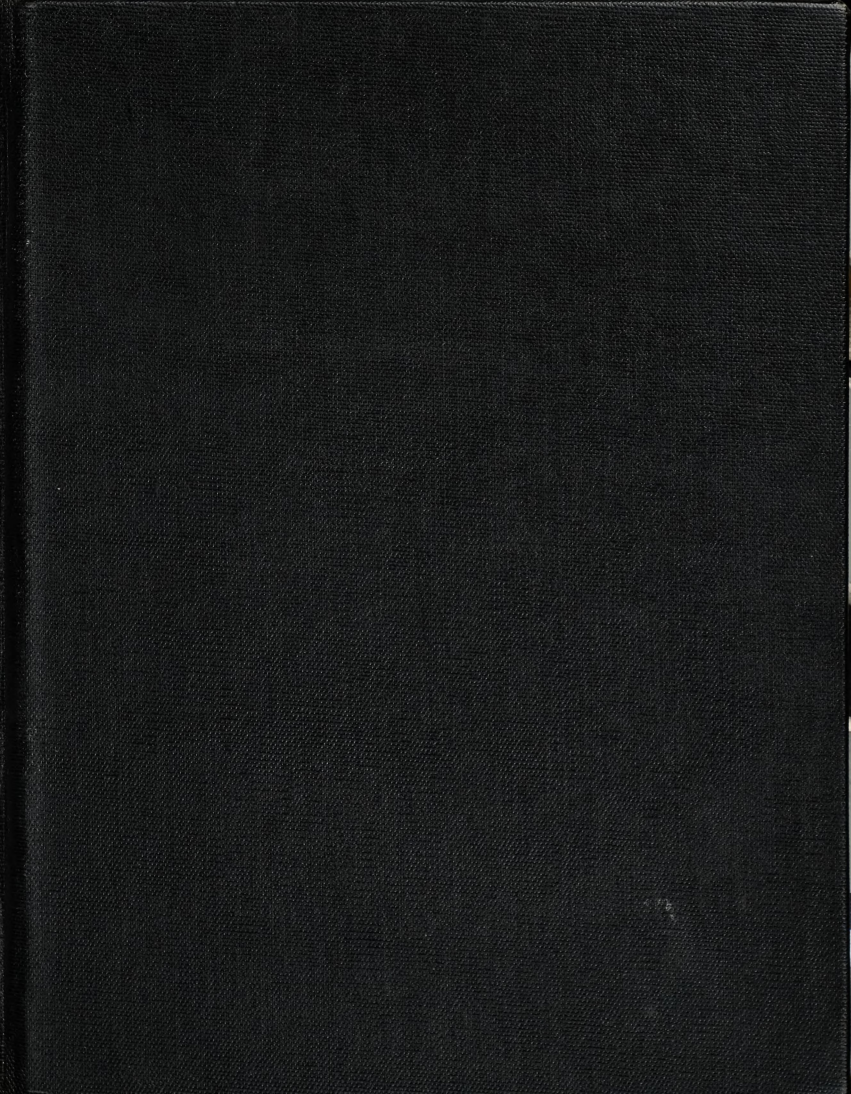






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thesis entitled

the effect of preharvest sprouting on seed
germination, storability, and field performance
of four winter wheat varieties (*Triticum aestivum* L.
grown in Michigan presented by

Sabry Gobran Elias

has been accepted towards fulfillment
of the requirements for

MS degree in Seed Technology,
Crop and Soil Sciences

L. O. Copeland

Major professor

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THE EFFECT OF PREHARVEST SPROUTING ON SEED GERMINATION,
STORABILITY, AND FIELD PERFORMANCE OF FOUR WINTER
WHEAT VARIETIES (TRITICUM AESTIVUM L.) GROWN
IN MICHIGAN

By

Sabry Gobran Elias

A THESIS

Submitted to
Michigan State University
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1987

ABSTRACT

THE EFFECT OF PREHARVEST SPROUTING ON SEED GERMINATION,
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Three experiments were conducted to measure the effects of different levels of sprouting on two soft white and two soft red winter wheat varieties grown in Michigan on germination, storability and field performance. Eight levels of sprouting were selected for the experiments.

At higher levels of sprouting, red varieties stored better than white ones for the first six weeks, as indicated by their germination percent. However, after eight weeks, no differences occurred in germination of white and red varieties.

Exposure of unthreshed heads to high moisture levels caused preharvest sprouting, accompanied by a gradual decrease in the germination of the white variety Augusta, while the red variety Hillsdale resisted sprouting and retained its high germinability for up to twelve weeks of storage. As the number of sprouted seeds increased, germination decreased.

No differences were observed in field performance of seed from white vs. red varieties for the same levels of



Sabry Gobran Elias

sprouting. However, as the level of sprouting increased, field performance as measured by field emergence and yield decreased at similar rates in both varieties.



TO THE MEMORY OF

My father to whom I owe my success
and my brother-in-law Fakhry Khalil who made the
graduate study opportunity available to me
They departed during the completion of this work



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INTRODUCTION

Under preharvest conditions of continued rainfall and high humidity, wheat (Triticum aestivum L.) seed may start to germinate while still in the head. Changes in the chemical constituents of the wheat kernel accompany this process and have a deleterious effect on the subsequent commercial use. These changes are collectively referred to as preharvest sprouting damage (53). It culminates when the radicle and/or the plumule penetrates the pericarp.

Preharvest sprouting is a periodic problem (about 2-3 years out of 10) with certain wheat varieties grown in Michigan. For instance, in both 1980 and 1986, much damage from preharvest sprouting was noted (72). Although seed with minimum presprouting can retain its germination capacity for a time, it is known to lose germination capacity more rapidly than unsprouted seed. The time required for loss of germination depends on the extent of the presprouting and the storage conditions.

Preharvest sprouting of wheat can result in serious quality losses (2,8,17,25,35,45,49,51,54,55,71), depending on the duration of the adverse weather and the proportion of wheat harvested prior to such weather. Such sprouted wheat can represent a serious problem if used for seed (17,34,36,39,55,56).

The objectives of this study were: (1) to measure the effect of preharvest sprouting on germination; (2) to study the effect of storage on the germination of seeds with different levels of sprouting; (3) to observe the performance of the sprouted seed in field trials; and to determine the potential impact of the sprouting problem on Michigan seed producers and wheat growers.

The literature review will cover the following topics:

1. the extent of preharvest sprouting damage.
2. the relationship between sprouting and enzyme activities.
3. the effect of the covering layers on sprouting.
4. preharvest sprouting and seed coat color.
5. sprouting and dormancy.
6. plant hormones and preharvest sprouting.
7. general aspects of breeding for preharvest sprouting resistance.



LITERATURE REVIEW

The extent of preharvest sprouting damage

The problem of grain sprouting in the field is widespread throughout the world wherever wheat is grown. It has been reported in northern and western Europe, South America (Chile and Argentina), western Canada, New Zealand, Australia, and in many areas of the United States (2,11, 36,37,39,52,53) (see Fig. 1). In the United States, preharvest sprouting in wheat has been reported in the Pacific Northwest (11), New York (35), the Great Plains (54), and Michigan (11,17). Soft white winter wheat varieties in Michigan are much more susceptible to preharvest sprouting than the soft red varieties (25). In some years, as much as 50-60% of the Michigan acreage of soft white wheat may be affected. Some fields are almost 100% sprouted, while others may be much less affected (17).

Significant economic losses from both yield reduction and poor grain quality can occur as a result of preharvest sprouting. Sprouting in the spike reduces yield per acre because of loss of weight after removal of extended plumules and radicles during threshing as well as weight loss from the partially depleted seeds (2).

Since substantial physiological and biochemical changes may have taken place in the grain without producing any

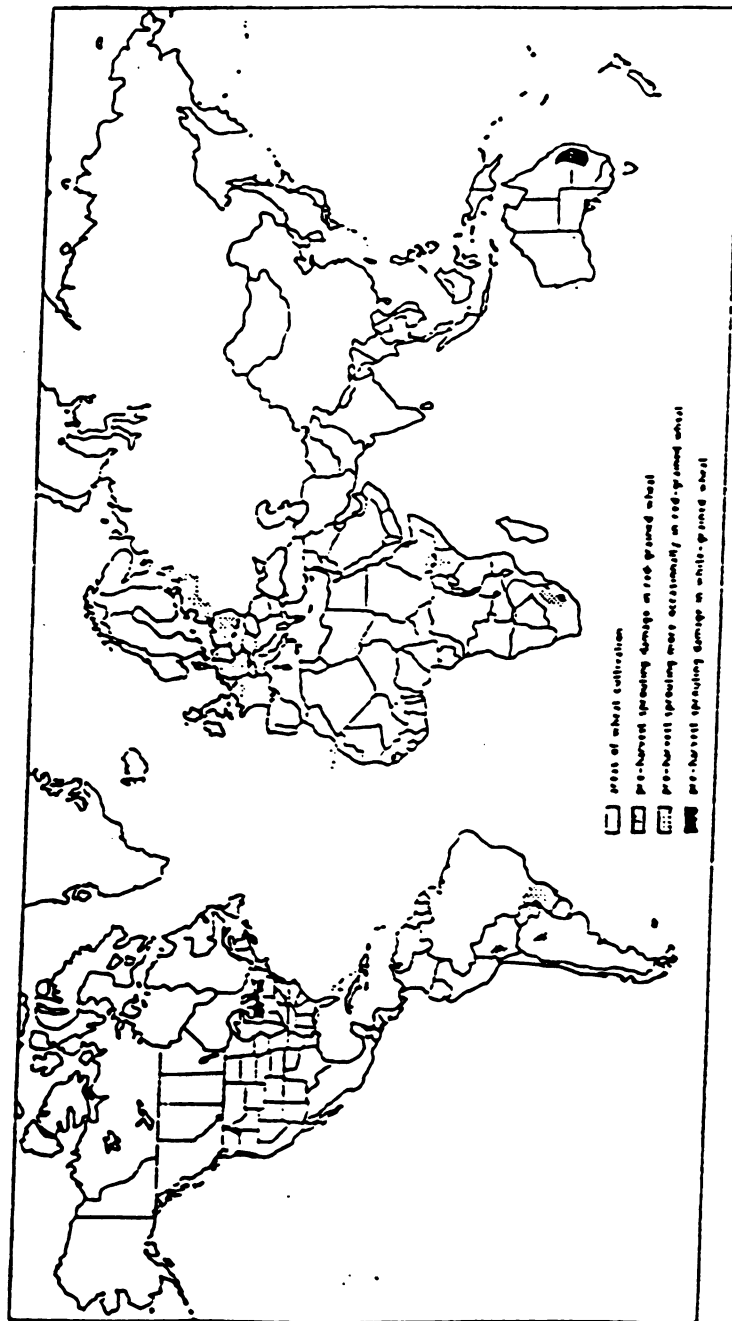


Figure 1. Main regions for preharvest sprouting damage in wheat (from Mackey, J. Cereal Res. Comm. Vol. 4 No. 2 1976).

external evidence, it may be necessary to test the grain for its acceptability for some uses (56).

Copeland et. al. (1980) reported on the use of sprouted wheat for seed. They stated that any level of preharvest sprouting will lower the seed quality to some extent, but may not destroy its subsequent germination potential if sprouting is not too severe, and if the moisture content is reduced to safe levels (13.5 - 14 %) immediately. Occurrence of warm dry weather to hasten grain ripening, followed by prolonged rain and high humidity is most favorable for sprouting. Cold damp conditions are less likely to result in widespread sprouting (34).

The seriousness of preharvest sprouting depends on the variety, the stage of maturity, the temperature, and the duration of the unfavorable conditions (53,65). Mares (1984) noted that as grain matures and ripens, the risk of damage increases dramatically and the range of temperatures favorable to germination broadens, particularly if the first rainfall is accompanied by temperatures below 15 C for several hours (53).

The danger of preharvest sprouting increases if the rainfall persists for several days accompanied by warm temperatures. Even very dormant seed will eventually sprout (34,38,56) if wet conditions persist. In order to avoid excessive presprouting damage some countries have



developed warning systems based on susceptibility of varieties and prevailing weather conditions (50).

The relationship between sprouting and enzyme activities

Preharvest sprouting beyond minimal levels increases alpha-amylase activity and decreases quality of wheat for many purposes (10,54). Many researchers have reported lower baking quality of the flour from sprouted wheat (2,8,17,25,34,35,36,37,51,54,55,71). Baking experiments with flour milled from sprouted wheat showed that excessive alpha-amylase causes a highly colored loaf, stickiness of dough, and difficulties in using bread-making machinery (12,51). A high level of protease affects the gluten properties, producing an expanded loaf volume with poor internal quality (51). Conversely, wheat damaged by sprouting can be used satisfactorily for animal feed (17,56).

Increase in hydrolytic enzyme activity, particularly by alpha-amylase, is the most important change that accompanies germination (10,33,35,51). Normally, alpha-amylase is present in immature grain but its activity decreases to a very low level during ripening and does not reappear until germination begins (10).

Another important physiological change is gibberellic acid synthesis in the embryo and its transfers to aleurone layer where it stimulates the synthesis of alpha-amylase. During sprouting, alpha-amylase catalyzes starch

degradation in the endosperm into free sugars needed for seedling growth.

Johansson (1976) found a close correlation between germination and enzyme activities (40). McCrate et. al. (1981) showed that sprouting and alpha-amylase activity were highly correlated (10,54).

As alpha-amylase activity increases, the falling number which measures the amount of endosperm degradation, decreases. Greenaway (1969) reported that the falling number test is the best method to measure alpha-amylase activity (33). Hagmann and Ciha (1984) showed that the falling number test and other enzymatic tests measure the quantity of endosperm degradation or the amount of alpha-amylase that has been already synthesized de novo, and thus indicate whether germination has occurred. They found that germination tests are better in predicting sprouting susceptibility, whereas enzymatic tests are better in quantifying actual sprout damage (35). Svensson (1976) found that the falling number reduced more quickly at a germination temperature of 15 C than at 20 C (79). Huang and Varriano-Marston (1980) studied two methods for determining alpha-amylase activity in two hard white winter wheat varieties and one hard red winter wheat variety grown in Kansas. They reported that the falling number method was more highly correlated with sprouting damage than was alpha-amylase activity, as measured by the production of

reducing sugars from a soluble starch substrate (38).

The induction of alpha-amylase synthesis is specific to gibberellins. Neither auxins nor cytokinins have any effect in this system. However, it is inhibited by various naturally occurring growth inhibitors such as abscisic acid (41).

Persson (1976) reported that selection for low alpha-amylase activity has no deleterious effect in field emergence (73). Svensson (1976) tested a number of varieties and breeding lines for sprouting resistance and found significant differences in the alpha-amylase activity among the varieties during dormancy (79).

Gale and Marshall (1973) showed that the dwarf wheat "Tom Thumb" possesses desirable characteristics for resisting preharvest sprouting such as low alpha-amylase synthesis and insensitivity to gibberellic acid (28). In (1976) McMaster found that the white wheat variety "Tordo" had a limited capacity to synthesize alpha-amylase on germination and a low sensitivity to respond to gibberellic acid. He reported that these two characteristics were strongly associated with the dwarfness of "Tordo" (59). Bhatt et. al. (1977) supported the previous findings and confirmed that plant height was positively correlated with alpha-amylase synthesis and response to gibberellic acid (6). Breeding for a complex resistance to preharvest sprouting in white wheats is possible by transferring



gibberellic acid insensitivity and low alpha-amylase synthesis using dwarf wheat varieties such as Tom Thumb as a source of resistance (5,6,59).

Gordon et. al. (1977) studied the germination sequence of non-dormant wheat enclosed in head. They identified the germination sequence as sprouting, endosperm degradation, and alpha-amylase response. They suggested that other enzymes, such as proteolytic enzymes, starch phosphorylases, and hemicellulases contributed substantially to endosperm degradation. However, they suggested that low levels of alpha-amylase in conjunction with beta-amylase may be sufficient to cause endosperm degradation. They also noted that the early decline in falling number preceded the increase in alpha-amylase activity. They added that the final massive increase in the alpha-amylase activity was associated with a minor drop in falling number (30). Johansson (1976) and Gordon et. al. (1977) confirmed that sprouting preceded increased alpha-amylase activity by at least 20 hours (30,40). Olered and Jonsson (1970) suggested that two alpha-amylase systems operated during different stages of the development of the grain. During the early stages, alpha-amylase is continuously inactivated (green amylase) and is reversible. Later, a new kind of alpha-amylase develops. This form of alpha-amylase is irreversible and causes a great and permanent reduction in the falling number (69).

Kruger (1976) suggested that the increases in enzyme levels during germination can occur in two ways. One is by re-activation of enzymes previously formed during kernel growth and maturation. This release of pre-existent enzymes may occur very soon after germination starts. One such enzyme is beta-amylase which is bound in an inactive form via its thiol groups and is released during germination by either proteolytic enzymes or disulfide reductases. The second manner of enzyme formation occurs by de novo synthesis, and alpha-amylase is a good example of this. Such enzyme formation usually requires a day or more of germination to be detectable. He reported that three groups of oxidases are involved in the germination process. These include peroxidases, polyphenol oxidases and catalase. Activity levels for these groups increase during seed formation and then decrease as the kernel matures and rise again during germination (47). Noll (1983) found a positive correlation between peroxidase activity and grain dormancy (68). Kruger and Perston (1976) reported that there is a little evidence of proteolytic enzymes activity in wheat prior to visual sprouting. They found no large difference in activity between sprout-resistant and sprout-susceptible wheat. Furthermore, they found no correlation between sprout resistance and proteolytic activity (48).

The effect of the covering layers on sprouting

In a study of white and red wheat at maturation, Wellington (1956) confirmed earlier reports that white wheat germinated faster than red wheat. He reported that neither the presence of pigment in the testa nor the impermeability of the seed coat to water of the red grains appears to directly influence germination. He attributed that behavior to the mechanical properties of the covering layers, especially the pericarp (82). However, Miyamoto et. al. (1961) reported that a mechanically tough seed coat was not a major factor in post-maturity dormancy (63).

Takahashi reported that removal of the lemmas from dormant seeds allowed them to germinate immediately (80). Other researches suggest that the site of dormancy is mainly in the pericarp-testa layers of the grain (2,3,21, 28,63).

In 1961 Wellington and Durham studied the effect of the covering layers on the uptake of water by the embryo of a white and a red wheat variety. They found that in mature white wheat, the embryo was able to rupture the germ cover when water was available. However, the germ cover of the red grains prevented water uptake by the embryo until a sufficient period had elapsed. They suggested that this behavior might be due to a differences in either the pressure exerted by the embryo, or the mechanical

resistance of the pericarp-testa layers (83).

Bucher and Stenvert (1973) studied water penetration into the seed of three hard and three soft white wheat varieties. They reported that the physical hardness of the grain did not appear related to the rate of moisture penetration. However, they showed that the protein which binds water could retard the movement of moisture into the grain. In addition, they confirmed that the presence of substances (e.g., hemicelluloses) in the bran, which are capable of strongly binding water, and the presence of lipids in the testa and aleurone layers can act as a physical barrier to the movement of water. They considered both substances capable of influencing the amount of water that penetrates the seed (13,14). A similar study was conducted by King (1984) who studied water uptake by mature wheat seed for a group of 50 white vs. red and soft vs. hard wheat varieties. He concluded that neither seed coat color, pericarp nor testa thickness, grain hardness, nor seed protein were correlated with water uptake. He reported that there can be differences in rate of water absorption by the seed itself (46). Moss (1973) studied the differences in the rate of water penetration of six varieties of white Australian wheat. He concluded that these differences might be due to variations in thickness and composition of the outer cuticle of testa, the extent to which the outer epidermal and inner

paranchymal cells have been compressed, and the number and size of protein masses in the sub-aleurone endosperm cells (66).

Miyamoto et. al. (1961) reported that the seed coat of red wheat tightly covers the embryo whereas in white wheat it is often separated from the embryo. They suggested that water might enter the embryo of white wheat more easily than in red wheat varieties. However, they confirmed that dormancy was not due to seed coat impermeability (63).

Durham and wellington (1961) studied the influence of the pericarp and testa on the germination of wheat and concluded that the permeability of these layers to oxygen had no inhibiting effect on germination (23). This agrees with observations made by other researchers that restriction of water and oxygen uptake of the seed coat is not a limiting factor in wheat dormancy (3,23,63).

Belderok (1976) assumed that high molecular weight proteins are present in the testa of wheats during dormancy. These swell readily during water imbibition and thus make the testa impermeable to oxygen. During after-ripening, a break-down of the high molecular weight proteins to low-molecular weight proteins takes place, along with a decrease in swelling capacity and an increase in oxygen permeability (4).

King and Richards (1984) showed that seeds of varieties and near-isogenic lines with awns absorbed up to 30 percent

more water than those of awnless varieties. Preharvest sprouting was increased by at least 40 percent and water also penetrated to the grain more rapidly in awned lines. Loss of free water during drying was hardly affected by the awns. They found also that water uptake was more rapid in club wheat varieties. Pubescence and glaucousness (waxy or low wax) had no effect on water uptake. They could not determine how the spike structure of awned varieties influenced the response to water, but suggested that the glumes and/or lemmas of awned varieties capture more water (45). Their findings confirmed those of earlier studies by Pool and Patterson (1958) and King and Chadim (1983) except that Pool and Patterson reported faster drying of awned vs. awnless varieties (44, 75).

King and Chadim (1983) studied the effect of seed size on wheat germination. They found that smaller grain of the peripheral floret positions germinates most rapidly. Thus, they suggested that selection for large grain may be of value (44).

Belderok (1976) studied the chemical analysis of the testa layers of two sprouting susceptible vs. sprouting resistant wheat varieties by means of energy dispersive x-ray spectroscopy. He found that the unripened grains of the two susceptible varieties had low sulphur levels and that insignificant changes occurred during ripening and storage. Testa of the two resistant varieties possessed a high

sulphur content one week prior to harvesting which decreased gradually during ripening and after-ripening. However, there was a time lag between the decrease in sulphur content and the increase in germinability. He suggested that another factor, such as the anatomical structure of the seed coat might also have an effect on the disappearance of dormancy (4).

Preharvest sprouting and seed coat color

The relationship between susceptibility to sprouting and seed color is of considerable importance in breeding for sprouting resistance. As early as 1914, Nilsson-Ehle suggested that the capacity for a variety to germinate readily at harvest is conditioned by hereditary, especially that which control red testa coloration (67). Many researchers have since confirmed this (25,26,27,55,56,81, 82). However, Derera et. al. (1977) identified varieties with white seed coat which possessed relatively high degrees of dormancy, e.g., Kenya 321 sib and Ford (7,20). Also, red lines (e.g., Sonora 64 A) with little or no sprouting resistance were identified (4,31,57,63).

Everson and Hart (1961) studied 16 red and 5 white seeded varieties to determine the effect of seed coat color on post-harvest dormancy. They found that duration of dormancy in red varieties ranged from 5 days to 3 weeks after maturity. Conversely, all white seeded varieties

germinated in less than 3 days after they reached maturity. They reported that the association between seed coat color and dormancy could be due to a tight linkage between the genes controlling seed coat color and those controlling dormancy (phototropic gene action) (25).

McEwan reported that the association between seed coat color and sprouting resistance is by no means absolute. Varieties with a white seed coat are uniformly sprouting-susceptible, whereas a range of sprouting reaction is exhibited by those with a red seed coat, from highly susceptible to highly resistant (57,58). In 1959 and 1967, he studied the relationship between sprouting and seed coat color. He concluded that the red seed coat color is due to three independent genetic factors, and suggested that slightly resistant varieties have only a single gene for red color, moderately resistant varieties have two genes, and the highly resistant ones have all three. He concluded that since some red varieties are quite susceptible to sprouting, there must be different forms of the three basic genes for red color differing in their ability to produce sprouting resistance, or the expression of the genes must be modified by other genetic factors which repress the ability of the red factors to inhibit germination. He suggested that the pigment itself might play a role in the suppression of germination (55,56). In a later study, McEwan (1980), reported no association between intensity



of red color and dosage of red genes, since high levels of sprouting resistance can be conferred by a single red grain factor in the homozygous condition. He showed that a marked level of transgressive segregation is possible for the sprouting resistance character (58). Freed (1972) studied the nature of the association between seed coat color and dormancy in different hybrid crosses. He demonstrated that dormancy in wheat is associated with the pigmented maternal testa, and that red pigmentation always suppressed germination. Freed established the number of genes controlling seed coat color in six dormant red varieties in crosses with a non-dormant white varieties. The varieties with strong dormancy at harvest all had three genes for seed coat color, whereas the others had two genes controlling seed coat color. He reported that the embryo does not play a significant role in controlling dormancy (26). Freed et. al. (1976) confirmed that the different genes controlling pericarp color contribute different levels of dormancy. They added that the pigmentation gene system is very likely only one of several systems which affect dormancy. They suggested that other genes control the rate of release of gibberillic acid from the scutellum and its movement to the aleurone layer where it activates the amylase system (27).

Miyamoto and Everson (1958) suggested that the main pigment in the wheat pericarp is phlobaphene, a reddish

brown pigment whose precursors are catechin and catechin tannin. They reported that the soluble precursors might also inhibit germination (62,63). Also, tannins are known to inactivate enzymes and thus promote dormancy (52). Stoy and Sundin (1976) confirmed the finding that catechins and catechin tannins can also inhibit germination (78). The loss of dormancy during the weeks after maturity might then be correlated with the natural inactivation of inhibitors by conversion of the colorless water soluble catechin via catechin tannin into the brown, water insoluble phlobaphene (3,62) as in the following.

Catechin -----	Catechin tannin -----	Phlobaphene
Colorless	Yellow	Brown
Water soluble		Water insoluble

A close positive correlation was found between the degree of kernel color in wheat and quantity of catechin and catechin tannin present in immature kernel (62).

A comparative study between sprouting resistance and sprouting damage of three white vs. three red spring wheat varieties was made by McEwan (1976). He concluded that the red varieties had higher initial seed dormancy, a lower tendency for sprout damage (starch degradation), a greater capacity to maintain test weight, less visible sprout damage to the grain by rupture of the pericarp by the developing embryo, and higher seed viability under sprouting conditions than do similar white varieties (57).

De Pauw and McCaig (1983) crossed a spring wheat (RL 4137) with a long dormancy period and three genes for red seed coat color with a white-seeded wheat (7722). They found a positive relationship between red seed coat color and sprouting resistant in both the F3 and F5 generations. The variability for dormancy within the white-seeded progeny of 7722/RL 4137 ranged from the white-seeded parent 7722 to red-seeded controls (e.g., Neepawa and Glenlea). They suggested that some of the dormancy of RL 4137 was transferred to the white-seeded progeny. None of the white-seeded progeny, however equalled the dormancy of RL 4137. The evidence supported the hypothesis that RL 4137 has a genetic mechanism for dormancy associated with the red seed coat color and one or more mechanisms not associated with seed color (18).

Sprouting and dormancy

Dormancy occurs when morphologically mature seeds fail to germinate even under favorable conditions of temperature, moisture, light or oxygen. Although dormancy is recognized to be genetically controlled, it is influenced by environmental conditions during seed formation and development (1,2,11,80). Takahashi (1980) noted that high temperatures 10-20 days after fertilization decrease dormancy, whereas low temperatures tend to increase dormancy (80).



Freshly harvested seeds of the cereals typically require a maturation or after-ripening period during which physiological and chemical changes occur resulting in the disappearance of dormancy (29,34). Harrington (1940) reported that differences in germination among varieties are due to differences in dormancy, rather than differences in speed of germination (37). However, Chang (1943) mentioned that in some cases the differences in dormancy may be due to differences in speed of germination (15). Belderok (1961) found that the amount of water available to the plants and the relative humidity of the atmosphere before harvest had no influence on dormancy (1). However, the influence of temperature was quite different. In 1968 he reported that the duration of dormancy depends both on variety and the accumulated temperature (e.g., the sum of the daily mean temperatures) during the soft dough stage which can last as long as 10 to 23 days. He observed that hot weather during this stage shortens the ensuing dormant period, while cool weather prolongs it. He assumed that a 10-day dormancy is required for sprouting resistance. Consequently, varieties with little or no dormancy are susceptible to sprouting, while those with prolonged dormancy are sprouting resistant (2). However, Olsson and Mattsson (1976) reported that the influence of the accumulated temperature during the dough stage on the duration of dormancy varies among years and locations.

Their investigation which included 9 winter and 14 spring varieties grown in Sweden in 1972-1974 indicated that accumulated temperatures can not be used as a basis for an efficient warning system. They also found differences in the duration of dormancy among varieties. They noted that high temperatures during and following ripening appears to shorten the dormancy period, however other factors, such as temperature before the dough stage, the length of this stage, and the relative humidity also have an effect (70). Similar results were obtained by Lallukka (1976) who found that weather prior to ripening had little effect on the duration of seed dormancy in varieties grown in Finland. He reported that the duration of dormancy is more dependent on the weather following ripening and on the genetic characteristic of the variety (50).

George (1967) studied the effect of the temperature of germination on dormancy in 12 wheat varieties. He found that at 10 C none of the 12 varieties displayed clear-cut evidence of dormancy as measured by speed and completeness of germination relative to nondormant one-year-old seed. However, at 20 C all varieties were dormant at harvest. The duration of dormancy varied from 20 to 60 days depending on the cultivar. At 30 C all 12 varieties displayed a deep, persistent dormancy, except one which recovered after 80 days (29). His findings were confirmed by Plett and Larter (1986).

Olsson and Mattsson (1976) studied the effect of storage temperature on dormancy of several wheat varieties. They found that dormancy lasted 12 days at 22 C, 15 days at 18 C, and as long as 50 days at 2 C (70). Belderok (1961) observed that duration of dormancy may differ from year to year, even for the same variety (1).

Wellington (1956) studied the germination of a white and a red wheat variety during the development, ripening, and after-ripening. He found that none germinated as long as the pericarp remained green. Six weeks after anthesis, when the pericarp had changed color, most white seed in the top and middle spikelets germinated, compared to only a few of the red seed. However, germination of red seed increased after harvest without any further drying, however the increase was greater at lower moisture contents (81).

It has already been suggested that dormancy in cereals may be caused by inadequate oxygen permeability of the pericarp and integument layers. However, many investigators have proved that the impermeability of these layers has no effect on dormancy in wheat (3,63). Belderok (1976) reported that lack of respiration was not a factor inhibiting germination during dormancy. He suggested that competition may exist between respiration and growth processes for oxygen within the embryo. During dormancy so much oxygen is consumed for respiration that not enough



is available for germination and growth. After ripening an increase in oxygen permeability of the pericarp and integument layers occurs so that eventually sufficient oxygen reaches the embryo to supply the demands of both respiration and growth (3).

Embryo dormancy means that the germination inhibiting factors occur within the embryo, and thus no germination takes place when the surrounding layers are damaged or removed. True embryo dormancy has been described for wild oat, some primitive barleys and some older wheat cultivars (3). Gordon (1979) found that embryo dormancy and amylase dormancy were not always associated. He suggested that breeding a white-grained wheat for a useful period of amylase dormancy may be possible (32). Miyamoto et. al. (1961) found that embryo immaturity did not seem to be an important factor in post harvest dormancy of certain wheat varieties (63).

Greer and Hutchinson (1945) reported that nitrogen had no substantial influence on the length of dormancy in wheat (34). In a later study, Morris and Paulsen (1985) concluded that high nitrogen fertilization level increase rain-induced preharvest sprouting in genotypes with moderate or low levels of resistance. They suggested that nitrogen fertilization would not affect preharvest sprouting of genotypes with strong sprouting resistance and all

genotypes under conditions not conducive to preharvest sprouting (64).

Ciha and Goldstein (1983) studied the effects of different nitrogen levels and artificial wetting of heads at various stages of grain development of "Moro" soft white winter and "Mironovskaya 808" hard red winter wheat on protein content, starch quality, and alpha-amylase activity. They found that the red variety was not generally influenced by the head wetting or fertilizer treatments while the white variety was significantly influenced by both. Wetting the heads at the early stages of seed development generally highly increased grain protein. Increasing the fertilizer level significantly increased the seed protein in the white variety but not in the red one. Mironovskaya 808 had a higher grain protein content, a higher amylograph value, and lower alpha-amylase activity than Moro (16). Wild wheat, rye, barley and oats are all characterized by a substantial seed dormancy as a requisite in their adaptive pattern (52).

Plant hormones and preharvest sprouting

The initiation of embryo growth and endosperm breakdown in cereal seeds is caused by a series of complex and interacting processes. These processes, to a large extent, are regulated and controlled by the activities of various endogenous growth substances which either promote or inhibit several key germination reactions (78). For



example, it is a well established that the first step in embryo growth of cereals is the formation of gibberellins, a process for which aerobic conditions are essential (3,76). Rowsell et. al. (1966) observed that oxygen must be present for gibberellic acid to promote wheat endosperm hydrolyses, especially protase and alpha-amylase (76). Stoy and Sundin (1976) studied the effects of growth regulating substances on germination in different spring wheat cultivars. They found that gibberellic acid suppressed the inhibition effect of catechins and catechin tannins on germination. They showed that the effect of abscisic acid was more drastic than that of catechin tannins and that gibberellic acid seemed to suppress the abscisic acid effect more completely than the catechin tannins. Furthermore, they observed that the sprout-susceptible varieties displayed both a high gibberellic acid response and a high percentage of germination after a short period of after-ripening, whereas resistant types exhibited low germination percentage and very low gibberellic acid responses even after several months of after-ripening in the field. Finally, they reported that the gibberellin response was closely related to the moisture content of the kernels (78).

It is believed that the cause of dormancy resides mainly in the pericarp and integumentary layers of the grain because if these tissues above the embryo are

removed, the dormant grains will germinate normally when moistened (2,3). This may be attributed to the presence of inhibitors in the seed coat, particularly abscisic acid (21,28,63).

King (1976) suggested the lack of clear evidence for a role of abscisic acid in the dormancy of the mature wheat seed. He showed that while ABA increased during seed development, no difference in ABA content existed in seed of dormant and non-dormant varieties. He also found that ABA levels in wheat decreased when individual seeds are artificially dried (42,43).

Simpson (1965) suggested that dormant oat embryos fail to germinate because they are unable to produce a gibberellin-like factor in sufficient amounts to stimulate growth since this dormancy can be broken simply by supplying GA (77). The interaction of various substances such as abscisic acid, gibberellins and cytokinins support the promoter-inhibitor hypothesis of dormancy control (22).

In the absence of dormancy, some alternative germination inhibition is desirable in wheat for protection against preharvest sprouting. Even then, further protection could be superimposed (22). The presence of germination inhibitors in the surrounding wheat bracts has been found to contribute to resistance to preharvest sprouting in wheat (20,21,22).

General aspects of breeding for preharvest sprouting resistance

Resistance to preharvest sprouting in wheat is a complex character (60). King and Richards (1984) reported that considerable progress could be made by breeding for awnless lines. They noted that this character is easily identified and controlled by single genes so that immediate advance would be possible (45). Transfer of gibberellic acid insensitivity and low alpha-amylase synthesis using dwarf wheat varieties as a source of resistance is a possible way of breeding for preharvest sprouting resistance (5,7,59).

Bhatt et. al. (1983) studied the inheritance of dormancy in two white dormant varieties, Kenya 321 sib and Ford, and two white non-dormant varieties, Gamut and Shortim. They found dormancy to be controlled by two recessive genes. The segregation ratio from the crosses they conducted was 15 non-dormant : 1 dormant in F₂ in two out of three crosses. A lack of transgressive segregation for dormancy was found in this study. They reported that Kenya 321 sib possessed higher dormancy (67%) than Ford (56%). They concluded that the two most important aspects in breeding for dormant white wheat are a high level of dormancy in the parent material and the control of dormancy by dominant factors (9).



Svensson (1976) reported that it is possible to increase the frequency of sprouting resistant genotypes in a segregating population if appropriate mass selection is applied (79). Sprouting resistance differs among varieties (40). Derera et. al. (1976) studied six white-seeded and six red-seeded Australian wheat varieties for resistance to preharvest sprouting. They suggested that no single component of sprouting resistance will provide sufficient protection from sprouting, but that a combination of components of resistance such as low alpha-amylase and/or gibberellic acid insensitivity, germination inhibitors in the husk etc. may provide operative resistance (19). Therefore, breeding for partial dormancy, low alpha-amylase synthesis, insensitivity to gibberellic acid, and germination inhibitors in the bracts should act together to help minimize preharvest sprouting in wheat (5,6,10,20,21, 22,28,52,53,59,71,77).

MATERIALS AND METHODS

The objectives of this study were to measure the effects of preharvest sprouting on germination, storability, and field performance of seed of two soft white winter wheat varieties, Augusta and Frankenmuth, and two soft red winter wheat varieties, Hillsdale and Arthur, grown in Michigan. Three experiments were conducted to study these objectives during 1985 and 1986.

FIRST EXPERIMENT

Levels of Sprouting

The objectives of the first experiment were to obtain different levels of sprouting in seed of the four wheat varieties (i.e. Augusta, Frankenmuth, Hillsdale, and Arthur) and then measure the effects of each sprouting level on germination, storability of each variety. These levels are described in Table 1 and shown in Figure 2.

Table 1. Description of the sprouting levels used in the first experiment in 1985 and 1986.

Rating	Levels of sprouting
1	No evidence of sprouting (the seeds received certain amounts of water but showed no visable evidence of sprouting).



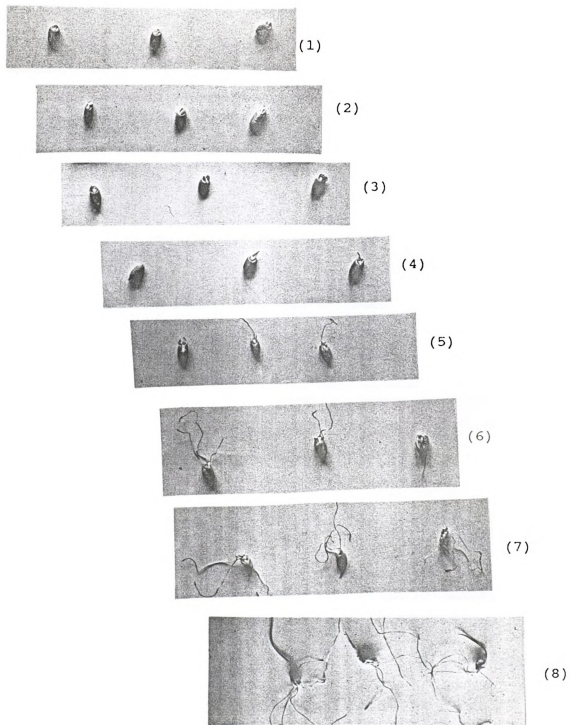


Figure 2. Levels of Sprouting.

- 2 Split germ cover; no apparent growth of root-shoot axis.
 - 3 Rupture of the germ cover; root-shoot axis beginning to emerge.
 - 4 absence of the germ cover; little growth of root-shoot axis.
 - 5 small amount of sprouting; plumule less than 2 mm long.
 - 6 Medium amount of sprouting; plumule 2-5 mm long.
 - 7 Large amount of sprouting; plumule 6-10 mm long.
 - 8 Plumule more than 10 mm long.
-

The seeds of the control sample of each variety were not exposed to any amount of water and were kept at room temperature until used.

First Year (1985)

To obtain the different levels of sprouted seeds, the following procedure was followed:

1. Two thousands entire stems and heads of each of the four varieties, Augusta, Frankenmuth, Hillsdale and Arthur, were randomly selected at approximate harvest maturity and harvested by cutting near the stem base with scissors.
2. Fifty plants from each variety were taped together in a bundle and five bundles of each variety were set in a clay pot (5 inches). Eight pots of each



Figure 3. Bundles of wheat in clay pots.



Figure 4. Wheat inside mist chamber to stimulate sprouting.

variety were prepared (Fig. 3).

3. To stimulate sprouting, the 32 pots were randomly distributed inside a mist chamber in the greenhouse (Fig. 4) and exposed to different periods of misting as described below. During the misting period, the misting device was alternately active one minute and inactive one and one-half minutes.

- First day: 19 hours- 2:00 p.m. to 9:00 a.m. the next day.
- Second day: 15 hours- 5:00 p.m. to 8:00 a.m.
- Third day: 15 hours- 5:00 p.m. to 8:00 a.m.
- Fourth day: 15 hours- 5:00 p.m. to 8:00 a.m. the next day.

After four days and 49 hours inside the mist chamber, nine pots showing varying levels of sprouting were removed, and the remaining pots were exposed to additional misting for 11 hours from 9:00 a.m. to 8:00 p.m.

After five days and 60 hours in the mist chamber all pots were removed except two each of Hillsdale and Arthur which still exhibited no evidence of sprouting. These were exposed to 48 additional hours of misting during three successive days and then removed.

4. All plants were allowed to air-dry for two weeks and then hand-threshed to avoid dislodging the sprouted root-shoot axes. The threshed seeds were then

separated into the eight sprouting levels mentioned earlier. Two 100-seed replicates were prepared from each sprouting levels (8 levels plus control).

5. Standard germination tests (25 C for seven days) were conducted for six successive weeks to detect differences in dormancy among varieties.
6. Prechilling treatment of 5 C for five days, followed by a standard warm germination test at 25 C for seven days on blotters for each level of sprouting and unsprouted controls for each of the four varieties were conducted. Such tests were conducted at weekly intervals for six successive weeks.

The seeds were stored at room temperature (21 ± 2 C) during the experiment.

Second Year (1986)

The same procedure of the first year,s experiment was repeated the second year except for the following differences:

1. Only Augusta, the soft white variety and Hillsdale, the soft red variety were tested.
2. 1500 entire stems and heads of each variety were randomly collected at approximate harvest maturity, on July 20, 1986.
3. Plants in six pots containing five bundles of 50 plants each of both varieties were exposed to four



successive eight-hour days of continuous misting.

After the fourth day the Augusta pots were removed and those containing Hillsdale were exposed to forty additional hours of mist. The plants were then allowed to air-dry for two weeks and were then hand-threshed and separated into the eight sprouting levels described earlier.

4. Prechilling treatments followed by warm germination tests were conducted for each variety and sprouting level at weekly intervals for six successive weeks, the eighth week, and the twelveth week.
5. All samples were treated with "Vitavax 200" at a rate of 4 fl.oz./100 lbs.

SECOND EXPERIMENT

Sprinkling Trial

In order to simulate a natural environment to stimulate preharvest sprouting, freshly harvested intact plants (stems and heads) were placed outside and exposed to a daily sprinkling for different periods of time as described in Tables 2 and 3. Germination tests were conducted to measure the effects of exposing plants to different hours of moisture on germination and storability.

First Year (1985)

1. Forty eight 5-inch clay pots containing a bundle of fifty plants (entire stems and heads) each were

prepared for each of the varieties Frankenmuth, Augusta, Hillsdale, and Arthur.

2. The pots were randomly set at a circle (Fig. 5) at the Turfgrass Research Center in Michigan State University and exposed to four hours of daily misting from 2:00 p.m. to 6:00 p.m., to stimulate sprouting (Table 2).

Table 2. Duration of plant exposure to moisture in 1985

Days	The accumulated hours of exposure to moisture	
1	4	
2	8	(First sample tested)
3	12	(Second)
4	16	(Third)
5	20	(Fourth)
6	24	(Fifth)
7	28	(Sixth)
8	32	(Seventh)
9	36	(Eighth)

3. Each day, starting from the second day, two randomly selected pots from each variety were removed and allowed to air-dry. From the sixth day till the ninth day, only one pot was removed. Thus, the first samples were removed on the second day and received



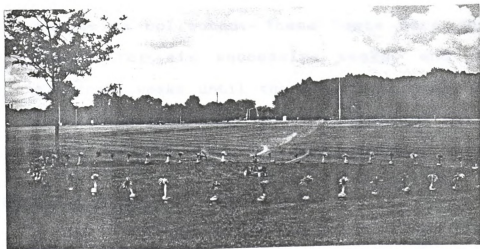


Figure 5. Wheats in clay pots in a circle around sprinkler.

eight hours of mist, the second samples were removed on the third day and received twelve hours of mist, and the last samples were removed on the ninth day and received thirty six hours of mist. The dry seeds were hand-threshed and stored at room temperature.

4. Two replicates of one hundred seeds each were randomly selected each day from each variety. A control sample of each variety receiving no water was prepared. Prechilling treatments (5 C for five days) followed by standard warm germination tests (25 C for seven days) were conducted on each sample of the four varieties collected. These tests were conducted weekly for six successive weeks, and then on alternate weeks until the fourteenth week. Starting from the eighth week, only one sample of one hundred seeds was used because of the shortage of seeds.

Second Year (1986)

The same procedure of the first year's experiment were repeated in the second year except for the following differences:

1. Two varieties, Augusta (white) and Hillsdale (red) were used.
2. Eleven 5-inch clay pots containing two bundles of 50 plants each randomly arranged at a circle (Fig. 5) around a sprinkler in an open area and exposed



daily to six hours of sprinkling from 8:00 a.m. to 2:00 p.m. (Table 3).

Table 3. Duration of plant exposure to moisture in 1986.

Days	The accumulated hours of exposure to moisture	
1	6	
5	30	(First sample tested)
6	36	(Second)
7	42	(Third)
8	48	(Fourth)
9	54	(Fifth)
10	60	(Sixth)
11	66	(Seventh)
12	72	(Eighth)
13	78	(Ninth)
14	84	(Tenth)
15	90	(Eleventh)

- Starting with the fifth day, plants from pots containing each variety were randomly removed and allowed to air-dry. Thus, the first sample was removed on the fifth day and received thirty hours of sprinkling, the second sample was removed on the sixth day and received thirty six hours of



sprinkling, and the last sample was removed on the fifteenth day and received ninety hours of sprinkling, as shown in Table 3. A control sample of each variety which received no sprinkling was collected.

4. Enough seed for two 100-seed replicates was randomly selected from each variety. Prechilling treatments at 5 C for five days followed by standard warm germination tests were conducted on each sample of the two varieties in addition to the control samples at weekly intervals for six successive weeks and then weeks eight and twelve. The seeds were stored at room temperature during the experiment.
5. All seeds were treated with "Vitavax 200" at a rate of 4 fl.oz./100 lbs.

THIRD EXPERIMENT

Field Performance (1985/1986)

Four levels of sprouting shown in Table 4 were selected to measure the effects of preharvest sprouting on field performance (emergence index, emergence percent, 1000-seed weight, number of heads per meter, biological yield, straw yield and grain yield) of one white and one red soft winter wheat variety, Augusta and Hillsdale.

Table 4. Description of the sprouting levels used in the field performance experiment in 1985/1986.

Rating	Levels of sprouting
1	No evidence of sprouting.
2	Split germ cover; no apparent growth of root-shoot axis.
3	Rupture of the germ cover; root-shoot axis beginning to emerge.
4	Combination of absence of the germ cover with little growth of root-shoot axis, and small amount of sprouting (less than 2 mm).

The control samples did not receive any amount of water. All seeds were treated with Vitavax 200 at the rate of 4 fl. oz./100 lbs.

A completely randomized block design with three replications was used in this experiment. Each block had ten rows ten feet long and 0.8 foot width. Two hundred and thirty seeds of each treatment were planted in a row. The first block was planted October 11, and second and third on October 16, 1985 because of adverse weather conditions. After nine days, the field emergence was recorded every



other day for two weeks. The emergence index (see below) and the emergence percentage after fourteen days from the initial emergence were calculated.

The plots were harvested on July 19, 1986. The output of each row was divided by 3.05 to estimate number of heads, seed weight, straw yield, and biological yield per meter of row, 1000-seed weight, and grain yield bushel per acre.

Emergence index (EI) was calculated by using the following formula:

$$EI = P(1/D) + \dots + P(1/N)$$

where P is the number of plumules penetrating the soil surface, D is the number of days after initial emergence, and N is the last day emergence was counted.

The biological yield per meter was calculated by adding the grain yield per meter of row to the straw yield per meter.

The grain yield in bushel per acre was calculated by converting the yield of one row area in grams (10 feet length x 0.8 foot width) to yield in bushel per acre.

The computer program MSTAT was used in the statistical analysis. PLOTIT program was used to make the graphical presentations.



RESULTS

Preliminary germination tests showed that the two red varieties Arthur and Hillsdale had the highest dormancy levels, whereas the white varieties Augusta and Frankenmuth showed little dormancy. After six weeks of storage, the dormancy of Hillsdale was partially broken down, whereas Arthur still possessed a high level of dormancy. These results indicate that the amount of water the red varieties received during misting was responsible for partially breaking down their dormancy (Table 1, App. A).

FIRST EXPERIMENT

In 1985, the levels of sprouting (LOS) and six-week storage period, as well as the interaction between them had highly significant effects on the germination of both white and red varieties. The white variety Frankenmuth was most affected by both LOS and time of storage and the interaction between them, followed by Augusta. The red variety Arthur was the least influenced by the same factors (Table 2, App. A).

Results in 1986 were similar to those of 1985, in that germination of both Augusta and Hillsdale was significantly influenced by LOS and time of storage. Again the interaction between these two factors was significant.

Effect of LOS and storage on the germination of Frankenmuth in 1985

The germination of the first two LOS was not significantly different from the control throughout the six weeks of storage. The germination percentage (GP) ranged from 97 to 100. Seeds from the third LOS retained their viability until the fifth week of storage, with GP ranging from 97 to 99 except for the fourth week which was 85. However, in the sixth week, significant decreases occurred and the GP dropped to 69. LOS four, five and six retained their high germinability for the first three weeks of storage with the GP ranging from 95 to 100. However, during the next two weeks the GP dropped to the 70's and further declines occurred in the sixth week. Low GP were recorded for the last two LOS from the first week (Table 4-9; 12, App. A and Fig. 6,8).

Effect of LOS and storage on germination of Augusta in 1985 and 1986

The GP of the first two LOS after six and twelve weeks of storage in 1985 and 1986 ranged from 95 to 99 except for the second LOS in the eighth week in 1986 which was 93 and significantly different from the control. During five weeks of storage, no significant differences between GP of the third LOS and the control were occurred in either year, with GP's ranging from 87 to 98 (Tables 4-7, App. A).

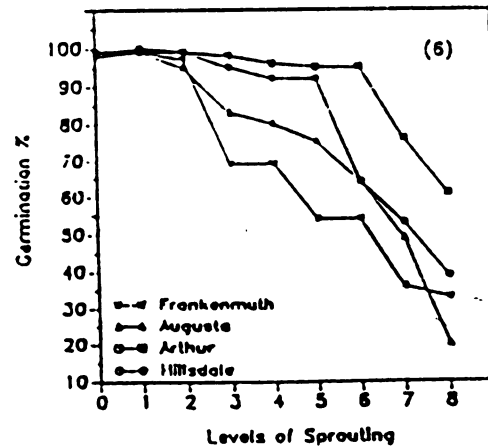
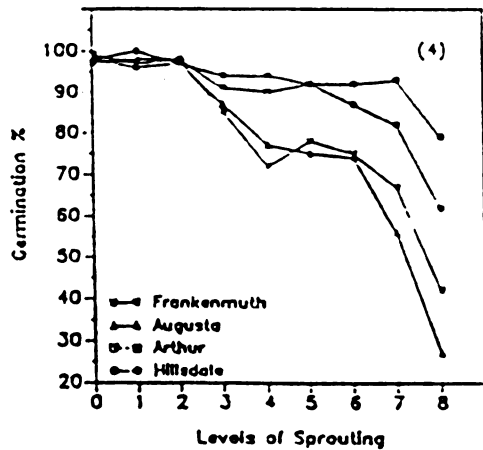
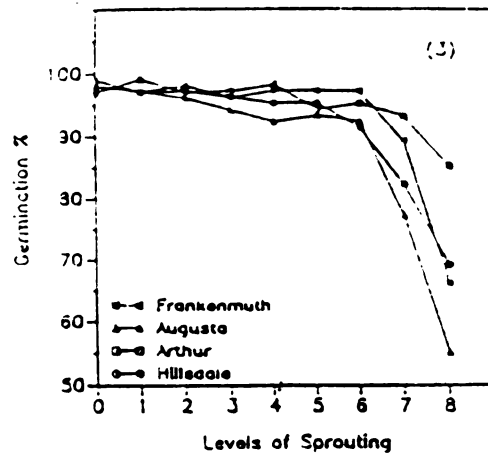
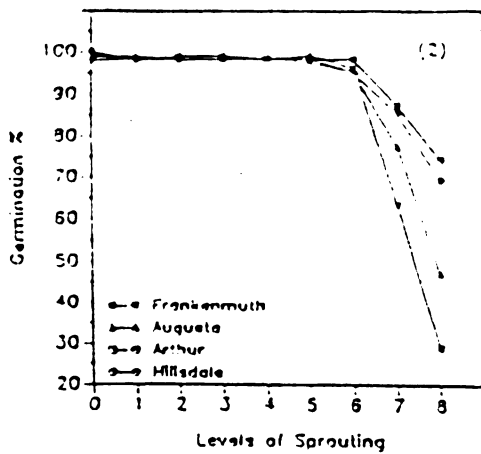


Figure 6. The effect of different levels of sprouting on the germination percent of four winter wheat varieties after two, three, four and six weeks of storage in 1985.

However, during week six in 1985 and weeks six, eight and twelve in 1986, GP of this LOS was significantly different from the control, and ranged from 83 to 89 (Tables 9-11, App. A). No significant differences in GP occurred for this LOS throughout the entire twelve weeks of storage (Table 14, App. A).

LOS four, five and six retained their high germinability until the third week, with GP's ranging from 92 to 99. During the next three weeks, LOS four and five dropped to the 80's and 70's and to 70's and 60's for the sixth LOS. Further deterioration occurred during weeks eight and twelve (Tables 4-11; 14, App. A, Fig. 6). Gradual deterioration was observed in LOS seven, with a GP of 86 for week one and zero for week twelve. The last LOS (eight) had a low GP from the first week (Table 4-11; 14, App. A and Fig. 6,7,8).

Effect of LOS and storage on germination of Arthur in 1985

No significant differences between GP of the first six LOS and their control were observed except for levels five and six in week five which were significantly different from the control. However, they maintained a high GP of 96 and 94 respectively. The GP of the first six LOS ranged from 90 to 100 during the six weeks of storage (Table 4-9; 13, App. A). Levels seven and eight had the highest GP among the four varieties. A GP of 93 occurred

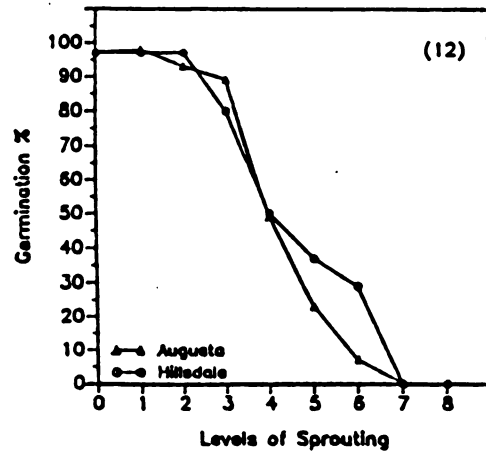
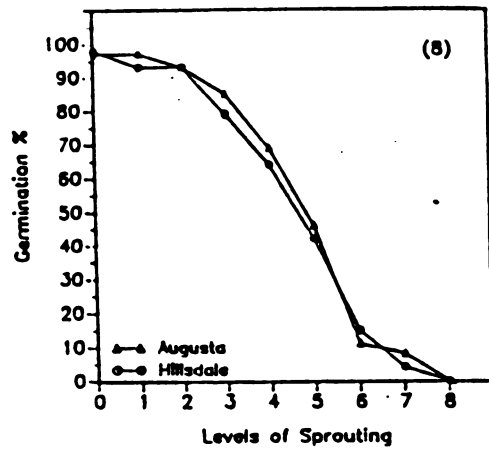


Figure 7. The effect of different levels of sprouting on the germination percent of two winter wheat varieties after eight and twelve weeks of storage in 1986.

in weeks three and four for LOS seven and 85 for LOS eight in the third week of storage (Tables 4-9; 13, App. A and Fig. 6,8).

Effect of LOS and storage on germination of Hillsdale in 1985 and 1986

These results indicate that Hillsdale seed which is not sprouted beyond LOS two in this study can be safely stored for twelve weeks without losing viability. The GP's found in these studies ranged from 93 to 100 (Tables 4-11; 15, App. A and Fig. 6,7,8).

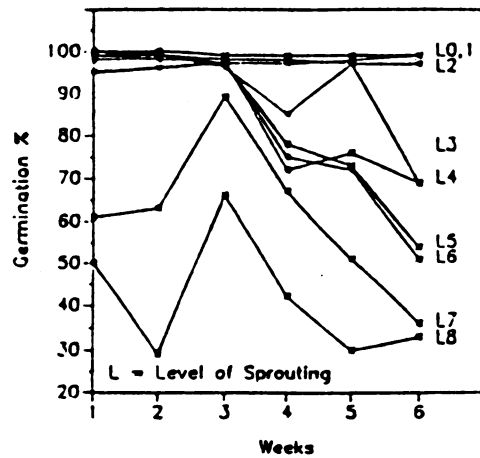
LOS three, four and five retained their high germinability for six weeks with GP's ranging from 92 to 98. However, during weeks eight and twelve gradual reduction in GP was observed (Tables 4-11; 15, App. A). No significant differences were found between the GP of the LOS six and the control throughout three weeks of storage, with GP's of 96, 91 and 95 respectively. However, during the next two weeks the GP dropped to 87, followed by continued decline throughout the next seven weeks (Tables 4-11; 15, App. A).

No significant differences in germination of LOS seven occurred during the first five weeks of storage, with GP's ranging from 82 to 86. However, at week six, a GP of 53 occurred, and declined to 0% in week twelve. A low GP was found for LOS eight from the first week (Tables 4-11; 15,

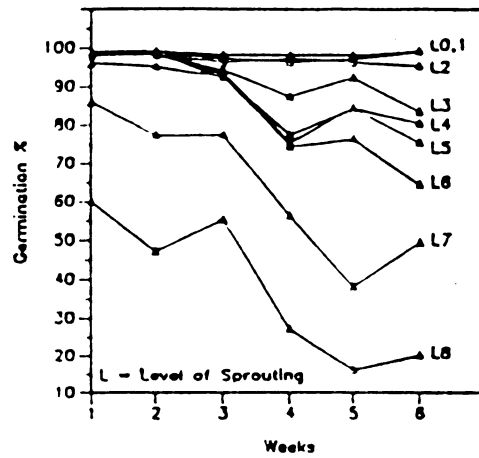
App. A and Fig. 6,7,8).

The results of 1985 indicated that Arthur has the best ability to not only resist sprouting but also to maintain its germinability for six weeks for all eight LOS, followed by Hillsdale, Augusta and Frankenmuth (Tables 16-21, App. A, Fig. 8). In 1986 Hillsdale stored better than Augusta as indicated by the GP during the first six weeks, however no significant differences occurred in the germinability of sprouted seeds of Augusta and Hillsdale after eight weeks of storage (Tables 22,23, App. A).

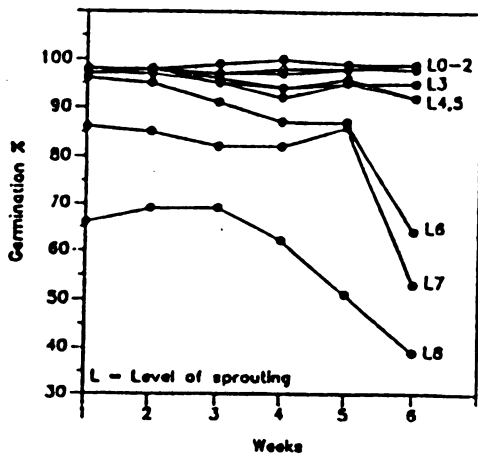
No significant differences occurred in the germination of the first two LOS for any of the four varieties during six weeks of storage (Table 21, App. A). Also, no significant differences occurred in the germinability of the third LOS for any of the four varieties during five weeks of storage (Tables 19,20, App. A). Finally, no significant differences in the germination of the first six LOS were found for any of the four varieties during three weeks of storage (Tables 16-18, App. A). However, LOS four of the white varieties began to show evidence of deterioration after four weeks of storage, whereas the red variety Arthur retained its high germinability up to LOS six throughout six weeks of storage. The other red variety, Hillsdale retained its high germinability up to the fifth LOS for six weeks of storage (Tables 16-21, App. A).



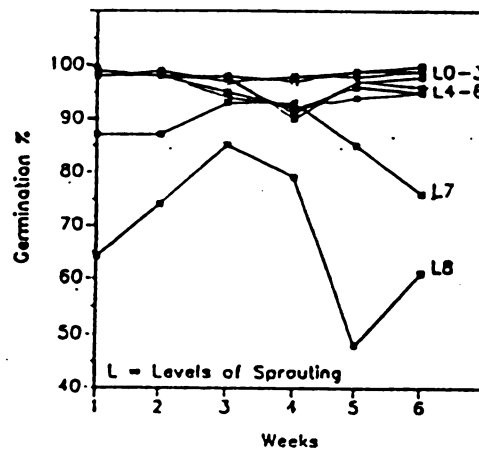
Frankenmuth



Augusta

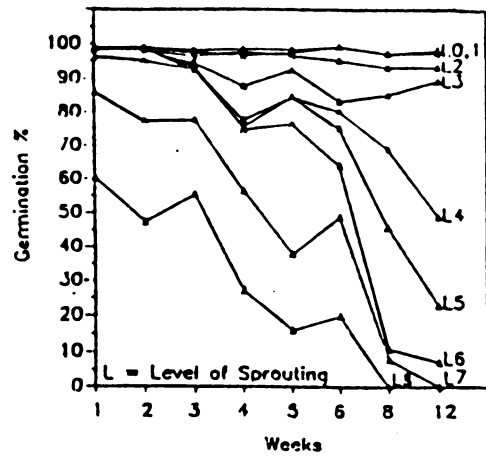


Hillsdale

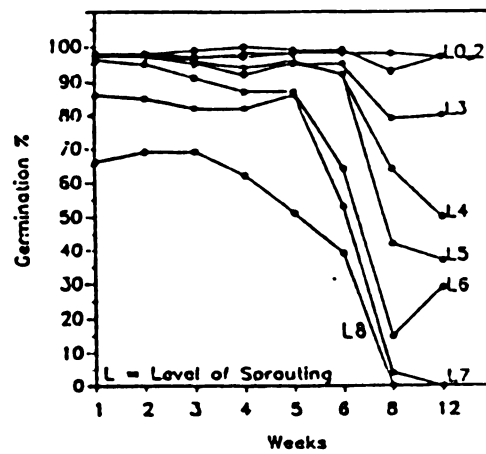


Arthur

Figure 8. The effect of storage on the germination percent of differnt levels of sprouting of four winter wheat varieties in 1985.



Augusta



Hillsdale

Figure 9. The effect of storage on the germination percent of different levels of sprouting of two winter wheat varieties in 1986.

SECOND EXPERIMENT

In 1985, samples from four varieties were exposed to moisture for periods of 8 to 36 hours. The first evidence of sprouting was observed in Augusta and Frankenmuth on the fifth day after 20 total hours (4 hrs/day) of moisture exposure. At this point, only a few seeds within each sample showed rupture of the germ cover and the beginning of root-shoot emergence. In the ninth day, after 36 hours of moisture, some seeds in both white varieties exhibited germ cover rupture, with some growth of root-shoot axis. The level of sprouting was slightly greater in Frankenmuth than in Augusta. The red variety Hillsdale showed little evidence of sprouting after 24 hours of moisture and few seeds showed splits in the germ cover. After 36 hours, only a few seeds showed much growth of root-shoot axis. Arthur had the least sprouting of the four varieties. Germination of all varieties in the first six weeks was influenced by duration of storage and length of water exposure (Table 1, App. B), and ranged from 94 to 100 percent. From the eighth through the fourteenth week, the GP ranged from 94 to 100 for all varieties (Tables 11-14, App. B and Fig.9).

In 1985, neither the number of sprouted seeds nor the level of the sprouting were enough to cause deterioration in either white or red varieties during the fourteen week storage period.

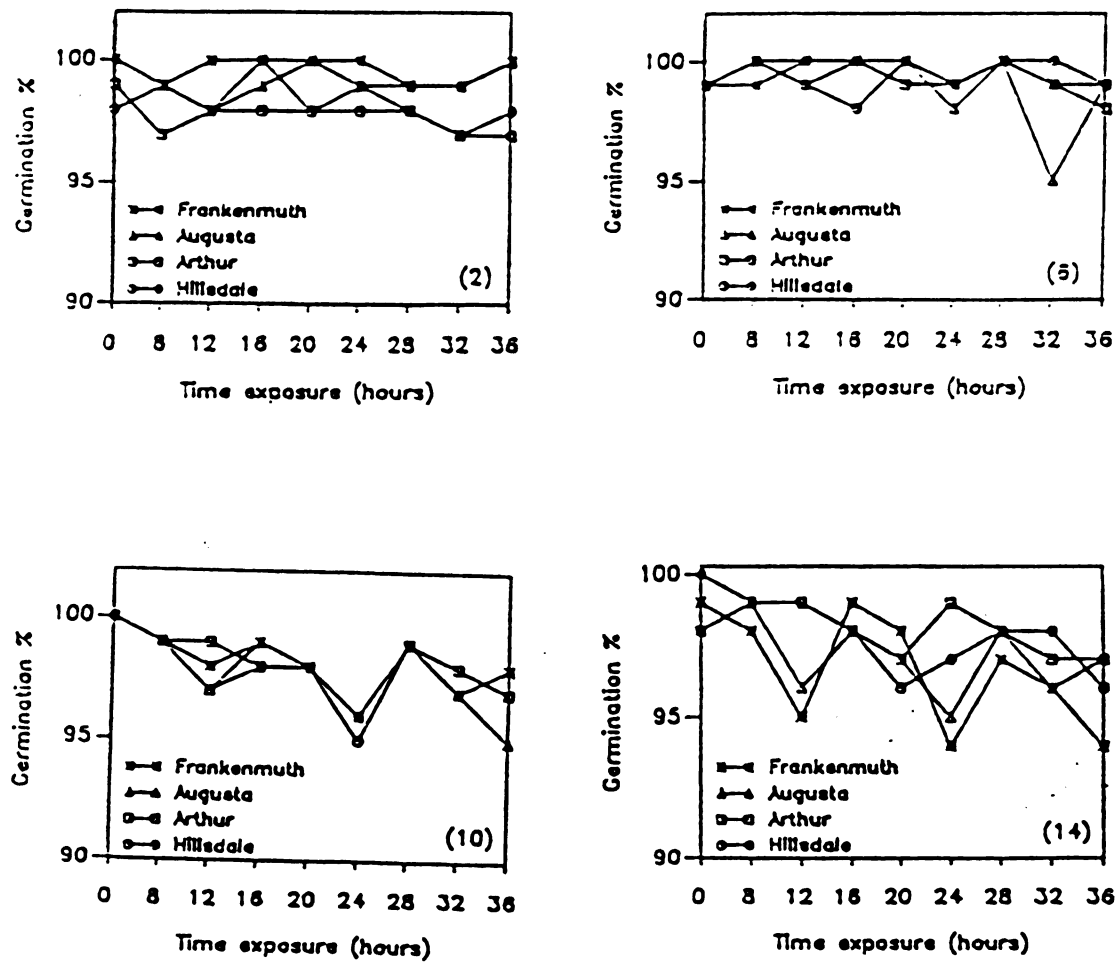


Figure 10. The effect of time of exposure to misting on the germination percent of four winter wheat varieties after two, six, ten and fourteen weeks of storage in 1985.

In 1986 both Augusta and Hillsdale seed received longer exposures to moisture in order to promote more sprouting. The minimum exposure was thirty hours and the longest ninety hours. As the length of exposure increased, the number of the sprouted seeds and the level of sprouting also increased. For example, few seeds of Augusta which received only 30 hours of moisture showed rupturing in the germ cover, while about 90% of the sample had varying levels of sprouting after 78 hours of moisture. Some seeds in the last three samples had plumule lengths up to 7 mm, with considerably less sprouting in Hillsdale than Augusta. The ninth sample of Hillsdale which received 78 hours of moisture had about 10% sprouted seeds, varying from a split in the germ cover to minimal growth of the root-shoot axis and plumule lengths up to 3 mm. The percentage of sprouted seeds did not increase beyond this in the last sample which received 90 hours of moisture.

In 1986, the germination of both Augusta and Hillsdale was significantly influenced by duration of moisture exposure and time, however the effects of these factors on Augusta was much more than on Hillsdale (Table 2, App. B).

Effect of duration of moisture exposure and storage on the germination of Augusta in 1986

No significant differences between GP of each of the eleven Augusta samples exposed to different amount of

moisture and the control were occurred during the first two weeks of storage (Tables 3,4,15, App. B). However, from the third to the twelfth week, GP of seed exposed to different misting periods was significantly different from non-moisted controls (Tables 5-10; 15, App. B). after three weeks of storage, the GP of sample ten which received 84 hours of misting was 87%, significantly below the unmisted control (Tables 5,15, App. B). At the fourth week of storage, GP of last three samples was significantly below the unmisted control, it was 89, 82 and 90 respectively (Tables 6,15, App. B). At the fifth week, sample ten was also significantly below the unmisted control, with a GP of 85 (Tables 7,15, App. B). After six weeks of storage, GP of six of eleven samples was significantly below that of unmisted controls, it ranged from 86 to 92 for samples one, five, seven, nine, ten and eleven respectively (Tables 8,15, App. B). In the eighth week, germination of samples four, five, six, seven, nine, ten and eleven was significantly different from that of unmisted controls, with GP's ranging from 78 to 91 (Table 9,15, App. B). After twelve weeks of storage, the GP of only samples one, three and four was not significantly different from their control, with GP's of 96, 93 and 92 respectively. The rest of the samples had GP's ranged from 68 to 90 (Tables 10,15, App. B and Fig. 10,11).

Effect of duration of moisture exposure and storage on the germination of Hillsdale in 1986

Seed of Hillsdale exposed up to 90 hours of mist showed almost no significant differences in GP from that of unmisted control during the twelve weeks of storage. The only exceptions occurred for the ninth sample in the third week which had 91% germination, the last sample in the fourth week which had 93%, and the last sample in the eighth week which had 86%. The GP during twelve weeks of storage ranged from 94 to 100 (Tables 3-10; 16, App. B and Fig. 10,11).

These results showed that Augusta seeds exposed up to 42 hours of moisture can be safely stored for 12 weeks, those exposed up to 72 hours can be safely stored for six weeks, those exposed up to 78 hours can be safely used up to five weeks, and those exposed up to 90 hours can be safely stored for three weeks. Gradual deterioration can be expected for seeds stored for longer durations (Tables 3-10; 15, App. B). However, for Hillsdale, the seeds receiving up to ninety hours of moisture could be safely stored for twelve weeks without significant loss of germinability (Table 16, App. B).

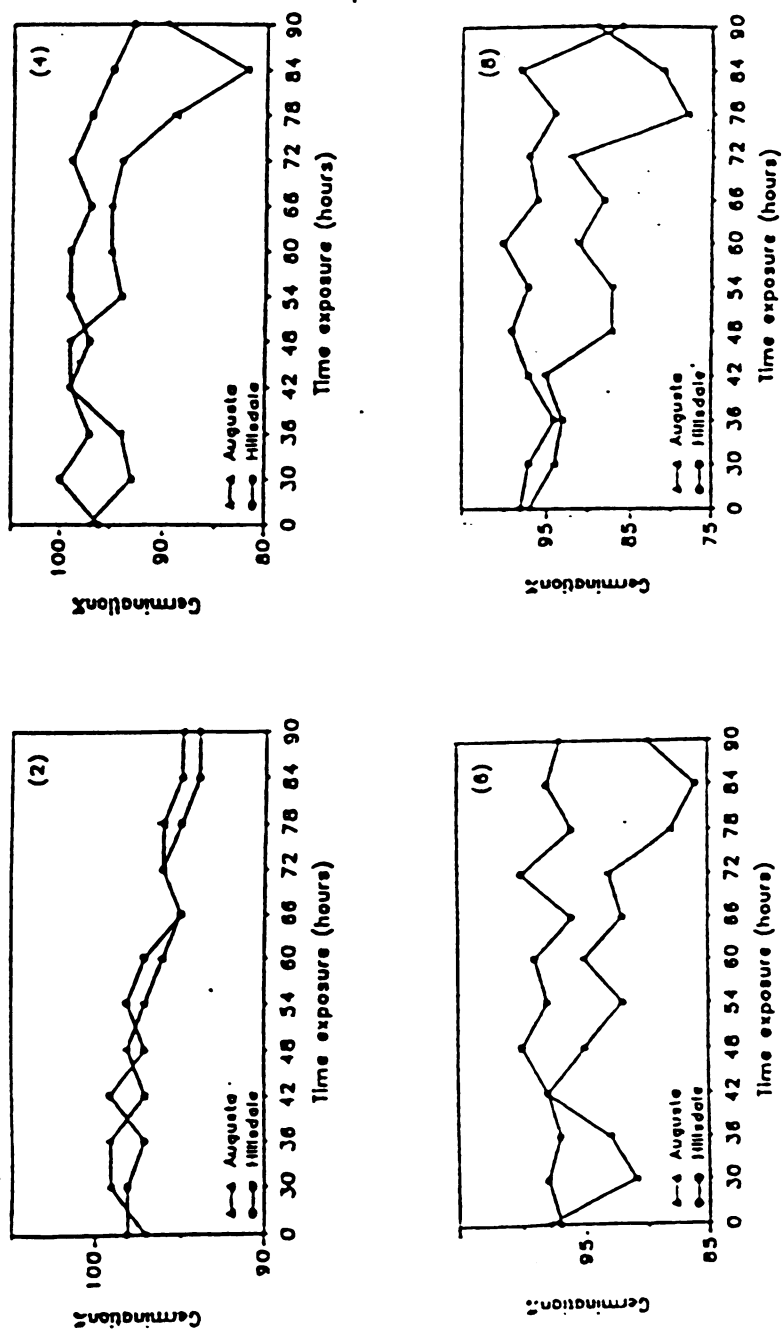


Figure 11. The effect of time of exposure to misting on the germination percent of two winter wheat varieties after two, four, six and eight weeks of storage in 1986.

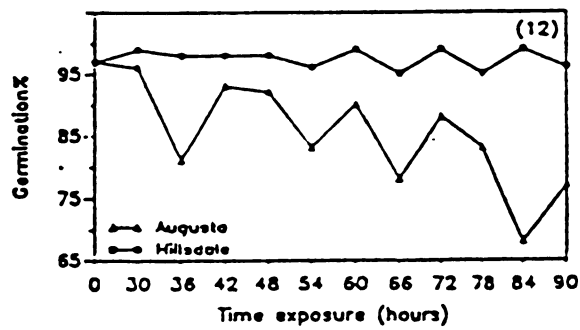


Figure 12. The effect of time of exposure to misting on the germination of two winter wheat varieties after twelve weeks of storage in 1986.

THIRD EXPERIMENT: Field PerformanceEmergence index (EI) and Emergence percentage (EP)

In 1986, both the 14-day emergence index (EI) and the emergence percentage (EP) were significantly influenced by the sprouting levels (LOS). Neither the varieties nor their interaction with LOS had a significant effect on the EI and the EP (Table 1, App. C). No significant differences occurred in the EI between the control and the first two LOS in either Augusta or Hillsdale. The EI of the third LOS was significantly different from the control in both varieties (Table 2, App. C). Also no significant differences occurred between the white and red variety in either the EI or the EP (Tables 4,5, App. C).

No significant differences between the EP of the first two LOS and the control occurred in Augusta. The EP was 91.9, 85.8 and 80.3 for the control and the first two LOS, respectively, and the last LOS had 32.7 EP. In Hillsdale, no significant differences were found between the control and the first three LOS, with EP's ranged from 59.7 to 80.9. The last LOS had 41.0 EP (Table 3, App. C). The EP was highly correlated with the grain yield in both varieties, with correlation coefficients of 0.94 and 0.99 for Augusta and Hillsdale, respectively (Table 6, App. C).

Number of heads per meter

Neither LOS, varieties, nor the interaction between them had significant effect on the number of heads per meter (Table 1, App. C). No significant differences between the number of heads per meter for the first three LOS and the control in Augusta, and between the four LOS and the control in Hillsdale were found (Table 2, App. C).

The control and the first two LOS in Augusta had higher number of heads per meter than Hillsdale. They were 152, 152 and 130 respectively, whereas they were 111, 106 and 123 for the same levels in Hillsdale (Table 4, App. C). The number of heads per meter was highly correlated with the grain yield in Augusta ($r = 0.98$) but not for Hillsdale ($r = -0.14$) (Table 6, App. C).

1000-seed weight

Thousand seed weight was significantly influenced by both LOS and variety (Table 1, App. C). The results also showed no significant differences in 1000-seed weight between the first two LOS and their control in both varieties, while the next two LOS were significantly different from the control for both (Table 2, App. C). Significant differences between the 1000-seed weight of the white variety Augusta and the red variety Hillsdale were observed, with that of Hillsdale higher than Augusta. The 1000-seed weight ranged from 25.6 to 29.9 grams for the control and the four LOS in Hillsdale, whereas it



ranged from 22.5 to 27.0 grams in Augusta (Table 4, App. C). 1000-seed weight was highly correlated with the grain yield in both varieties, with correlations of ($r = 0.85$ and 0.98 for Augusta and Hillsdale, respectively (Table 6, App. C).

Grain yield

Yield in both varieties was significantly influenced by LOS (Table 1, App. C). No significant differences between the grain yield of the first two LOS and the control occurred in Augusta, or between the first three LOS and the control in Hillsdale. In Augusta, the yield was 62, 49.9 and 50.1 bushel/acre for the control and the first two LOS respectively, and 58.2, 58.4, 58.9 and 47.8 bushel/acre for the control and the first three LOS in Hillsdale. Yield of the last LOS was 30.4 bu/acre in Augusta and 37.3 bushel/acre in Hillsdale (Table 2, App. C), and no significant differences between the grain yield of the two varieties were observed for all LOS (Table 4, App. C). Grain yield was highly correlated with the emergence percent, 1000-seed weight, and the biological yield per meter in both varieties, but only with number of heads per meter in Augusta. No correlation was found between the grain yield and straw yield in either variety (Table 6, App. C).

Biological yield

LOS had significant effects on the biological yield in both varieties (Table 1, App. C). However, no significant differences between the biological yield of the first three LOS and the control occurred in Augusta, and between the four LOS and the control in Hillsdale. The biological yield per meter was 164.2, 155.0, 141.7 and 118.7 grams for the control and the first three LOS in Augusta respectively, and 146.3, 136.3, 140.7, 139.3 and 117.2 grams for the control and the four LOS in Hillsdale (Table 3, App. C). No significant differences in the biological yield between the two varieties were found (Table 5, App. C). However, high correlation between the biological yield and the grain yield in both varieties occurred ($r = 0.96$ and 0.86) for Augusta and Hillsdale (Table 6, App. C).

Straw yield

Sprouting levels (LOS) had no significant effects on the straw yield in either variety (Table 1,3, App. C). Also, no significant differences in the straw yield between the two varieties were found (Table 5, App. C). Neither did any correlation occur between the straw yield (per meter) and grain yield (bushel/acre) in either variety with correlation coefficients of 0.57 and -0.43 for Augusta and Hillsdale, respectively (Table 6, App. C).

In general the results of the field experiment showed no significant differences between the yield and the other field measured parameters of the first two LOS and the control in either variety. However, gradual reduction in the yield was observed in the last two LOS (Table 2, App. and Fig. 12,13).

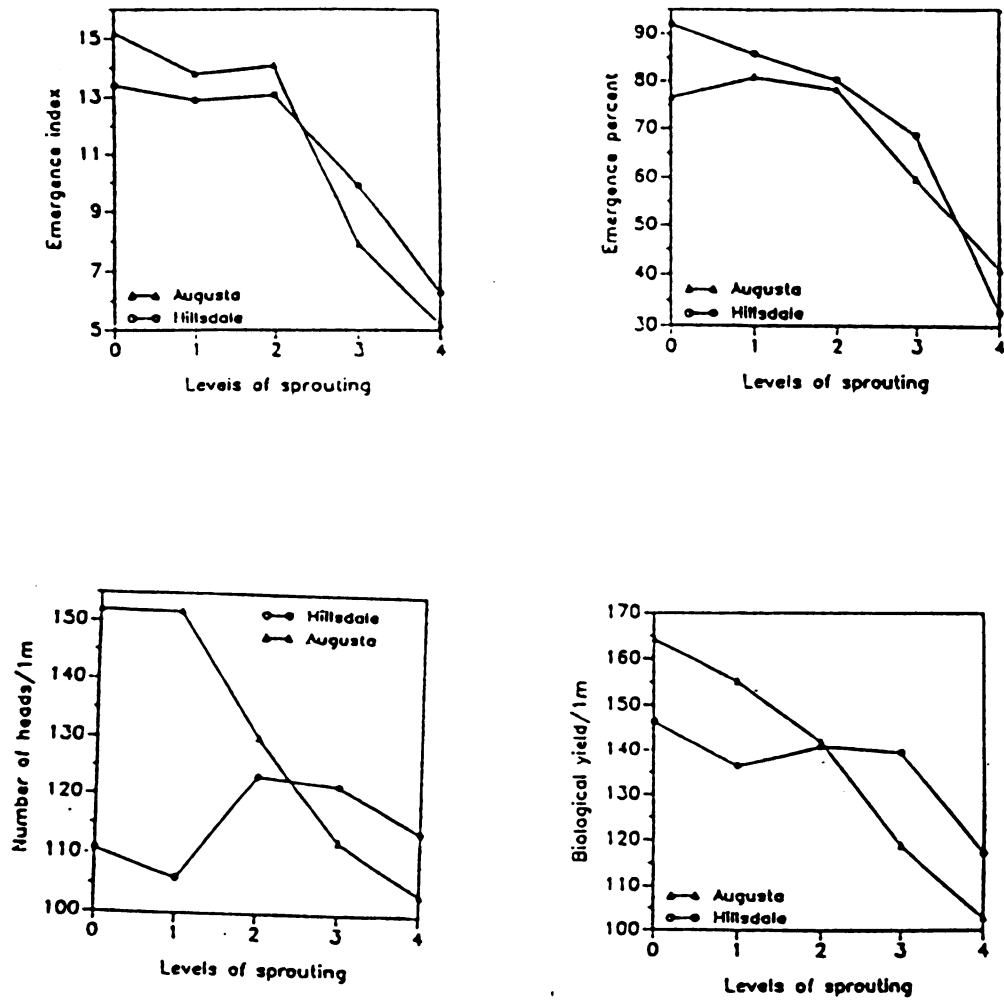


Figure 13. The effect of different levels of sprouting on the emergence index, emergence percent, number of heads/m and biological yield of two winter wheat varieties in 1986.

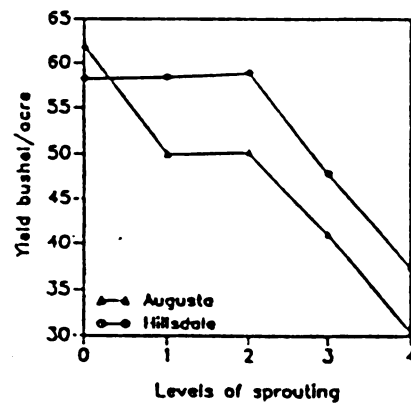
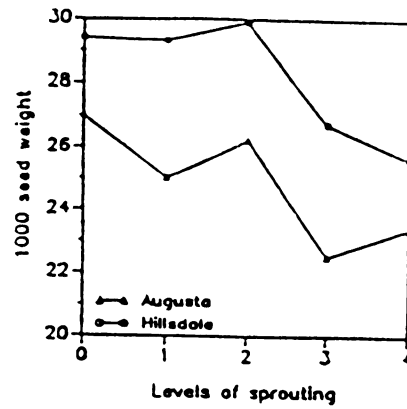


Figure 14. The effect of different levels of sprouting on the 1000-seed weight and grain yield of two winter wheat varieties in 1986.

DISCUSSION AND RECOMMENDATIONS

Results of preliminary germination tests in 1985 indicated that the red varieties, Arthur and Hillsdale, had higher initial seed dormancy and lower tendency for presprouting while the white varieties, Augusta and Frankenmuth, had little dormancy and high susceptibility to sprouting. These results confirmed the well known association between grain color and resistance to presprouting (4,17,24,25,26,54,55,56,57,61,66,80) in wheat.

FIRST EXPERIMENT

The first two levels of sprouting (LOS) in both white and red varieties showed no significant loss in germination throughout the 12-week storage period. These results suggest that seeds with such low sprouting levels (no more than split germ cover) can be safely stored up to 12 weeks without significant loss in viability. However, at higher sprouting levels, the red varieties showed better storability, as measured by the germination percent after six weeks of storage (Tables 8-13, App. A). At higher LOS, germination loss in the white was faster than in the red varieties. This supports the well-documented association between pigmentation in red varieties (25,26,27,62,63,67) and sprouting resistance. Though the basis for this

resistance is not known, it has been suggested that such varieties are more insensitive to GA or exhibit less alpha-amylase synthesis (5,7,21,22).

In 1986, after eight weeks of storage, no differences occurred in the germination of any sprouting levels in either Augusta and Hillsdale. Thus, after eight weeks of storage, the rate of the deterioration in both the white and red varieties was the same for all LOS. The germination tests after twelve weeks of storage confirmed the eight week results. The results of the field experiment supported this finding. No significant differences in the field emergence or yield of either the white and the red varieties were observed for any of the four LOS in the experiment.

SECOND EXPERIMENT

The importance of this experiment was that the environment provided was similar to that which usually occurs in nature, leading to preharvest sprouting.

In 1985, neither the four daily hours of misting for nine days nor the fourteen week storage period had deleterious effects on the germination of either the white and the red varieties (Tables 3-8 and 12-15, App. B). Apparently, the daily four hours of misting followed by twenty hours without misting allowed the plants a chance to dry and stop the sprouting process which might tend to

occur. The amount of moisture the plants received was not enough to cause excessive sprouting damage in either the white or the red varieties, thus no seed deterioration occurred during the fourteen week storage period. Apparently, not enough sustained wetness occurred to promote activation of hydrolytic enzymes, i.e., alpha-amylase, which permit germination.

In 1986, the plants were exposed to longer daily misting periods. This increased the deleterious effect of the storage on the germination of the white variety. Thus, Augusta which was exposed to different amount of mist had varying levels of sprouting, whereas Hillsdale seed retained its high germinability even after 90 hours of sprinkling, when stored for 12 weeks (Table 16, App.). Since the samples used in the germination tests were randomly selected from the plants that had been exposed to sprinkling, numbers of sprouted seeds as well as levels of sprouting varied from one sample to another. This explains why some samples exposed to shorter sprinkling periods had lower GP than others exposed to longer sprinkling periods. For example, after 12 weeks of storage, Augusta, exposed to 36 hours of sprinkling had a GP of 81, but after 42 hours of sprinkling had a GP of 93 (Table 15, App. B). Again, the better performance of the red variety reconfirms the earlier findings of the association between seedcoat color and dormancy. In general, the results of this experiment

showed that as the number of the sprouted seeds and the amount of the sprouting increase in the sample, the deleterious effect on storability increases.

THIRD EXPERIMENT

Results of the third experiment showed no significant differences in the field performance and grain yield between the white and the red varieties, Augusta and Hillsdale. The results also showed that as the level of sprouting increased, the field emergence and the yield decreased at the same rate in both varieties. These results supported observations in the first experiment showing no differences in the germination of white and red varieties after eight weeks of storage (Table 10, App. A). This might reflect the amount of the starch deposited during the seed filling period in the red variety relative to that in the white one. Thus, the red varieties were clearly superior to the white ones in resistance to preharvest sprouting. However, once sprouting occurred, the red varieties germinated and stored better than the white ones only for higher levels of sprouting and only for a six week storage period. After eight weeks of storage no differences occurred in the germination, field performance and yield between the white and the red varieties for any level of sprouting except for 1000-seed weight which was found to be significantly greater in the red variety than in the white

one. This confirms the earlier finding of McEwan in 1976 (57) and apparently reflects differences in the genotype.

In order to avoid excessive sprouting damage, breeding for some characteristics such as low alpha-amylase, insensitivity to GA, inhibitors in the bracts and dormancy (10 days) may provide operative protection (5,6,10,20,21,22,28,52,53,59,71,77).

Finally, to avoid the ever-present possibility of adverse weather and the danger of sprouting, wheat growers should harvest their crop as soon as possible after it attains ripeness (2).

To maintain adequate quality control in wheat, the two following recommendations should also be considered:

1. Both white and red varieties can be safely stored up to three months if sprouting damage does not exceed a split in the germ cover.
2. If the plumule is up to 2 mm in length, white varieties used in these studies can be safely stored no longer than three weeks and the red varieties no longer than six weeks.

APPENDIX A

TABLES OF THE FIRST EXPERIMENT

Table 1. Germination of different levels of sprouted seed of two white and two red winter wheat varieties before and after six weeks of storage.

Levels* of sprouting	white				red			
	Frankenmuth		Augusta		Arthur		Hillsdale	
	before	after	before	after	before	after	before	after
	Germination Percentage							
0	100	99	96	97	10	35	44	88
1	93	97	85	97	32	87	38	97
2	91	92	85	91	76	97	84	96
3	85	68	73	80	91	93	86	93
4	78	68	73	77	94	84	90	95
5	78	53	78	83	92	88	82	83
6	89	53	84	72	94	89	88	60
7	87	36	90	56	88	69	82	57
8	63	32	70	27	84	57	82	42

* See the description of "Levels of Sprouting" in pp. 29

Table 2. Analysis of variance for the effect of different levels of sprouting (LOS) and storage for six weeks on germination of two white and two red winter wheat varieties in 1985.

Source of variation	df	white		red	
		Frankenmuth	Augusta ⁺	Arthur	Hillsdale ⁻
		Mean squares			
LOS	3	4438.7**	4793.7**	1195.2**	2032.2**
Weeks	5	1532.5**	1247.4**	54.9**	334.5**
LOS x W	40	185.2**	127.2**	57.0**	74.5**

⁺ The means of Augusta and Hillsdale represent the average of two years experiment.

** Significant at the 0.01 level of probability.

Table 3. Analysis of variance for the effect of different levels of sprouting (LOS) and storage for twelve weeks on germination of Augusta and Hillsdale in 1986.

Source of variation	df	Augusta ⁺	Hillsdale ⁺
		Mean squares	
LOS	8	9487.0 ^{**}	5703.1 ^{**}
Weeks	7 ⁺⁺	4234.4 ^{**}	5019.1 ^{**}
LOS x W	56	446.3 ^{**}	444.6 ^{**}

⁺ The means of Augusta and Hillsdale represent the average of two years experiment.

⁺⁺ The germination tests performed at weekly intervals for six weeks and then in week eight and week twelve.

^{**} Significant at the 0.01 level of probability.

Table 4. The effect of different Levels of Sprouting on germination of two white and two red winter wheat varieties after one week of storage in 1985.

levels of sprouting	white		red	
	Frankenmuth	Augusta	Arthur	Hillsdale
	Germination Percentage			
	**			
0	100a	99a	99a	98a
1	99a	98a	98a	98a
2	99a	98a	98a	97a
3	99a	98a	98a	98a
4	98ab	99a	98a	97a
5	100a	98a	98a	97a
6	95b	95a	98a	96a
7	61c	86b	87b	86b
8	50d	60c	64c	66c

* Means of Augusta and Hillsdale represent the average of two years experiment.

** Means followed by the same letter within each column are not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test.

Table 5. The effect of different levels of sprouting on germination of two white and two red winter wheat varieties after two weeks of storage in 1985.

levels of sprouting	white		red	
	Frankenmuth	Augusta *	Arthur	Hillsdale *
	Germination Percentage			
0	100a **	99a	99a	98a
1	98a	99a	98a	98a
2	99a	98a	98a	98a
3	99a	98a	98a	98a
4	98a	98a	98a	98a
5	99a	98a	98a	97a
6	96a	95a	98a	95a
7	63b	77b	87a	85a
8	29c	47c	74b	69b

* Means of Augusta and Hillsdale represent the average of two years experiment.

** Means followed by the same letter within each column are not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test.

Table 6. The effect of different levels of sprouting on germination of two white and two red winter wheat varieties after three weeks of storage in 1985.

levels of sprouting	white		red	
	Frankenmuth	Augusta *	Arthur	Hillsdale *
	Germination Percentage			
	**			
0	99a	98a	98a	97ab
1	97a	97a	97a	99a
2	98a	96a	97a	97ab
3	96a	94a	97a	96ab
4	97a	92a	98a	95ab
5	97a	93a	94a	95ab
6	97a	92a	95a	91b
7	89b	77b	93a	82c
8	66c	55c	85b	69d

* Means of Augusta and Hillsdale represent the average of two years experiment.

** Means followed by the same letter within each column are not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test

Table 7. The effect of different levels of sprouting on germination of two white and two red winter wheat varieties after four weeks of storage in 1985.

levels of sprouting	white		red	
	----- *		----- *	
	Frankenmuth	Augusta	Arthur	Hillsdale
	----- Germination Percentage -----			
	**			
0	99a	98a	97a	98a
1	97a	96a	98a	100a
2	98a	97a	98a	97a
3	85b	87ab	91a	94ab
4	72cd	77bc	90a	94ab
5	78bc	75c	92a	92ab
6	75bcd	74c	92a	87bc
7	67d	56d	93a	82c
8	42e	27e	79b	62d

* Means of Augusta and Hillsdale represent the average of two years experiment.

** Means followed by the same letter within each column are not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test.

Table 8. The effect of different levels of sprouting on germination of two white and two red winter wheat varieties after five weeks of storage in 1985.

levels of sprouting	white		red	
	Frankenmuth	Augusta	Arthur	Hillsdale
	Germination Percentage			
	**			
0	99a	98a	99a	98a
1	98a	97a	99a	99a
2	97a	96a	98a	98a
3	97a	92a	97ab	95a
4	76b	84b	97ab	96a
5	73b	84b	96bc	95a
6	72b	76c	94c	87b
7	51c	38d	85d	86b
8	30d	16e	48e	51c

* Means of Augusta and Hillsdale represent the average of two years experiment.

** Means followed by the same letter within each column are not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test.

Table 9. The effect of different levels of sprouting on germination of two white and two red winter wheat varieties after six weeks of storage in 1985.

levels of sprouting	white		red	
	Frankenmuth	Augusta	Arthur	Hillsdale
	Germination Percentage			
	**			
0	99a	99a	99ab	98a
1	99a	99a	100a	99a
2	97a	95a	99ab	99a
3	69b	83b	98ab	95a
4	69b	80b	96ab	92a
5	54c	75b	95b	92a
6	54c	64c	95b	64b
7	36d	49d	76c	53c
8	33d	20e	61d	39d

* Means of Augusta and Hillsdale represent the average of two years experiment.

** Means followed by the same letter within each column are not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test.

side

side

Table 10. The effect of different levels of sprouting on germination of one white and one red winter wheat variety after eight weeks of storage in 1986.

Levels of sprouting	Augusta	Hillsdale
----- Germination percentage -----		
	*	
0	97a	98a
1	97a	93b
2	93b	93b
3	85c	79c
4	69d	64c
5	46e	42d
6	11f	15e
7	8f	4f
8	0g	0g

* Means followed by the same letter within each column are not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test.

Table 11. The effect of different levels of sprouting on germination of one white and one red winter wheat variety after twelve weeks of storage in 1986.

Levels of sprouting	Augusta	Hillsdale
	Germination Percentage	
0	97a *	97a
1	98a	97a
2	93ab	97a
3	89b	80b
4	49c	50c
5	23d	37d
6	7e	29e
7	0f	0f
8	0f	0f

* Means followed by the same letter within each column are not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test.

Table 12. The effect of storage on the germination
of different levels of sprouting (LOS) of
Frankenmuth seed in 1985.

LOS	weeks					
	1st	2nd	3rd	4th	5th	6th
Germination Percentage						
0	100a [*]	100a	99a	99a	99a	99a
1	99a	98a	97a	97a	98a	99a
2	99a	99a	98a	98a	97a	97a
3	99a	99a	96a	85b	97a	69c
4	98a	98a	97a	72bc	76b	69c
5	100a	99a	97a	78b	73b	54c
6	95a	96a	97a	75b	72b	51c
7	61b	63b	89a	67b	51c	36d
8	50b	29d	66a	42c	30d	33d

* Means followed by the same letter within each row are not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test.

Table 13. The effect of storage on the germination of different Levels of sprouting (LOS) of Arthur seed in 1985.

LOS	weeks					
	1st	2nd	3rd	4th	5th	6th
Germination Percentage						
0	[*] 99a	98a	98a	97a	99a	99a
1	98a	99a	97a	98a	99a	100a
2	98a	98a	97a	98a	98a	99a
3	98a	98a	97a	91a	97a	98a
4	98a	98a	98a	90a	97a	96a
5	98a	98a	94a	92a	96a	95a
6	98a	98a	95a	92a	94a	95a
7	87abc	87abc	93a	93a	85bc	76d
8	64bc	74ab	85a	79a	48d	61c

* Means followed by the same letter within each row are not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test.

Table 14. The effect of storage on the germination of different levels of sprouting (LOS) of Augusta seed in 1986.

LOS	* weeks							
	1st	2nd	3rd	4th	5th	6th	8th	12th
----- Germination Percentage -----								
	**							
0	99a	99a	98a	98a	98a	99a	97a	97a
1	98a	99a	97a	96a	97a	99a	97a	98a
2	98a	98a	96a	97a	96a	95a	93a	93a
3	98a	98a	94a	87a	92a	83a	85a	89a
4	99a	98ab	92abc	77de	84bcd	80cde	69e	49f
5	98a	98a	93ab	75c	84bc	75c	46d	23e
6	96a	95a	92a	74b	76b	64b	11c	7c
7	86a	77a	77a	56b	38c	49bc	8d	0d
8	60a	47a	55a	27b	16b	20b	0c	0c

* The means of the first six weeks represent the average of two years experiment.

** Means followed by the same letter within each row are not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test.

Table 15. The effect of storage on the germination of different levels of sprouting (LOS) of Hillsdale seed in 1986.

LOS	* weeks							
	1st	2nd	3rd	4th	5th	6th	8th	12th
----- Germination Percentage -----								
	**							
0	98a	98a	97a	98a	98a	98a	98a	97a
1	98a	98a	99a	100a	99a	99a	93a	97a
2	97a	98a	97a	97a	98a	99a	93a	97a
3	97a	98a	96a	94a	95a	95a	79b	80b
4	98a	98a	95a	94a	96a	92a	64b	50c
5	97a	97a	95a	92a	95a	92a	42b	37b
6	96a	95a	91a	87a	87a	64b	15d	29c
7	86a	85a	82a	82a	86a	53b	4c	0c
8	66a	69a	69a	62a	51b	39c	0d	0d

* The means of the first six weeks represent the average of two years experiment.

** Means followed by the same letter within each row are not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test.

Table 16. A comparison of the germination of different levels of sprouting of two white and two red winter wheat varieties after one week of storage in 1985.

levels of sprouting	white		red	
	Frankenmuth	Augusta *	Arthur	Hillsdale *
	Germination Percentage			
	**			
0	100a	99a	99a	98a
1	99a	99a	98a	98a
2	99a	99a	98a	97a
3	99a	98a	98a	97a
4	98a	99a	98a	98a
5	100a	98a	98a	97a
6	95a	96a	98a	96a
7	61b	86a	87a	86a
8	50b	61a	64a	66a

* The means of Augusta and Hillsdale represent the average of two years experiment.

** Means followed by the same letter within each row are not significantly different at .05 level of probability according to Duncan's Multiple range test.

Table 17. A comparison of the germination of different levels of sprouting of two white and two red winter wheat varieties after two weeks of storage in 1985.

levels of sprouting	white		red	
	Frankenmuth	Augusta	Arthur	Hillsdale
	Germination Percentage			
0	100a	99a	99a	98a
1	98a	99a	98a	98a
2	99a	98a	98a	98a
3	99a	98a	98a	98a
4	98a	98a	98a	98a
5	99a	98a	98a	97a
6	96a	95a	98a	95a
7	63c	77b	87a	85a
8	29c	47b	74a	69a

* The means of Augusta and Hillsdale represent the average of two years experiment.

** Means followed by the same letter within each row are not significantly different at 0.05 level of probability according to Duncan's Multiple range test.

Table 18. A comparison of the germination of different levels of sprouting of two white and two red winter wheat varieties after three weeks of storage in 1985.

levels of sprouting	white		red	
	Frankenmuth	Augusta *	Arthur	Hillsdale *
	Germination Percentage			
	**			
0	99a	98a	98a	97a
1	97a	97a	97a	99a
2	98a	96a	97a	97a
3	96a	94a	97a	96a
4	97a	92a	98a	95a
5	97a	93a	94a	95a
6	97a	92a	95a	91a
7	89ab	77b	93a	82ab
8	66b	55b	85a	69b

* The means of Augusta and Hillsdale represent the average of two years experiment.

** Means followed by the same letter within each row are not significantly different at 0.05 level of probability according to Duncan's Multiple range test.

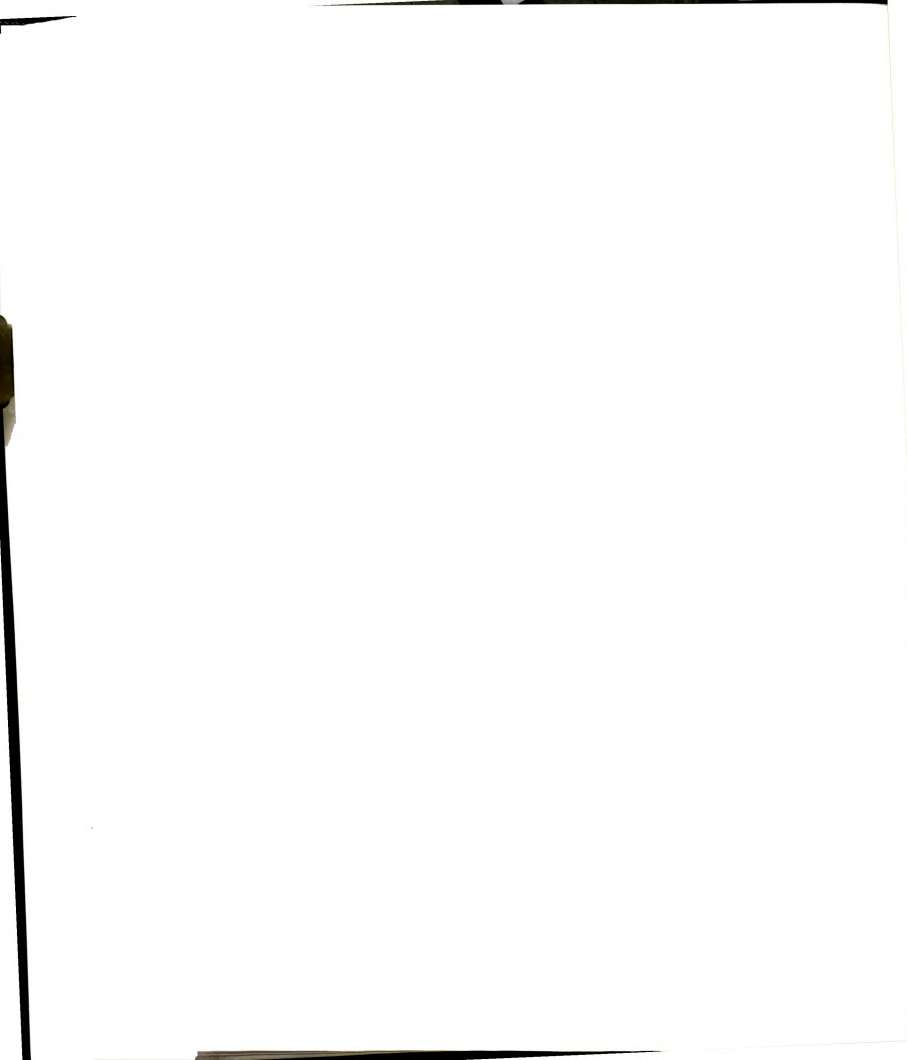


Table 19. A comparison of the germination of different levels of sprouting of two white and two red winter wheat varieties after four weeks of storage in 1985.

levels of sprouting	white		red	
	Frankenmuth	Augusta *	Arthur	Hillsdale *
	Germination Percentage			
	**			
0	99a	98a	97a	98a
1	97a	96a	98a	100a
2	98a	97a	98a	97a
3	85a	87a	91a	94a
4	72c	77bc	90ab	94a
5	78ab	75b	92a	92a
6	75b	74b	92a	87ab
7	67b	56b	93a	82a
8	42c	27d	79a	62b

* The means of Augusta and Hillsdale represent the average of two years experiment.

** Means followed by the same letter within each row are not significantly different at 0.05 level of probability according to Duncan's Multiple range test.

Table 20. A comparison of the germination of different levels of sprouting of two white and two red winter wheat varieties after five weeks of storage in 1985.

levels of sprouting	white		red	
	Frankenmuth	Augusta *	Arthur	Hillsdale *
	Germination Percentage			
	**			
0	99a	98a	99a	98a
1	98a	97a	99a	99a
2	97a	96a	98a	98a
3	97a	92a	97a	95a
4	76c	84b	97a	96a
5	73c	84b	96a	95a
6	72c	76c	94a	87b
7	51b	38c	85a	86a
8	30b	16c	48a	51a

* The means of Augusta and Hillsdale represent the average of two years experiment.

** Means followed by the same letter within each row are not significantly different at 0.05 level of probability according to Duncan's Multiple range test.

Table 21. A comparison of the germination of different levels of sprouting of two white and two red winter wheat varieties after six weeks of storage in 1985.

levels of sprouting	white		red	
	Frankenmuth	Augusta	Arthur	Hillsdale
	Germination Percentage			
0	99a	99a	99a	98a
1	98a	99a	100a	99a
2	97a	95a	99a	99a
3	69c	83b	98a	95ab
4	69b	80b	96a	92a
5	54c	75b	95a	92a
6	54b	64b	95a	64b
7	36c	49b	76a	53b
8	30b	16c	48a	51a

* The means of Augusta and Hillsdale represent the average of two years experiment

** Means followed by the same letter within each row are not significantly different at 0.05 level of probability according to Duncan's Multiple range test.

Table 22. A comparison of the germination of different levels of sprouting of one white and one red winter wheat variety after eight weeks of storage in 1986.

Levels of sprouting	Augusta	Hillsdale
	----- Germination Percentage -----	
	*	
0	97a	98a
1	97a	93a
2	93a	93a
3	85a	79a
4	69a	64a
5	46a	42a
6	11a	15a
7	8a	4a
8	0a	0a

* Means followed by the same letter within each row are not significantly different at .05 level of probability according to LSD test.

Table 23. A comparison of the germination of different levels of sprouting of one white and one red winter wheat variety after twelve weeks of storage in 1986.

Levels of sprouting	Augusta	Hillsdale
	----- Germination Percentage -----	
	★	
0	97a	97a
1	98a	97a
2	93a	97a
3	89a	80a
4	49a	50a
5	23b	37a
6	7b	29a
7	0a	0a
8	0a	0a

* Means followed by the same letter within each row are not significantly different at .05 level of probability according to LSD test.

APPENDIX B

TABLES OF THE SECOND EXPERIMENT

Table 1. Analysis of variance for the effects of exposure to different hours of water and storage on the germination of two white and two red winter wheat varieties in 1985.

source of variation	df	Mean squares
	++	**
No. of samples exposed to water (time exposure)	8	1.563
Storage (weeks)	5	8.065
Exposure x wks.	40	1.545
Varieties	3	16.114
Exposure x Var.	24	1.765
Storage x Var.	15	3.873
Expose. x wks. x Var.	120	1.079

+ Frankenmuth and Augusta are the white varieties and Arthur and Hillsdale are the red varieties.

++ See the description in pp. 36

** Significant at the 0.01 level of probability.

Table 2. Analysis of variance for the effects of exposure to different hours of water, storage on the germination of one white and one red winter wheat variety⁺ in 1986.

source of variation	df	Mean squares
No. of samples exposed to water (time exposure) ⁺⁺	11	152.639**
Storage (weeks)	7	171.791**
Exposure x wks.	77	12.708**
Varieties	1	1729.753**
Exposure x Var.	11	66.781**
Storage x Var.	7	188.235**
Expose. x wks. x Var.	77	13.607**

+ Augusta is the white variety and Hillsdale are the red variety.

++ See the description in pp. 39

** Significant at the 0.01 level of probability.

Table 3. The effect of water exposure on the germination of two white and two red winter wheat varieties after one week of storage during 1985 and 1986.

No. of hrs. exposed to mist		* Augusta	* Hillsdale				
----- yr.-----		Frankenmth	--- yr.-----	Arthur	----- yr.-----		
1st	2nd		1st	2nd	1st	2nd	

----- Germination Percentage -----							

		**					
0	0	100a	99a	98a	99a	98a	97a
8	30	100a	100a	98a	97a	98a	97a
12	36	100a	99a	99a	98a	98a	98a
16	42	99a	99a	98a	98a	99a	97a
20	48	100a	98a	98a	98a	98a	97a
24	54	100a	99a	97a	98a	99a	97a
28	60	99a	99a	97a	98a	98a	97a
32	66	99a	99a	97a	97a	97a	98a
36	72	99a	99a	97a	97a	98a	97a

-	78	-	-	97a	-	-	96a
-	84	-	-	96a	-	-	96a
-	90	-	-	96a	-	-	96a

* Frankenmuth and Arthur were tested only in the first year.

** Means followed by the same letter within each column are not significantly different at 0.01 level of probability according to Duncan's Multiple Range Test.

*** Sprinkling discontinued after 36 hours.

Table 4. The effect of water exposure on the germination of two white and two red winter wheat varieties after two weeks of storage during 1985 and 1986.

No. of hrs. exposed to mist		* Augusta		* Hillsdale		
----- yr.-----		Frankenmth	--- yr.-----	Arthur	----- yr.-----	
1st	2nd		1st	2nd	1st	2nd
----- Germination Percentage -----						
		**				
0	0	100a	100a	97a	99a	98ab 98a
8	30	99a	99a	99a	97a	99ab 98a
12	36	100a	98a	99a	98a	98ab 97a
16	42	100a	99a	97a	98a	100a 99a
20	48	100a	100a	98a	98a	98ab 97a
24	54	100a	99a	97a	98a	99ab 98a
28	60	99a	99a	96a	98a	98ab 97a
32	66	99a	99a	95a	97a	97b 95a
36	72	100a	100a	96a	97a	98ab 96a

-	78	-	-	96a	-	- 95a
-	84	-	-	95a	-	- 94a
-	90	-	-	95a	-	- 94a

* Frankenmuth and Arthur were tested only in the first year.

** Means followed by the same letter within each column are not significantly different at 0.01 level of probability according to Duncan's Multiple Range Test.

*** Sprinkling discontinued after 36 hours.

Table 5. The effect of water exposure on the germination of two white and two red winter wheat varieties after three weeks of storage during 1985 and 1986.

No. of hrs. exposed to mist		* Frankennmuth		* Augusta		* Hillsdale	
----- yr.-----		----- yr.-----		----- yr.-----		----- yr.-----	
1st	2nd	1st	2nd	1st	2nd	1st	2nd
----- Germination Percentage -----							
0	0	98a	98a	96ab	98ab	98a	96a
8	30	99a	100a	96ab	97ab	98a	99a
12	36	99a	96a	94ab	96b	100a	97a
16	42	99a	99a	99a	98ab	98a	99a
20	48	99a	98a	98a	98ab	99a	97a
24	54	99a	99a	91bc	99a	99a	99a
28	60	100a	99a	92bc	99a	98a	99a
32	66	100a	100a	93ab	98ab	99a	97a
36	72	99a	99a	97ab	98ab	99a	97a

-	78	-	-	92bc	-	-	91b
-	84	-	-	87c	-	-	98a
-	90	-	-	92bc	-	-	94ab

* Frankennmuth and Arthur were tested only in the first year.

** Means followed by the same letter within each column are not significantly different at 0.01 level of probability according to Duncan's Multiple Range Test.

*** Sprinkling discontinued after 36 hours.

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Table 6. The effect of water exposure on the germination of two white and two red winter wheat varieties after four weeks of storage during 1985 and 1986.

No. of hrs. exposed to mist		* Frankenmuth	Augusta		* Arthur	Hillsdale	
---- yr.-----		---	yr.-----		---	yr.-----	
1st	2nd		1st	2nd		1st	2nd
----- Germination Percentage -----							
**							
0	0	99a	100a	97a	97c	99a	96ab
8	30	99a	100a	93abc	98abc	99a	100a
12	36	100a	100a	94abc	98abc	99a	97ab
16	42	99a	100a	99a	100a	100a	99ab
20	48	100a	100a	99a	98abc	100a	97ab
24	54	100a	99a	94abc	99ab	99a	99ab
28	60	99a	98a	95ab	99ab	100a	99ab
32	66	100a	99a	95ab	99ab	99a	97ab
36	72	98a	99a	94abc	97bc	100a	99ab

-	78	-	-	89c	-	-	97ab
-	84	-	-	82d	-	-	95ab
-	90	-	-	90bc	-	-	93b

* Frankenmuth and Arthur were tested only in the first year.

** Means followed by the same letter within each column are not significantly different at 0.01 level of probability according to Duncan's Multiple Range Test.

*** Sprinkling discontinued after 36 hours.

Table 7. The effect of water exposure on the germination of two white and two red winter wheat varieties after five weeks of storage during 1985 and 1986.

No. of hrs. exposed to mist		* Frankennmuth		* Augusta		* Arthur		* Hillsdale	
yr.		yr.		yr.		yr.		yr.	
1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
----- Germination Percentage -----									
**									
0	0	99a	99a	97a	99a	99a	99a	97a	
8	30	99a	99a	94a	100a	99a	99a	97a	
12	36	100a	100a	94a	99a	99a	99a	98a	
16	42	99a	99a	95a	99a	99a	99a	98a	
20	48	99a	99a	95a	100a	100a	100a	97a	
24	54	100a	100a	94a	100a	100a	100a	97a	
28	60	100a	99a	92a	99a	99a	99a	100a	
32	66	100a	94b	96a	100a	100a	100a	97a	
36	72	99a	100a	96a	100a	100a	100a	100a	

-	78	-	-	96a	-	-	-	96a	
-	84	-	-	85b	-	-	-	94a	
-	90	-	-	93a	-	-	-	95a	

* Frankennmuth and Arthur were tested only in the first year.

** Means followed by the same letter within each column are not significantly different at 0.01 level of probability according to Duncan's Multiple Range Test.

*** Sprinkling discontinued after 36 hours.

Table 8. The effect of water exposure on the germination of two white and two red winter wheat varieties after six weeks of storage during 1985 and 1986.

No. of hrs. exposed to mist		* Augusta	* Hillsdale
----- yr.-----		Frankenmuth	----- yr.-----
1st	2nd	1st	2nd
----- Germination Percentage -----			
		**	
0	0	99a	99a
8	30	99a	100a
12	36	100a	99a
16	42	100a	100a
20	48	100a	100a
24	54	99a	98a
28	60	100a	100a
32	66	99a	95b
36	72	99a	99a

-	78	-	-
-	84	-	-
-	90	-	-

* Frankenmuth and Arthur were tested only in the first year.

** Means followed by the same letter within each column are not significantly different at 0.01 level of probability according to Duncan's Multiple Range Test.

*** Sprinkling discontinued after 36 hours.

Table 9. The effect of water exposure on the germination of one white and one red winter wheat variety after eight weeks of storage in 1986.

No. of hrs. exposed to mist	Augusta	Hillsdale
	----- Germination Percentage -----	
	*	
0	97a	98a
30	94abc	97a
36	93abcd	94a
42	95ab	97a
48	87d	99a
54	87d	97a
60	91bcd	100a
66	88d	96a
72	92abcd	97a
78	78e	94a
84	81e	98a
90	89cd	86b

* Means followed by the same letter within each column are not significantly different at 0.01 level of probability according to Duncan's Multiple Range Test.

Table 10. The effect of water exposure on the germination of one white and one red winter wheat variety after twelve weeks of storage in 1986.

No. of hrs. exposed to mist	Germination Percentage	
	Augusta	Hillsdale

	* -----	
0	97a	97a
30	96a	99a
36	81c	98a
42	93ab	98a
48	92ab	98a
54	83c	96a
60	90b	99a
66	78c	95a
72	88b	99a
78	83c	95a
84	68d	99a
90	77c	96a

* Means followed by the same letter within each column are not significantly different at 0. 01 level of probability according to Duncan's Multiple Range Test.

Table 11. The effect of storage on the germination of Frankenmuth seeds exposed to different hours of water in 1985.

No. of hrs. exposed to mist	weeks									
	1st	2nd	3rd	4th	5th	6th	8th	10th	12th	14th
----- Germination Percentage -----										
	**									
0	100a	100a	98a	99a	99a	99a	99	100	99	99
8	100a	99a	99a	99a	99a	99a	100	99	100	98
12	100a	100a	98a	100a	100a	100a	97	98	98	95
16	99a	100a	99a	99a	99a	100a	98	99	96	99
20	100a	100a	99a	100a	99a	100a	100	98	97	98
24	100a	100a	99a	100a	100a	99a	97	96	97	94
28	99a	99a	100a	99a	99a	100a	96	99	98	97
32	99a	99a	100a	100a	100a	99a	98	97	94	96
36	99a	100a	99a	98a	99a	99a	99	98	97	94

* One sample of 100 seeds was used in weeks eight, ten, twelve and fourteen.

** Means followed by the same letter within each row are not significantly different at 0.01 level of probability according to Duncan's Multiple Range Test.

Table 12. The effect of storage on the germination of Augusta seeds exposed to different hours of water in 1985.

No. of hrs. exposed to mist	weeks									
	1st	2nd	3rd	4th	5th	6th	* 8th	* 10th	* 12th	* 14th
Germination Percentage										
0	99a	100a	98a	100a	99a	99a	98	100	99	98
8	100a	99a	100a	100a	99a	100a	100	99	98	99
12	99a	98ab	96b	100a	100a	99a	99	97	98	96
16	99a	99a	99a	100a	99a	100a	98	99	96	98
20	98a	100a	98a	100a	99a	100a	100	98	99	97
24	99a	99a	99a	99a	100a	98a	97	96	97	95
28	99a	99a	99a	98a	99a	98a	99	99	98	98
32	99a	99a	100a	99a	94b	95b	98	97	94	96
36	99a	100a	99a	98a	99a	100a	98	95	98	97

* One sample of 100 seeds was used in weeks eight, ten, twelve and fourteen.

** Means followed by the same letter within each row are not significantly different at 0.01 level of probability according to Duncan's Multiple Range Test.

Table 13. The effect of storage on the germination of Arthur seeds exposed to different hours of water in 1985.

No. of hrs. exposed to mist	weeks									
	1st	2nd	3rd	4th	5th	6th	* 8th	* 10th	* 12th	* 14th
Germination Percentage										
0	** 99a	99a	98a	97a	99a	99a	100	100	99	98
8	97b	97b	98ab	98ab	100a	100a	99	99	100	99
12	98ab	98ab	96b	98ab	99a	100a	100	99	98	99
16	98a	98a	98a	100a	99a	100a	99	98	98	98
20	98a	98a	98a	98a	99a	99a	100	98	99	97
24	98ab	98ab	99a	99a	100a	99a	100	96	97	99
28	98a	98a	99a	99a	100a	100a	99	99	96	98
32	97b	97b	98ab	99ab	100a	99ab	98	98	99	97
36	97b	97b	98b	97b	100a	98b	99	97	98	97

* One sample of 100 seeds was used in weeks eight, ten, twelve and fourteen.

** Means followed by the same letter within each row are not significantly different at 0.01 level of probability according to Duncan's Multiple Range Test.

Table 14. The effect of storage on the germination of Hillsdale seeds exposed to different hours of water in 1985.

No. # of hrs. exposed to mist	weeks									
	1st	2nd	3rd	4th	5th	6th	8th	10th	12th	14th
----- Germination Percentage -----										
	**									
0	98a	98a	98a	99a	99a	99a	100	100	99	100
8	98a	99a	98a	99a	99a	100a	99	99	100	99
12	98a	98a	100a	99a	99a	99a	100	97	98	99
16	99a	100a	98a	100a	99a	99a	99	98	100	98
20	98b	98b	99ab	100a	100a	100a	99	98	99	96
24	99a	99a	99a	99a	100a	99a	100	95	97	97
28	98a	98a	98a	100a	99a	100a	99	99	97	98
32	97b	97b	99ab	99ab	100a	100a	99	98	96	98
36	98ab	98ab	99ab	99ab	100a	99ab	98	97	95	96

* One sample of 100 seeds was used in weeks eight, ten, twelve and fourteen.

** Means followed by the same letter within each row are not significantly different at 0.01 level of probability according to Duncan's Multiple Range Test.

Table 15. The effect of storage on the germination of Augusta seeds exposed to different hours of water in 1986.

No. of hrs. exposed to mist	weeks							
	1st	2nd	3rd	4th	5th	6th	8th	12th
----- Germination Percentage -----								
0	98a*	97a	96a	97a	97a	98a	97a	97a
30	98a	99a	96ab	93ab	94ab	91b	94ab	96ab
36	98ab	99a	94ab	94ab	94ab	93b	93b	81c
42	98ab	97ab	99a	99a	95ab	98ab	95ab	93b
48	98a	98a	98a	99a	95ab	95ab	87c	92bc
54	97a	97a	91bc	94ab	94ab	92bc	87cd	83d
60	97a	96ab	92abc	95abc	92abc	95abc	91bc	90c
66	97a	95a	93ab	95a	96a	92ab	88b	78c
72	97a	96a	97a	94ab	96a	93ab	92ab	88b
78	97a	96a	92ab	89b	96a	88b	78c	83c
84	96a	95a	87b	82bc	85bc	86bc	81c	68d
90	96a	95a	92ab	90ab	93ab	90ab	89b	77c

* Means followed by the same letter within a row are not significantly different at the probability level of 0.01 according to Duncan's Multiple Range Test.

Table 16. The effect of storage on the germination of Hillsdale seeds exposed to different hours of water in 1986.

No. of hrs. exposed to mist	weeks							
	1st	2nd	3rd	4th	5th	6th	8th	12th
----- Germination Percentage -----								
0	97a*	98a	96a	96a	97a	97a	98a	97a
30	97a	98a	99a	100a	97a	98a	97a	99a
36	98a	97a	97a	97a	98a	97a	94a	98a
42	97a	99a	99a	99a	98a	98a	97a	98a
48	97a	97a	97a	98a	97a	100a	99a	98a
54	97a	98a	99a	99a	97a	98a	97a	96a
60	96a	97a	99a	99a	100a	99a	100a	99a
66	98a	95a	97a	97a	97a	96a	96a	95a
72	97a	97a	97a	99a	100a	100a	97a	99a
78	96ab	95ab	91b	97a	96ab	96ab	94ab	95ab
84	96a	94a	98a	95a	94a	98a	98a	99a
90	96a	94a	94a	93a	95a	97a	86b	96a

* Means followed by the same letter within a row are not significantly different at the probability level of 0.01 according to Duncan's Multiple Range Test.

APPENDIX C

TABLES OF THE THIRD EXPERIMENT

Table 1. The effect of different levels of sprouting (LOS) on some field characteristics of one white and one red winter wheat variety in 1986.

Field characteristic	Source of variation		
	LOS (df=4)	Varieties (df=1)	LOS x Var.
	----- Mean squares -----		
Emergence index	82.26 **	0.12	3.75
Emergence percent	2393.54 **	157.32	115.48
No. of heads/m	528.78	1642.80	1101.38
1000-seed weight	20.22 **	83.33 **	1.48
Grain yield	643.60 **	222.62	41.24
Biological yield	1829.76	1.63	488.91
Straw yield	94.81	310.41	349.40

++ See the description of "Levels of Sprouting" in pp. 41

** Significant at the 0.01 level of probability.

1910

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1918

Table 2. Emergence index, number of heads/m, 1000-seed weight and grain yield of the field performance of one white and one red winter wheat variety in 1986.

+ LOS	Emergence index		No.of heads/m		1000-seed weight		Grain yield	
	Aug.++	Hills.++	Aug.	Hills.	Aug.	Hills.	Aug.	Hills.
							--- bu/acre ---	
0	15.2a [*]	13.4a	152.0a	110.7a	27.0a	29.4a	62.0a	58.2a
1	13.8a	12.9a	151.7a	106.0a	25.0ab	29.3a	49.9ab	58.4a
2	14.1a	13.1a	130.0ab	123.3a	26.2a	29.9a	50.1ab	58.9a
3	7.9b	9.9b	112.3ab	121.7a	22.5c	26.7b	40.9bc	47.8ab
4	5.2c	6.3c	103.7b	114.0a	23.4bc	25.6b	30.4c	37.3b

+ See the description of "Level of Sprouting" in pp.41

++ Varieties Augusta and Hillsdale.

* Means followed by the same letter within each column are not significantly different at the probability level of 0.05 according to LSD test.



Table 3. Emergence percent, straw yield/m, and biological yield/m of the field performance of on white and one red winter wheat variety in 1986.

* LOS	Emergence percent		Straw yld/m		Biol. yld/m	
	Aug.++	Hills.++	Aug.	Hills.	Aug.	Hills.
			gms.			
0	91.9a	76.5ab	61.1a	60.6a	164.2a	146.3a
1	85.8ab	80.9a	72.0a	43.7a	155.0a	136.3a
2	80.3ab	78.3ab	58.2a	42.7a	141.7ab	140.7a
3	68.7b	59.7bc	50.6a	59.8a	118.7ab	139.3a
4	32.7c	41.0c	52.1a	55.1a	102.7b	117.2a

+ See the description of "Level of Sprouting" in pp.41

++ Varieties Augusta and Hillsdale.

* Means followed by the same letter within each column are not significantly different at the probability level of 0.05 according to LSD test.

Table 4. Comparison of the field performance of one white and one red winter wheat variety in emergence index, number of heads/m, 1000-seed weight, and grain yield in 1986.

+ LOS	Emergence index		No. of heads/m		1000-seed weight		grain yield	
	Aug.++	Hills.++	Aug.	Hills.	Aug.	Hills.	Aug.	Hills.
					---- grs -----		--- bu/acre ---	
0	15.2a	13.4a	152.0a	110.7a	27.0b	29.4a	62.0a	58.2a
1	13.8a	12.9a	151.7a	106.0a	25.0b	29.3a	49.9ab	58.4a
2	14.1a	13.1a	130.0ab	123.3a	26.2b	29.9a	50.1a	58.9a
3	7.9a	9.9a	112.3a	121.7a	22.5b	26.7a	40.9a	47.8a
4	5.2a	6.3a	103.7a	114.0a	23.4b	25.6a	30.4a	37.3a

+ See the description of "Level of Sprouting" in pp.41

++ Varieties Augusta and Hillsdale.

* Means followed by the same letter within each character in a row are not significantly different at the probability level of 0.05 according to LSD test.

Table

100

100

Table 5. Comparison of the field performance of on white and one red winter wheat variety in emergence percent, straw yield/m, and biological yield/m in 1986.

* LOS	Emergence percent		Straw yld/lm		Biol. yld/lm	
	Aug.++	Hills.++	Aug.	Hills.	Aug.	Hills.
			gms.			
0	91.9a	76.5a	61.1a	60.6a	164.2a	146.3a
1	85.8a	80.9a	72.0a	43.7a	155.0a	136.3a
2	80.3a	78.3a	58.2a	42.7a	141.7a	140.7a
3	68.7a	59.7a	50.6a	59.8a	118.7a	139.3a
4	32.7a	41.0a	52.1a	55.1a	102.7a	117.2a

+ See the description of "Level of Sprouting" in pp.41

++ Varieties Augusta and Hillsdale.

* Means followed by the same letter within each character in a row are not significantly different at the probability level of 0.05 according to LSD test.

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Table 6. Simple correlation for the relationship between grain yield and each of emergence percent, number of heads/m, 1000-seed weight, biological yield/m, and straw yield/m of one white and one red winter wheat variety in 1986.

		Emergence percent	No. of heads/m	1000-seed weight	biol. yld/m	straw yld/m
		**	**	**	**	
Grain yield	Augusta	0.94	0.98	0.85	0.96	0.57
	Hillsdale	0.99	-0.14	0.98	0.86	-0.43
Emergence percent	Augusta		0.88	0.69	0.93	0.64
	Hillsdale		-0.19	0.97	0.83	-0.47
No. of heads/m	Augusta			0.78	0.98	0.87
	Hillsdale			-0.16	0.10	0.03
1000-seed weight	Augusta				0.84	0.55
	Hillsdale				0.76	-0.52
biological yield	Augusta					0.78
	Hillsdale					0.03

*,** Correlation coefficient significant at the 0.05 and 0.01 levels of probability, respectively.

++ Simple correlation coefficients were calculated on the basis of entry means.



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