



Stem-solidness stability of selected winter wheat cultivars
by Vicki Lynn Bradley

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Agronomy

Montana State University

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Abstract:

The wheat stem sawfly, *Cephus cinctus* Norton, has caused considerable economic damage in both winter and spring wheat (*Triticum aestivum*) since it was first reported in 1890. Several north-central and north-eastern Montana counties have had severe sawfly infestations. Stem-solidness is at present the only known type of resistance to the wheat stem sawfly. Some solid-stemmed cultivars are more stable in stem-solidness than others. Due to the varied environmental conditions of Montana, a sawfly resistant cultivar must maintain solidness in many environments. The stem-solidness stability of three hollow-stemmed and four solid-stemmed Montana winter wheat cultivars was studied. Stem-solidness data were gathered at eight Montana locations in 1989 and three locations in 1990. Significant differences ($P \leq 0.01$) among the cultivars were indicated. Significant ($P \leq 0.01$) location x cultivar interactions were also noted. Solid-stemmed cultivars were more variable in stem-solidness than the hollow-stemmed cultivars. The seven cultivars were subsequently separated into three groups according to stem-solidness: hollow, intermediate solid, and solid-stemmed. The intermediate solid-stemmed group was least stable in stem-solidness.

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ABSTRACT

The wheat stem sawfly, Cephus cinctus Norton, has caused considerable economic damage in both winter and spring wheat (Triticum aestivum) since it was first reported in 1890. Several north-central and north-eastern Montana counties have had severe sawfly infestations. Stem-solidness is at present the only known type of resistance to the wheat stem sawfly. Some solid-stemmed cultivars are more stable in stem-solidness than others. Due to the varied environmental conditions of Montana, a sawfly resistant cultivar must maintain solidness in many environments. The stem-solidness stability of three hollow-stemmed and four solid-stemmed Montana winter wheat cultivars was studied. Stem-solidness data were gathered at eight Montana locations in 1989 and three locations in 1990. Significant differences ($P \leq 0.01$) among the cultivars were indicated. Significant ($P \leq 0.01$) location x cultivar interactions were also noted. Solid-stemmed cultivars were more variable in stem-solidness than the hollow-stemmed cultivars. The seven cultivars were subsequently separated into three groups according to stem-solidness: hollow, intermediate solid, and solid-stemmed. The intermediate solid-stemmed group was least stable in stem-solidness.

CHAPTER 1

INTRODUCTION

The wheat stem sawfly (Cephus cinctus Norton) is an insect native to the United States (Ainslie, 1920; Criddle, 1922; Farstad, 1940; Callenbach and Hansmeier, 1945; Mills, 1945). It has caused considerable economic damage in both winter and spring wheat (Triticum aestivum L. em. Thell.) since it was first reported in 1890 (Ainslie, 1920, 1929). This pest was originally a grass feeder, but larval feeding preference changed to small grains in the early 1900's (Ainslie, 1929) when sowing and planting of large acreages to wheat and other small grains provided conditions favorable for the transfer of sawfly from grass to wheat (Munro, 1945; Davis, 1955). Cephus occidentalis Riley and Marlatt is the early nomenclature for C. cinctus (Seamans et al., 1938). The wheat stem sawfly may infest grass species other than wheat and at least one broadleaf species but usually does not inflict major damage (Farstad, 1944; Munro, 1945; Farstad and Platt, 1946; Youtie and Johnson, 1988).

Several north-central and north-eastern Montana counties have had severe sawfly infestations (Weiss et al., 1987). Losses in Montana were estimated to be almost 218 million kilograms of spring wheat for 1945 and 1946 combined

(Montana Agriculture Experiment Station and Montana Extension Service Staffs, 1946), and approximately 38 million kilograms in 1951 (Davis, 1952). It has been estimated that use of the solid-stemmed spring wheat cultivar 'Rescue' saved Montana farmers \$40 million between 1944 and 1954 (Luginbill, 1969). Although yield and test weight of Rescue was comparable to other cultivars from 1945 to 1947 (Stoa, 1947), this cultivar is no longer competitive with current susceptible cultivars.

Because of high fuel prices, farmers now use reduced tillage or no-till systems. Many farmers also plant into stubble or use strip cropping to control soil erosion. These practices have resulted in an increase in sawfly problems because the standing stubble acts as a reservoir for sawflies that will emerge in the spring and infest nearby wheat plants. Several winter wheat fields in Pondera county, Montana had stem cutting by sawflies that was estimated to exceed 70% in 1989 (G.A. Taylor and W.L. Morrill, 1989, personal communication). A comparison of the area infested in 1946 and 1987 (Montana Agricultural Experiment Station and Montana Extension Service Staffs, 1946; Weiss et al., 1987) shows that the overall area is about the same although the actual sites of infestation have shifted (Figure 1). It appears then, that the problem is presently as devastating as it was in 1946 when the staffs of the Montana Agricultural Experiment Station and Montana

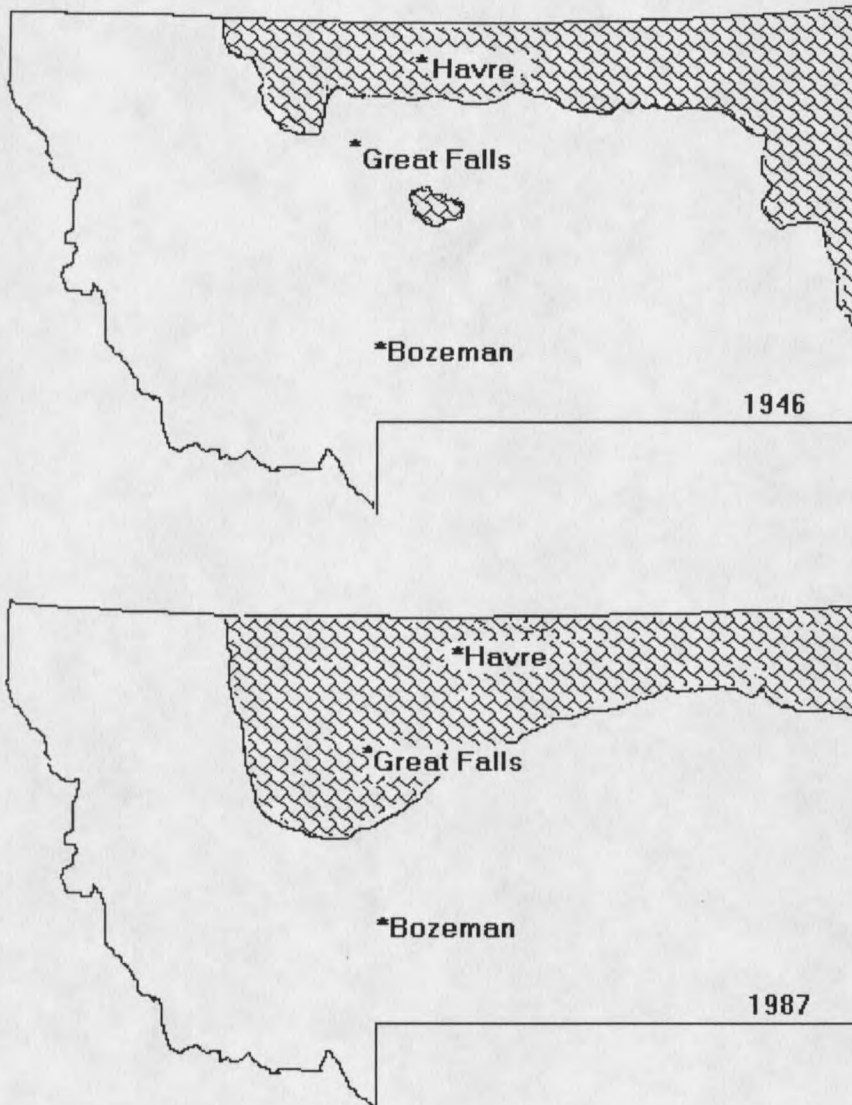


Figure 1. Comparison of area infested with sawfly in 1946 and 1987 (Montana Agriculture Experiment Station and Montana Extension Service Staffs, 1946; Weiss et al., 1987).

Extension Service reported "Emergency and sometimes drastic recommendations had to be made". Currently there are no insecticides registered for use in controlling the wheat stem sawfly (G.D. Johnson, 1991, personal communication). However, some Montana farmers have gotten approximately 50% control of sawflies using granular insecticides that are labeled for use on wheat, but not registered for use on sawflies (K. Kammerzell, 1991, personal communication).

Stem-solidness is at present the only known type of host plant resistance to the wheat stem sawfly. Selection for sawfly resistance in wheat is necessary in order to lessen the economic losses experienced by Montana farmers as a result of this pest. Due to the varied environmental conditions of Montana, a sawfly resistant cultivar will have to maintain solidness in many environments. The objective of this study was to determine the stem-solidness stability of seven Montana cultivars.

CHAPTER 2

LITERATURE REVIEW

Biology of the Insect

The sawfly is a thin, black wasp with yellow markings and is approximately six to 20 millimeters in length (Wallace and McNeal, 1966). In Montana, adults emerge from infested stubble in June. The date of emergence depends on temperature, soil type, and depth that the infested wheat stubble is buried (Luginbill and McNeal, 1955). Adult mating and oviposition activity usually occurs when the sun is shining and the temperature is above 17°C. This activity may cease during cloudy, windy weather conditions (Seamans, 1945; Butcher, 1946). The lifespan of adults is five to eight days (Wallace and McNeal, 1966).

Females will travel only as far as is necessary to find a grass stem which meets the conditions required for oviposition. Farstad (1940) found that stems must have reached the boot stage of development, and the stem must be of a diameter that is easily grasped and held in order for a female to deposit an egg. A preference for plants with elongating internodes has also been shown (Holmes and Peterson, 1960).

The wheat stem sawfly may reproduce sexually or parthenogenetically. Farstad (1938) stated that parthenogenetic reproduction appears to produce only females, and males can probably be produced only from fertilized eggs. However, a later study by Mackay (1955) indicated that it is common for male C. cinctus to develop from unfertilized, haploid eggs (arrhenotokous reproduction) and females from fertilized, diploid ones. Evidence was found to support the existence of a thelytokous race of C. cinctus in which unfertilized eggs developed into diploid females.

Adult females lay from 30 to 50 eggs (Mills, 1945). An individual female deposits only one egg per stem. Other females may lay eggs in the same stem, but do so at a different internode (Weiss et al., 1987). The eggs hatch in four to seven days (Roemhild, 1954). If more than one egg hatches in a stem cannibalism usually occurs; resulting in only one surviving larva which feeds in the inside of the stem and leaves digested plant material (frass) behind.

Larvae have chewing mouth parts and feed on parenchyma and vascular tissues. As they develop, their bodies take on an S-shape that enables them to move up and down inside the stem. All nutrients required for growth, development, and reproduction of C. cinctus are obtained from feeding inside the stem during the larval stage (Holmes, 1954). There have

been no reports of adult sawflies feeding (Wallace and McNeal, 1966a).

When the plant contains approximately 50% moisture (Holmes, 1975), and the moisture content of the kernels is 40 to 60% (Holmes and Peterson, 1965), the larva moves down the stem and girdles it just above the ground. The larva then plugs the top of the stub with frass and weaves a silk-like cocoon sack. Diapause takes place in the cocoon.

At 10°C the obligatory diapause of C. cinctus is broken within 40 to 110 days (Salt, 1947). Pupation occurs in the cocoon during spring and lasts from 10 to 21 days depending on air or soil temperature and soil moisture (Seamans, 1945). When wind blows, the stem breaks off at the girdle, and the adult is able to emerge in the spring by pushing out the plug of frass. The newly emerged adult is fully developed and immediately ready for flight and mating (Wallace and McNeal, 1966a).

Sawfly Damage

The greatest economic losses attributed to the sawfly are incurred because conventional harvest equipment is unable to gather lodged stems that have been cut by sawfly larvae (Seamans et al., 1938).¹ Grain produced from

¹ Generally, studies cited were performed on spring wheat. The conclusions are considered by the author to apply as well to winter wheat unless otherwise noted.

infested stems is graded lower and sawfly-damaged plants may produce fewer kernels that are lower in dry weight than those produced by a non-infested plant (Seamans et al., 1938; McNeal, 1955; Holmes, 1977). Reduced grain quality, dry weight, and kernel number result from physical damage to the vascular bundles of the plant and the concomitant reduction in translocation of assimilates from wheat stems; which, during the phase of rapid grain filling, accounts for 2.7 to 12.2% of final grain weight (Austin et al., 1977; Rawson and Evans, 1971). Holmes (1977) found a mean loss of 11.5% in kernel weight caused by sawfly cutting and a 6.2% loss in kernel weight caused by larval tunneling.

Host Preference

Wallace and McNeal (1966) stated "C. cinctus is very flexible in host possibilities". Wheat is the preferred host, but the sawfly will infest nearly all cultivated grains. Hordeum vulgare L. (barley), Secale cereale L. (rye), Triticum durum L. (now T. turgidum L.), T. polonicum L. (now T. turgidum), and T. timopheevii Zhukovskyi appear to be resistant to larval development (Wallace and McNeal, 1966). Although barley is more resistant to cutting than wheat, the amount of cutting in barley appears to vary with cultivars (Farstad and Platt, 1946). Farstad (1940) reported that oat (Avena sativa L.) is resistant to sawfly cutting, although sawfly oviposition was reported on this

crop. He also suggested that oat may be resistant because it does not provide the complete nutritional requirements for growth and development of the insect. Cephus cinctus will also infest many wild grasses. The most noteworthy of these are the Agropyrons which, according to Criddle (1917), were the preferred host prior to the commercial production of wheat.

Farstad (1944) found that although the preferred hosts of C. cinctus are wheat and other grasses, sawflies will oviposit in other plants if preferred hosts are unavailable. He found that sawflies would lay eggs in the stems of Linum usitatissimum L. (flax), however, larval development was stunted, and almost all of the larvae died before harvest. The sawflies did very little damage to the flax, and Farstad suggested that flax be used as a crop to rid fields of sawflies.

Control of the Insect

Control measures that may be used to minimize economic losses from sawfly infestation are: harvesting before wheat is ripe; using trap crops; and using resistant crops such as flax, oat, and barley in rotation (Butcher, 1946). Other factors that may influence sawfly numbers are: parasitism from both native and introduced parasitoids; field size (Holmes, 1982); tillage system; time of planting (Weiss et al., 1987); fertilizer application (Luginbill and McNeal,

1954); and resistant wheat cultivars (Callenbach and Hansmeier, 1945; Butcher, 1946; Agricultural Research Service Staff, 1955; Kasting and McGinnis, 1963). Disease and predators do not seem to have much effect on C. cinctus although birds may destroy a small part of the population (Davis et al., 1955).

In native grasses, the wheat stem sawfly is attacked by nine species of hymenopterous parasitoids (Holmes et al, 1963). The native parasitoids include: Bracon cephi Gahan, Bracon lissogaster Muesebeck, Eupelmella vesicularis Retzius, Eupelmus allynii French, Eurytoma atripes Gahan, Pleurotropis utahensis Crawford, and Scambus detritus Holmgren (Holmes, 1953; Davis et al., 1955). The introduced parasitoids are Collyria calcitrator Gravenhorst and Bracon terebella Wesmael (Agricultural Research Service Staff, 1955; Luginbill and McNeal, 1955). According to Holmes (1982), parasitism effects vary greatly from year to year. The variation in the effectiveness of parasitoids may be a result of reduced numbers of the parasitoids due to unfavorable environmental conditions or predators (Beirne, 1972). One study suggested that use of the parasitoid Bracon cephi to control C. cinctus is not successful because the life cycles of the two insects do not coincide (Holmes et al., 1963).

Holmes (1982) found that as field width was increased, infestation level decreased. Planting in narrow strips

increased the sawfly infestation level. If the stand is thin, the adult sawfly population is very high, or the wheat is planted into infested stubble, increasing the field width is less effective in lowering infestation levels.

Tillage systems affect sawfly population levels. As early as 1945, it was noted that no-till operations increased the number of sawflies (Farstad et al., 1945). Planting in infested stubble is not recommended because the stubble is a reservoir for sawflies and will most likely increase the level of infestation. Deep tillage in the fall or the early spring buries the stubble and causes larval mortality; shallow tillage in the fall may expose the larvae to desiccation if little snow cover is available during the winter (Wallace and McNeal, 1966a).

Delayed spring planting affects sawfly infestation. Weiss et al. (1987) used the susceptible spring wheat cultivar 'Len' to study the effect of delayed spring planting on sawfly infestation. They found that as planting was delayed, sawfly infestations decreased, and yield increased, although too much delay decreased yield as well as sawfly infestation. McNeal et al. (1955) examined four spring wheats and reported that delayed spring planting reduced sawfly cutting. Data are not available on the effect of late planting of winter wheat on sawfly infestation or cutting.

Luginbill and McNeal (1954) examined the effect of fertilizers on the resistance to sawfly in 'Yogo' winter wheat, and 'Thatcher' and Rescue spring wheat. They concluded that sawfly cutting in both winter and spring wheat is closely associated with phosphorus applied alone or in combination with nitrogen. They indicated that phosphorus caused an early flush of growth which initiated a physical or structural change that made the cultivars tested generally more susceptible to sawfly infestation and cutting. Nitrogen alone had little effect on sawfly cutting or infestation whereas potassium applied together with nitrogen and phosphorus decreased the amount of sawfly cutting on winter wheat. It was suggested that this was a result of the interaction of the three fertilizers.

Effective control of sawfly depends on the development of sawfly resistant wheat (Luginbill and Knipling, 1969). If a plant is resistant, it is capable of suppressing or retarding the development of a pest. Roberts (1954) indicated there are three types of resistance mechanisms to wheat stem sawfly. These include:

1. Resistance to egg laying.
2. Resistance to development of eggs and establishment of first-instar larvae.
3. Resistance to the development of older larvae.

Stem-solidness provides resistance to sawfly damage (Kemp, 1934; Farstad, 1940; Platt and Farstad, 1946; Platt et al., 1948; Luginbill and Knipling, 1969). The resistance results from hindrance of egg development, first-instar larval development, or older larval development. Population levels of the wheat stem sawfly were greatly reduced by use of solid-stemmed spring wheat cultivars (Holmes and Peterson, 1957). Female sawflies that developed in resistant spring wheat were found by Farstad to have far fewer eggs than females that developed in susceptible wheat (personal communication to Holmes, 1984). McNeal et al. (1955) reported that solid-stemmed wheat cultivars were less likely to be cut than hollow-stemmed cultivars, even if they had been tunneled by sawfly larvae.

Stem-Solidness

Characteristics

A plant is solid-stemmed if the inside of the stem is filled with undifferentiated parenchymous cells (pith). Apart from presence or absence of pith, no qualitative anatomical differences, such as maximum stem weight or sugar concentration, exist between solid and hollow winter wheat stems (Ford et al., 1979). There is a direct relationship between thickness of parenchyma cell walls and larval mortality in solid-stemmed spring wheat (Roemhild, 1954).

Kemp (1934) examined more than 10,000 stems from 38 solid-stemmed cultivars and found that larvae seldom succeeded in boring through the nodes. He found the wall of the stem at the nodes was thicker in solid-stemmed cultivars than those of hollow-stemmed cultivars, and the inside diameter of the solid stem at the node was small with adjoining tissue being more dense than in hollow stems.

Stem-solidness is the only proven type of host plant resistance in wheat (Eckroth, 1950). It offers protection from damage by the larvae, but not protection from oviposition by the female (Holmes and Peterson, 1960). Height, maturity, stem diameter, and head type of spring wheat were studied by Eckroth and McNeal (1953). They determined that these characters had little relation to infestation or cutting by the wheat stem sawfly.

Most solid-stemmed spring wheats have lower yield potential (McNeal et al., 1965; Wallace and McNeal, 1966a) and protein content, and poorer milling and baking quality than hollow-stemmed cultivars (McNeal et al., 1971; Weiss et al., 1987). As a result, some farmers in Montana and North Dakota have used blends of resistant and susceptible cultivars of hard red spring wheat in order to obtain higher yields (Weiss et al., 1990). Studies in winter wheat (Ford et al., 1979) and spring wheat (McNeal and Berg, 1979) led to the conclusion that solid-stemmed genotypes could have yields comparable to hollow-stemmed genotypes. The release

of the solid-stemmed spring wheat cultivars Fortuna (Lebsock et al., 1967) and Lew (McNeal and Berg, 1977), both of which had yields approaching the yield of hollow-stemmed cultivars at the time of their release, supports this conclusion.

Stem-solidness is a characteristic influenced by environmental conditions. Both Platt (1941) and Holmes (1984) found that as light intensity decreases, solidness, and therefore resistance, decreases. Other environmental factors that affect expression of stem-solidness are temperature, moisture supply, and spacing of plants (Platt, 1941). Luginbill and McNeal (1958) reported that as seeding rate increased and row spacing decreased the stem-solidness of Rescue decreased.

Stability

McNeal et al. (1966) observed that some solid-stemmed spring wheat cultivars had more stable stem-solidness than others. The term stable indicates consistent performance across different environments.

McNeal and Wallace (1967) evaluated stem-solidness in eight spring wheat plant introductions and four commercial cultivars at five locations. They examined 20 main stems from each row by making a cross-section through the center of each of five internodes starting at the head. When the fifth internode was missing, the fourth internode score was substituted. Significant cultivar differences in stem-solidness were obtained at all locations. This was expected

because the hollow-stemmed cultivar Thatcher was included in the study. They used the difference between the highest and the lowest score among locations to measure a cultivar's stability and found that some cultivars were influenced by environment much more than others, and the top internode was affected the most. It was indicated that the bottom two internodes are most important because the larva must pass through them before girdling the stem, and the top internode is least important because very few sawfly eggs are laid there.

Inheritance

Lebsock and Koch (1968) reported that heritability values for stem-solidness in spring wheat were 60 to 95%, which indicated that stem-solidness is highly heritable.

Holmes (1984) stated that the Portuguese spring wheat S-615 is a parent of all solid-stemmed bread wheats. Wallace et al. (1969) listed a group of spring wheat selections from Portugal that was both solid-stemmed and resistant to C. cinctus. According to Wallace et al. (1969) these selections may possess different or additional genes than those found in S-615.

Biffen (1905) was one of the first to study the inheritance of stem-solidness in wheat. In crosses of tetraploid 'Rivet' (Triticum turgidum), which is solid in the top internode, and hollow-stemmed cultivars of hexaploid

T. vulgare (now T. aestivum) he found that hollowness was dominant.

In spring wheat crosses of Rivet with 'Chinese' (T. vulgare) and tetraploid 'Kubanka' (T. durum, now T. turgidum), Engledow and Hutchinson (1925) concluded that stem-solidness is dominant to hollowness, and that stem-solidness was not associated with any other character of wheat. The difference between a solid and a hollow stem was found to be controlled by one gene.

Platt et al. (1941) reported that three gene pairs were involved in the inheritance of stem-solidness in T. aestivum spring wheat crosses; 'Renown' (hollow) by S-633-3 (solid), Renown by S-615-9 (solid), and Thatcher (hollow) by S-615-11 (solid). The solid-stemmed condition was expressed only in plants having these genes in a recessive state. The authors suggested that the genes were cumulative in action, and under normal conditions four or more dominant alleles would produce phenotypically hollow-stemmed plants.

Yamashita (cited by Platt et al., 1941) used a series of crosses among several species of Triticum to study the genetics of stem-solidness. He suggested the presence of several genes that varied in number and effect with each species.

McNeal (1956) examined Thatcher by Rescue spring wheat crosses. He hypothesized that Thatcher and Rescue were differentiated by one major gene pair designated AA in

Rescue and aa in Thatcher. He also suggested there were from two to four minor modifying genes, and Rescue probably had the minor genes in the dominant condition. The effect of the major gene was two and a half times that of all modifying genes. There appeared to be no interaction between the major gene pair and the minor modifying genes.

MacKenzie's data (1964) supported McNeal's (1955) findings. He reported that the two hollow-stemmed by solid-stemmed spring wheat crosses he studied differed by four genes for stem-solidness, and in both crosses a major gene was indicated. He found that solidness in each internode was highly correlated with solidness in each of the other internodes, but stem-solidness was not correlated with bunt (Tilletia caries, race T-2) reaction, glume color, awn type, or heading date.

Larson has been involved with several studies on the inheritance of stem-solidness. One study led to the hypothesis that top and bottom internode solidness was controlled by genes at different loci (Larson and MacDonald, 1959). After examining aneuploids of Rescue it was found that the line R 5A (an aneuploid for chromosome 3D (XVI)) had genes on the long arm for a solid top internode and genes for solid lower internodes on the short arm (Larson and MacDonald, 1962). Larson also found that chromosome [3D] of Rescue had a gene, or genes, inhibiting the production of pith, especially in the top internode; but in

S-615, a parent of Rescue, the [3D] chromosome promoted pith production in the top internode (Larson, 1959). A later experiment indicated Rescue had fewer chromosomes that influence stem-solidness than its solid-stemmed parent S-615 (Larson and MacDonald, 1962).

Apparently, the genes affecting stem-solidness, and the manner in which they affect solidness, may vary not only from species to species, but also from cultivar to cultivar.

CHAPTER 3

MATERIALS AND METHODS

Four solid-stemmed winter wheats; MT 88002, MT 88005, MT 88006, MT 88008, and three hollow-stemmed winter wheats; MT 88001, 'Redwin', and 'Judith', were grown at eight Montana locations in 1989 and three Montana locations in 1990 (Table 1). MT 88001 and MT 88002 are "short" cultivars (58 to 71 cm), and the other cultivars are "tall" (88 to 114 cm). Each location was considered to be a different environment, however, locations 10 and 11 differed only by planting date (Table 2). Location characteristics are summarized in Tables 3 through 5. All trials were located in non-irrigated fields, and were planted in tilled soil with the exception of location 6, which was planted in untilled soil that had previously been planted to spring wheat.

A randomized complete block design with three or four replications was used at each location. At each location, the seeding rate was approximately 8 g m^{-1} , planting depth was 3.81 cm and row spacing was 0.3 m. The number of rows per plot varied depending on location (Table 2). When plants reached maturity and no evidence of green tissue was apparent, one main stem was taken from each of five to ten

plants located in the center 2.4 m of the middle rows of the plots. Each stem was evaluated for solidness.

Table 1. Pedigrees of the seven winter wheat cultivars studied.

Cultivar	Pedigree
<u>Hollow-stemmed</u>	
Redwin	Yogo/Cheyenne 11-5-5//Yogo Short Straw 4662 20-4-1-1
Judith	Lancota/Froid//Nebraska Selection 69559/Winoka
MT 88001	Summit/Tendoy//Yogo Short Straw
<u>Solid-stemmed</u>	
MT 88002	<u>T. polonicum</u> / <u>T. turgidum</u> //Warrior
MT 88005	Wasatch/Yogo//Rescue/3/Tendoy 251
MT 88006	Wasatch/Yogo//Rescue/3/Tendoy 251
MT 88008	Wasatch/Yogo//Rescue/3/Warrior 189

Table 2. Year sampled, planting date, number of replications, row length, and number of rows per plot for trials at 11 Montana locations.

Location	Year Sampled	Planting Date	No. of Reps†	Rows/Plot	Row Length (m)
1 Conrad	1989	9/16/88	4	4	3.2
2 Bozeman	1989	9/15/88	4	6	3.2
3 Havre	1989	9/26/88	3	3	6.1
4 Moccasin	1989	9/26/88	4	3	6.1
5 Geraldine	1989	9/29/88	3	3	6.1
6 Highwood	1989	9/29/88	3	3	6.1
7 Denton	1989	9/27/88	3	3	6.1
8 Knees	1989	9/8/88	3	4	3.2
9 Bozeman	1990	9/21/89	4	6	3.2
10 Conrad	1990	9/21/89	4	8	3.2
11 Conrad	1990	10/5/89	4	8	3.2

† Number of replications

Table 3. Fertilizer formulation, placement, and amount, for trials at 11 Montana locations.

Location	Fertilizer		Amount kg/ha
	Form	Place	
1 Conrad	11-51-0	with seed	112.0
	34-0-0	topdress	50.4
2 Bozeman	50-80-25	preplant	56.0N
			89.6P
			28.0K
3 Havre	28-0-0	preplant	78.4
	10-34-0	preplant	35.8
4 Moccasin	0-30-0	with seed	33.6
	66-0-0	preplant	73.9
5 Geraldine	0-30-0	with seed	33.6
	60-0-0	topdress	67.2
6 Highwood	15-20-0	with seed	16.8N
			22.4P
7 Denton	0-30-0	with seed	33.6
	50-0-0	preplant	56.0
8 Knees	11-51-0	with seed	112.0
	34-0-0	preplant	72.8
9 Bozeman	42-25-25	preplant	47.0N
			28.0P
			28.0K
10 Conrad	11-51-0	with seed	112.0
	34-0-0	topdress	50.4
11 Conrad	11-51-0	with seed	112.0
	34-0-0	topdress	50.4

A cross section was cut through the center of each internode, beginning with the bottom internode (N1). The internodes were scored for solidness on a scale of 1 (hollow) to 5 (solid) (McNeal, 1956), as shown in Figure 2. Internode scores were averaged to give the stem a single score (abbreviated as NAVG). The five to ten individual

stem scores were averaged to give a mean stem-solidness score for the plot.

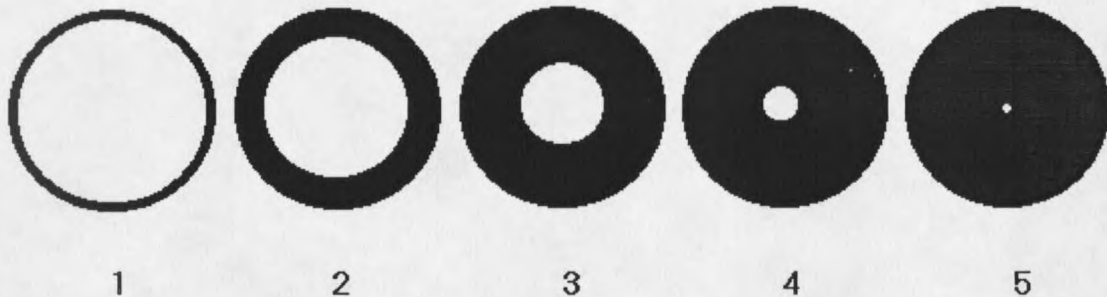


Figure 2. Diagram showing categories for stem-solidness rating. 1 = hollow, 5 = solid (McNeal, 1956).

Yield and test weight data were gathered at locations 1 through 7 (Appendix, Tables 23 and 24). Each 3.2 m row was trimmed to 2.4 m, and each 6.1 m row was trimmed to 4.8 m at all locations. At location 2, the center four rows were harvested, and at the other locations the entire plot was harvested. Location 8 was damaged by hail and not harvested. The cultivar means for yield and test weight at each location were taken from the Winter Wheat Annual Report (T.J. Kisha, 1991, personal communication). Yield was converted from bushels per acre to kilograms per hectare using a conversion factor of 1.12.

Test weight was measured on a Seedburo test weight scale using a standard of 772.2 kg m^{-3} (60 lb bu^{-1}).

The yield and test weight values obtained were used in the analysis of variance, with locations treated as replications. Locations 8 through 11 were not included in the analysis of variance performed on yield and test weight because yield and test weight were not taken at these locations.

Because the total number of above ground internodes per stem (abbreviated as NTOT) varied, the data were analyzed in two ways. The bottom internode scores were matched in the first method of analysis. There were always values for internode 1 (N1) and internode 2 (N2), because every stem had at least two internodes, but values for internode 3 (N3), internode 4 (N4), and internode 5 (N5), may have been missing. In the second method of analysis, internodes were matched starting at the top of the plant, and the top internode was called N5. There were always values for N4 and N5, but N3, N2, and N1 may have been missing. This method evaluated the top two internodes rather than the bottom two internodes. Data from the first method were referred to as normal data, whereas the data from the second method were referred to as adjusted data. All references to N4 or N5 refer to adjusted data unless otherwise noted.

Data for all variables were analyzed via analysis of variance using the plot means. Each location was analyzed

separately, and then all data were combined over locations. The cultivar sums of squares were partitioned into components attributed to variation among hollow-stemmed, variation among solid-stemmed, and a contrast of hollow-stemmed versus solid-stemmed cultivars. In the analysis of combined data, the pooled error mean square was used to test the significance of all interaction mean squares, and the interaction mean square was used to test the corresponding main effect mean square.

A linear regression analysis was used to further investigate the interaction of cultivars with environments. Cultivar means were regressed against the mean of all cultivars for a location (environmental index). The regression coefficients were tested against 1.0 using a t test.

Table 4. Latitude, longitude, elevation and soil characteristics for trials at 11 Montana locations.

Location	Latitude	Longitude	Elevation(m)	Soil Series	Soil Type
1 Conrad	48° 20'	111 57W	1124.8	Scobey	Clay loam
2 Bozeman	45° 40'	111 9W	1451.6	Bozeman	Silt loam
3 Havre	48° 33'	109 46W	785.5	Telstad	Loam
4 Moccasin	47° 03'	109 57W	1307.2	Judith	Clay loam
5 Geraldine	47° 36'	110 16W	951.8	Vida	Clay loam
6 Highwood	47° 33'	110 47W	1033.9	Bearpaw	Clay loam
7 Denton	47° 20'	109 57W	1100.5	Fairfield	Clay loam
8 Knees	48° 04'	111 15W	1010.8	Scobey	Clay loam
9 Bozeman	45° 40'	111 9W	1451.6	Bozeman	Silt loam
10 Conrad	48° 20'	111 57W	1124.8	Scobey	Clay loam
11 Conrad	48° 20'	111 57W	1124.8	Scobey	Clay loam

Table 5. Mean air temperature and total precipitation for trials at 11 Montana locations.

Location	Mean Temperature (°C)†											Total Precip‡ (cm)
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	
1	13.2	8.1	0.6	-3.3	-4.4	-13.4	-4.4	6.6	10.4	16.3	19.7	34.3
2	12.1	10.2	-0.2	-5.0	-4.3	-12.1	-0.8	6.2	9.8	14.8	20.0	40.2
3	13.6	8.1	-0.7	-5.1	-6.2	8.4	-3.8	6.1	11.8	17.1	21.9	26.3
4	12.7	9.7	0.5	-2.4	-3.9	-12.1	-2.5	4.4	9.4	14.3	20.0	42.8
5	14.2	9.7	3.2	-1.6§	-2.0	-10.8	-2.1	7.0	11.7	21.1	22.1	50.5
6	***** Not Available *****											
7	11.7	7.8	1.2	-2.7	-3.8	-12.9	-3.4	5.0	9.7	14.9	19.5	44.6
8	***** Not Available *****											18.3¶
9	12.8	6.9	2.6	-4.7	-2.4	-2.9	0.9	7.3	9.2	14.6	18.8	39.6
10	13.2	7.8	0.7	-5.9	-4.4	-8.2	2.6	5.9	9.9	14.9	19.5	26.4
11	13.2	7.8	0.7	-5.9	-4.4	-8.2	2.6	5.9	9.9	14.9	19.5	26.4

† Temperature data for Conrad 1989 and 1990 do not include weekends or windy days

‡ Total precipitation was calculated from September of previous year through July of listed year. Data are from the National Oceanic and Atmospheric Administration, except data for locations 1, 8, 10 and 11, which are from the Western Triangle Research Station.

§ Partial data, 1 to 9 values missing

¶ Data from 9/3/88 through 7/6/89 only

CHAPTER 4

RESULTS

General Reactions Among the Cultivars

The analysis of variance procedure indicated that cultivars differed ($P \leq 0.01$) in the stem-solidness scores (SSSs) at N1 (Table 6), N2 (Table 7), N4 (Table 8), N5 (Table 9), and NAVG (average stem-solidness score) (Table 10), and for NTOT (total number of above ground internodes) (Table 11). There was variation ($P \leq 0.05$) among the four solid-stemmed cultivars for all measured variables, and among the three hollow-stemmed cultivars for all variables except N5. Seventeen to twenty-one percent of the cultivar variation was due to the solid-stemmed group whereas .1 to 1% was attributed to the hollow-stemmed group. This indicated that variation among solid-stemmed cultivars was greater than variation among hollow-stemmed cultivars. The mean SSSs of the solid-stemmed cultivars differed from the mean of the hollow-stemmed cultivars ($P \leq 0.01$). This difference accounted for more than 75% of the variation among cultivars for all the SSS variables.

Location x cultivar interactions were significant ($P \leq 0.01$) in all instances (Tables 6 through 11). Solid-stemmed

Table 6. Analysis of variance for stem-solidness score at internode 1 (N1).

Source	df	SS	MS	F	p
Location (L)	10	38.00	3.80		
Block(L)	28	16.26	.58		
Cultivar (Cult)	6	342.74	57.13	320.91**	.0000
Hollow (H)	2	6.46	3.23	14.04**	.0001
Solid (S)	3	66.10	22.03	46.58**	.0000
S vs H	1	270.18	270.18	398.32**	.0000
L x Cult	60	25.52	.43	2.39**	.0000
L x H	20	4.55	.23	1.27	.2056
L x S	30	14.19	.47	2.66**	.0000
L x S vs H	10	6.78	.68	3.81**	.0001
Error	168	29.91	.18		

** Significant at the 0.01 probability level.

Table 7. Analysis of variance for stem-solidness score at internode 2 (N2).

Source	df	SS	MS	F	p
Location (L)	10	38.33	3.83		
Block(L)	28	10.42	.37		
Cultivar (Cult)	6	347.32	57.89	376.66**	.0000
Hollow (H)	2	1.56	.78	5.56*	.0120
Solid (S)	3	71.14	23.71	49.97**	.0000
S vs H	1	274.62	274.62	498.76**	.0000
L x Cult	60	22.55	.38	2.45**	.0000
L x H	20	2.81	.14	.91	.5750
L x S	30	14.24	.47	3.09**	.0000
L x S vs H	10	5.51	.55	3.58**	.0003
Error	168	25.82	.15		

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 8. Analysis of variance for stem-solidness score at internode 4 (N4).

Source	df	SS	MS	F	p
Location (L)	10	44.06	4.41		
Block(L)	28	11.30	.40		
Cultivar (Cult)	6	370.11	61.69	353.90**	.0000
Hollow (H)	2	1.18	.59	4.21*	.0298
Solid (S)	3	78.09	26.03	53.42**	.0000
S vs H	1	290.84	290.84	616.98**	.0000
L x Cult	60	22.13	.37	2.12**	.0001
L x H	20	2.80	.14	.80	.7112
L x S	30	14.62	.49	2.80**	.0000
L x S vs H	10	4.71	.47	2.70**	.0043
Error	168	29.29	.17		

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 9. Analysis of variance for stem-solidness score at internode 5 (N5).

Source	df	SS	MS	F	p
Location (L)	10	18.73	1.87		
Block(L)	28	10.48	.37		
Cultivar (Cult)	6	426.04	71.01	402.53**	.0000
Hollow (H)	2	.54	.27	2.41	.1154
Solid (S)	3	46.14	15.38	22.96**	.0000
S vs H	1	379.36	379.36	146.59**	.0000
L x Cult	60	48.23	.80	4.56**	.0000
L x H	20	2.25	.11	.64	.8780
L x S	30	20.10	.67	3.80**	.0000
L x S vs H	10	25.88	2.58	14.67**	.0000
Error	168	29.64	.18		

** Significant at the 0.05 probability level.

Table 10. Analysis of variance for average stem-solidness score (NAVG).

Source	df	SS	MS	F	p
Location (L)	10	32.43	3.24		
Block(L)	28	11.53	.41		
Cultivar (Cult)	6	361.45	60.24	420.74**	.0000
Hollow (H)	2	2.04	1.02	7.93**	.0029
Solid (S)	3	61.89	20.63	53.76**	.0000
S vs H	1	297.53	297.53	421.66**	.0000
L x Cult	60	21.14	.35	2.46**	.0000
L x H	20	2.57	.13	.90	.5875
L x S	30	11.51	.38	2.68**	.0000
L x S vs H	10	7.06	.71	4.93**	.0000
Error	168	24.05	.14		

** Significant at the 0.01 probability level.

Table 11. Analysis of variance for total number of internodes (NTOT).

Source	df	SS	MS	F	p
Location (L)	10	100.61	10.06		
Block(L)	28	2.97	.11		
Cultivar (Cult)	6	15.05	2.51	56.57**	.0000
Hollow (H)	2	4.06	2.03	4.94*	.0181
Solid (S)	3	7.55	2.52	31.55**	.0000
S vs H	1	3.44	3.44	5.53*	.0405
L x Cult	60	16.82	.28	6.32**	.0000
L x H	20	8.21	.41	9.26**	.0000
L x S	30	2.39	.08	1.80*	.0108
L x S vs H	10	6.22	.62	14.05**	.0000
Error	168	7.45	.04		

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

cultivars interacted significantly ($P \leq 0.01$) with locations for all SSS variables. No interaction with location ($P \leq 0.05$) was detected in the hollow-stemmed group. This means that the SSSs for hollow-stemmed cultivars remained more constant over environments than the SSSs for the solid-stemmed cultivars. Significant interactions with location for NTOT were detected in both the hollow ($P = .0000$) and solid-stemmed ($P = .0108$) groups. The solid versus hollow-stemmed contrast showed significant interactions with locations for all variables, which indicated that the relative difference between the solid and hollow-stemmed groups changed from location to location.

Results for N1, N2, N4, N5, and NAVG were similar, although for N5 the P value of .8780 indicated there were no location x cultivar interactions in the hollow-stemmed group (Table 9). This demonstrated that the two methods of data analysis (normal and adjusted) gave similar results.

The analysis of variance performed on yield and test weight data indicated differences among cultivars ($P \leq 0.01$) (Tables 12 and 13). The yields of the hollow-stemmed cultivars did not differ from one another ($P = .6648$). There were significant differences among the solid-stemmed group ($P = .0056$), but most of the variation among the cultivar yields was found to be in the solid-stemmed versus hollow-stemmed contrast. There were significant differences ($P \leq 0.05$) in test weight in both the hollow-stemmed and the

Table 12. Analysis of variance for yield of the cultivars at locations 1 through 7.

Source	df	SS	MS	F	p
Location (L)	6	26367411.86	4394568.64		
Cultivar (Cult)	6	5096359.43	849393.24	4.00**	.0036
Hollow (H)	2	175188.33	87594.16	.41	.6648
Solid (S)	3	3149317.51	1049772.50	4.95**	.0056
S vs H	1	1771853.60	1771853.60	8.35**	.0065
L x Cult	36	7634882.01	212080.06		

** Significant at the 0.01 probability level.

Table 13. Analysis of variance for test weight of the cultivars at locations 1 through 7.

Source	df	SS	MS	F	p
Location (L)	6	25433.97	4238.99		
Cultivar (Cult)	6	19303.92	3217.32	10.17**	.0000
Hollow (H)	2	2384.74	1192.87	3.77*	.0326
Solid (S)	3	16034.34	5344.78	16.89**	.0000
S vs H	1	883.84	883.84	2.79	.1035
L x Cult	36	11391.12	316.42		

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

solid-stemmed groups. The difference in test weight between the hollow and solid-stemmed groups was not significant ($P = .1035$).

Location Differences

Because the location x cultivar interactions were statistically important, it was necessary to examine individual cultivar performance at each location.

The location means for NTOT ranged from 2.86 to 4.28 (Table 14). The location SSS means for NAVG ranged from 2.33 to 3.27 (Table 15). There appeared to be no direct relationship between NTOT and the SSS variables. Mean values for locations 2, 8, 9, 10, and 11 were consistently lower than the other locations for all SSS variables (Tables 15 through 19).

Low SSSs for locations 9, 10, and 11 were attributed to lower values for the hollow-stemmed cultivars, with solid-stemmed values consistent with those at other locations. The low scores for the hollow-stemmed group were ascribed to the investigator having been familiar with the cultivars' phenotypic characteristics and assigning "typical" hollow scores to those known to be hollow-stemmed.

The mean values at location 2, which ranged from 2.16 to 2.34 for the SSS variables, were low. These low values were probably not due to precipitation since location 4 had 42.8 cm of precipitation, and retained higher scores than

Table 14. Mean for total number of internodes (NTOT) for each cultivar at each location.

Cultivar	Location											Mean
	1	2	3	4	5	6	7	8	9	10	11	
<u>Hollow-stemmed (H)</u>												
Redwin	3.38	4.18	3.00	3.00	3.00	3.00	3.00	5.00	4.18	4.10	4.35	3.68
Judith	3.35	4.03	2.67	3.00	3.00	3.00	3.00	3.00	3.75	4.20	4.00	3.42
MT 88001	3.20	3.95	3.00	2.00	2.67	3.00	3.00	3.33	3.78	3.58	3.75	3.23
Mean H	3.31	4.05	2.89	2.67	2.89	3.00	3.00	3.78	3.90	3.96	4.03	3.44
<u>Solid-stemmed (S)</u>												
MT 88002	3.51	4.05	2.47	3.00	2.60	2.40	2.53	3.00	3.95	4.00	3.85	3.30
MT 88005	3.98	4.38	3.00	3.00	3.00	3.00	3.00	3.73	4.63	4.60	4.73	3.80
MT 88006	4.18	4.53	3.00	3.00	3.00	3.00	3.00	3.17	4.60	4.28	4.63	3.75
MT 88008	4.13	4.53	3.00	3.00	3.00	3.00	3.00	3.82	4.80	4.45	4.63	3.83
Mean S	3.99	4.37	2.86	3.00	2.90	2.85	2.88	3.43	4.50	4.33	4.46	3.67
Overall Mean	3.67	4.23	2.87	2.86	2.90	2.91	2.93	3.58	4.24	4.17	4.28	3.56
LSD(0.05)	.20	.18	.17	.10	.12	.07	.09	.19	.20	.20	.19	.24

Table 15. Mean for average stem-solidness score (NAVG) for each cultivar at each location.

Cultivar	Location											Mean
	1	2	3	4	5	6	7	8	9	10	11	
<u>Hollow-stemmed (H)</u>												
Redwin	1.93†	1.03	2.00	2.00	2.00	2.00	2.00	1.00	1.02	1.00	1.02	1.51
Judith	1.98	1.01	2.00	2.00	2.00	2.00	2.00	2.00	1.05	1.00	1.04	1.60
MT 88001	1.98	1.68	2.40	2.28	2.07	2.38	2.00	2.11	1.30	1.05	1.30	1.83
Mean H	1.96	1.24	2.13	2.09	2.02	2.13	2.00	1.70	1.12	1.02	1.12	1.65
<u>Solid-stemmed (S)</u>												
MT 88002	3.34	2.56	3.45	3.28	3.00	3.13	3.38	3.42	2.81	2.87	3.16	3.11
MT 88005	4.79	3.51	3.93	4.49	4.67	5.00	4.74	3.67	4.52	4.04	4.26	4.32
MT 88006	4.91	3.45	3.98	4.85	4.56	4.96	4.91	3.34	4.00	4.39	4.69	4.44
MT 88008	3.76	3.05	3.60	3.17	3.05	3.45	2.73	3.04	2.75	2.95	3.10	3.15
Mean S	4.20	3.14	3.74	3.95	3.82	4.14	3.94	3.37	3.52	3.56	3.80	3.76
Overall Mean	3.24	2.33	3.20	3.17	3.05	3.27	3.07	2.61	2.49	2.47	2.65	2.71
LSD(0.05)	.12	.16	.21	.14	.18	.12	.18	.13	.16	.18	.17	.27

† 1 = Hollow, 5 = Solid

Table 16. Mean stem-solidness score for internode 1 (N1) for each cultivar at each location.

Cultivar	Location											Mean
	1	2	3	4	5	6	7	8	9	10	11	
<u>Hollow-stemmed (H)</u>												
Redwin	2.08†	1.15	2.00	2.00	2.00	2.00	2.00	1.00	1.08	1.00	1.08	1.55
Judith	2.08	1.03	2.00	2.00	2.00	2.00	2.00	2.00	1.18	1.00	1.13	1.63
MT 88001	2.18	2.05	3.00	2.55	2.07	2.33	2.00	2.33	1.85	1.18	1.73	2.08
Mean H	2.11	1.41	2.33	2.18	2.02	2.11	2.00	1.78	1.37	1.06	1.31	1.75
<u>Solid-stemmed (S)</u>												
MT 88002	3.33	2.63	4.00	3.45	3.00	3.40	3.60	3.47	3.10	2.78	3.15	3.23
MT 88005	4.88	3.03	4.00	4.43	5.00	5.00	4.43	3.80	4.83	4.03	4.28	4.32
MT 88006	4.83	2.98	5.00	4.79	5.00	5.00	5.00	3.67	4.48	4.43	4.60	4.50
MT 88008	3.09	2.70	3.87	3.25	3.20	3.40	2.73	2.91	2.60	2.70	2.95	3.01
Mean S	4.03	2.84	4.22	3.98	4.05	4.20	3.94	3.46	3.75	3.49	3.75	3.77
Overall Mean	3.20	2.22	3.42	3.23	3.18	3.31	3.10	2.70	2.73	2.44	2.70	2.76
LSD(0.05)	.17	.26	.21	.20	.16	.19	.23	.20	.23	.26	.27	.30

† 1 = Hollow, 5 = Solid

Table 17. Mean stem-solidness score for internode 2 (N2) for each cultivar at each location.

Cultivar	Location											Mean
	1	2	3	4	5	6	7	8	9	10	11	
<u>Hollow-stemmed (H)</u>												
Redwin	1.98†	1.00	2.00	2.00	2.00	2.00	2.00	1.00	1.00	1.00	1.00	1.51
Judith	1.98	1.03	2.00	2.00	2.00	2.00	2.00	2.00	1.00	1.00	1.03	1.59
MT 88001	2.03	1.73	2.20	2.00	2.07	2.33	2.00	2.05	1.30	1.00	1.38	1.79
Mean H	2.00	1.25	2.07	2.00	2.02	2.11	2.00	1.68	1.10	1.00	1.12	1.63
<u>Solid-stemmed (S)</u>												
MT 88002	3.13	2.58	3.20	3.25	3.00	3.00	3.07	3.47	2.68	2.55	2.98	2.97
MT 88005	4.70	3.00	4.00	4.53	4.87	5.00	4.93	3.58	4.28	3.85	4.23	4.24
MT 88006	4.93	3.03	5.00	4.83	4.73	5.00	48.7	3.58	4.25	3.88	4.75	4.41
MT 88008	3.15	2.75	3.47	3.25	2.93	3.33	2.60	3.18	2.85	2.78	2.83	3.00
Mean S	3.98	2.84	3.92	3.97	3.88	4.08	3.87	3.45	3.52	3.27	3.70	3.66
Overall Mean	3.13	2.16	3.12	3.14	3.09	3.24	3.01	2.64	2.48	2.29	2.60	2.64
LSD(0.05)	.19	.21	.28	.11	.27	.16	.23	.27	.24	.26	.24	.28

† 1 = Hollow, 5 = Solid

Table 18. Mean stem-solidness score for internode 4 (N4) for each cultivar at each location.

Cultivar	Location											Mean
	1	2	3	4	5	6	7	8	9	10	11	
<u>Hollow-stemmed (H)</u>												
Redwin	1.93†	1.00	2.00	2.00	2.00	2.00	2.00	1.00	1.00	1.00	1.00	1.51
Judith	2.00	1.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00	1.00	1.00	1.59
MT 88001	1.93	1.53	2.20	2.55	2.07	2.33	2.00	2.05	1.05	1.00	1.00	1.75
Mean H	1.95	1.18	2.07	2.18	2.02	2.11	2.00	1.68	1.02	1.00	1.00	1.62
<u>Solid-stemmed (S)</u>												
MT 88002	3.02	2.28	3.73	3.25	3.00	3.00	3.47	3.47	2.10	2.38	2.83	2.91
MT 88005	4.85	3.90	4.00	4.53	4.87	5.00	4.93	3.65	4.30	3.90	4.13	4.35
MT 88006	4.90	3.70	5.00	4.83	4.73	5.00	4.87	3.50	3.75	4.45	4.48	4.45
MT 88008	3.98	2.98	3.47	3.25	2.93	3.33	2.60	3.00	2.40	2.83	3.15	3.08
Mean S	4.19	3.22	4.05	3.97	3.88	4.08	3.97	3.40	3.14	3.39	3.65	3.70
Overall Mean	3.23	2.34	3.20	3.22	3.09	3.24	3.07	2.62	2.23	2.36	2.51	2.66
LSD(0.05)	.19	.18	.29	.17	.27	.16	.28	.31	.27	.28	.30	.28

† 1 = Hollow, 5 = Solid

Table 19. Mean stem-solidness score for internode 5 (N5) for each cultivar at each location.

Cultivar	Location											Mean
	1	2	3	4	5	6	7	8	9	10	11	
<u>Hollow-stemmed (H)</u>												
Redwin	1.70†	1.00	2.00	2.00	2.00	2.00	2.00	1.00	1.00	1.00	1.00	1.48
Judith	1.85	1.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00	1.00	1.00	1.57
MT 88001	1.78	1.40	2.00	2.00	2.07	2.47	2.00	1.93	1.00	1.00	1.05	1.65
Mean H	1.78	1.13	2.00	2.00	2.02	2.16	2.00	1.64	1.00	1.00	1.02	1.57
<u>Solid-stemmed (S)</u>												
MT 88002	3.80	2.78	2.87	3.15	3.00	3.00	3.27	3.33	3.33	3.78	3.63	3.29
MT 88005	4.75	4.23	3.80	4.53	4.13	5.00	4.87	3.73	5.00	4.70	4.50	4.50
MT 88006	4.98	4.18	4.93	4.92	3.93	4.87	4.87	2.80	3.73	4.95	4.85	4.48
MT 88008	4.88	3.75	3.47	3.00	3.00	3.60	2.87	3.07	3.33	3.78	3.80	3.54
Mean S	4.60	3.74	3.77	3.90	3.52	4.12	3.97	3.23	3.85	4.30	4.20	3.95
Overall Mean	3.39	2.62	3.01	3.11	2.88	3.28	3.07	2.52	2.63	2.89	2.83	2.76
LSD(0.05)	.23	.30	.29	.16	.33	.21	.27	.26	.31	.26	.29	.41

† 1 = Hollow, 5 = Solid

did location 2 which had 40.2 cm, and location 1 had 34.3 cm of moisture but retained higher values (Table 5). Elevation and soil type were probably not the cause of the low scores, since location 9, also a Bozeman location, had 39.6 cm of precipitation and still had higher values for all SSS variables except N4 (Tables 15 through 19). Data that included intensity and duration of sunlight may have been helpful in determining the cause of the low SSS values at location 2, but data of this type were unavailable.

The response of the cultivars at location 8 was different from that observed at other locations. The hollow-stemmed cultivars tended to have more variable SSSs while the solid-stemmed cultivars had lower SSSs than at most other locations, making the difference between the two groups small (Tables 15 through 19). Examination of individual analyses showed that error mean squares were an order of magnitude higher at this location than at other locations. The low SSSs for the solid-stemmed cultivars may have been caused by the limited moisture at this location, as only 18.3 cm of precipitation was received during the growing season. The moisture stress may have resulted in limited pith formation.

Cultivar Reaction at the Locations

Stem-Solidness Score

Because location 8 appeared to be very different from the other locations it is not included in the following discussion.

The mean SSS of the three hollow cultivars was lower than the average SSS of the four solid-stemmed cultivars over all locations at N1, N2, N4, N5, and NAVG (Figures 3 through 7, and Tables 6 through 10). The SSS of Redwin was always lowest. MT 88006 usually had the highest SSS (Tables 15 through 19).

The mean SSSs of the solid-stemmed cultivars decreased in the central internodes (Tables 16 through 19). The mean SSSs of the solid-stemmed group were higher at N1 and N5 (3.77 and 3.95, respectively), than they were at N2 and N4 (3.66 and 3.70). This was also evident in the hollow-stemmed cultivars for N1 (1.75) and N2 (1.63), but not for N4 (1.62) and N5 (1.57).

There was variation in SSS among the hollow-stemmed cultivars for the five SSS variables. Redwin and Judith were fairly constant having an approximate SSS for NAVG ranging from 1.0 to 2.0 at all locations (Figures 8 and 9, respectively). These two hollow-stemmed cultivars reacted in much the same manner at all locations. Redwin and Judith were not statistically different from one another at all locations for the SSS variables (Tables 15 through 19).

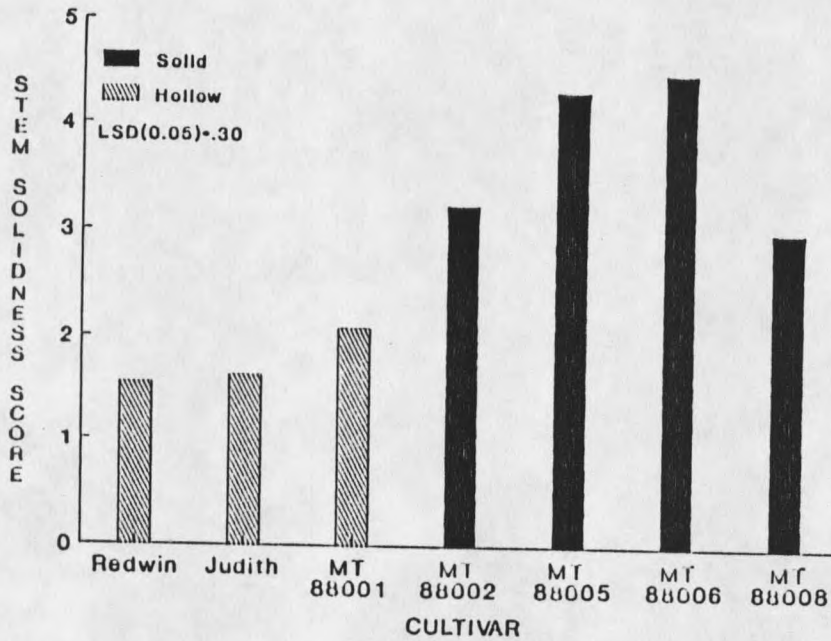


Figure 3. Mean stem-solidness scores for each of the cultivars at internode 1 (N1).

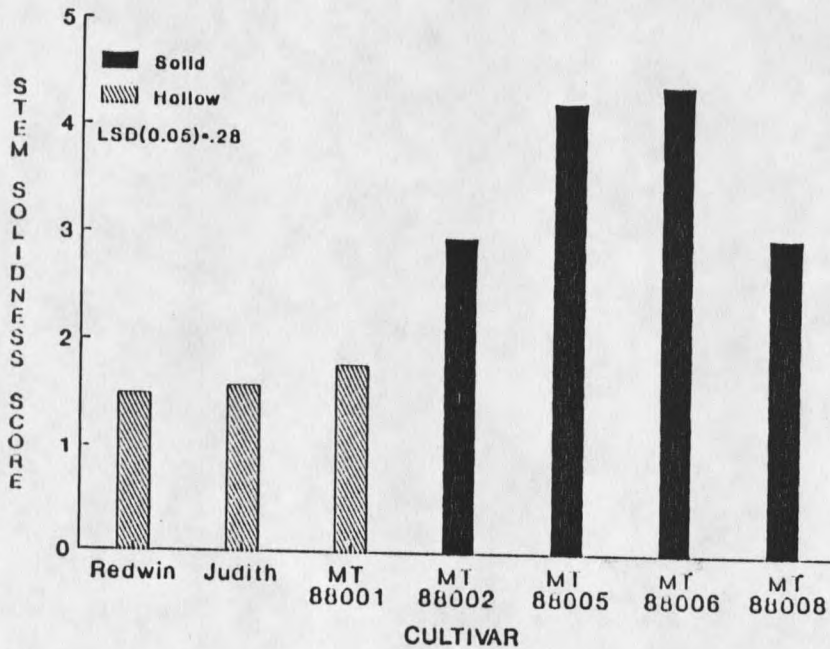


Figure 4. Mean stem-solidness scores for each of the cultivars at internode 2 (N2).

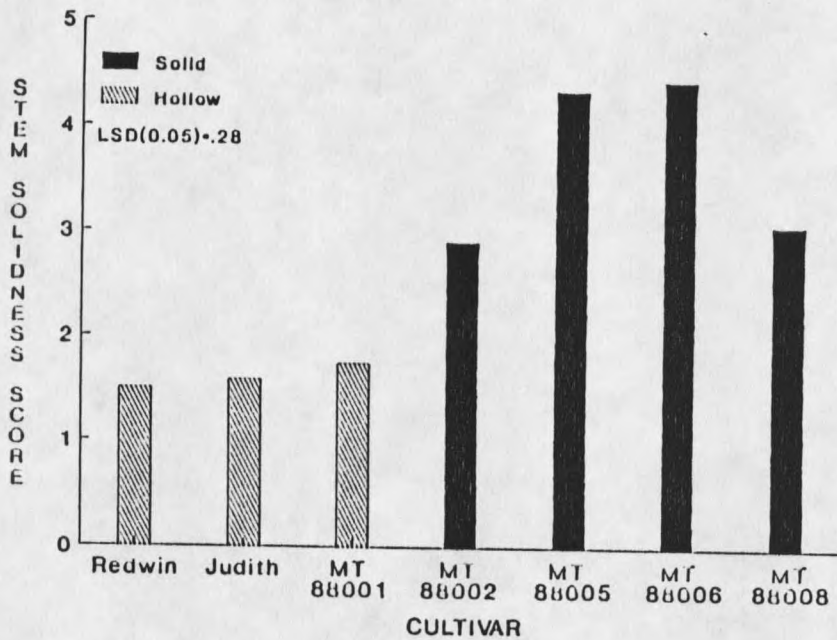


Figure 5. Mean stem-solidness scores for each of the cultivars at internode 4 (N4).

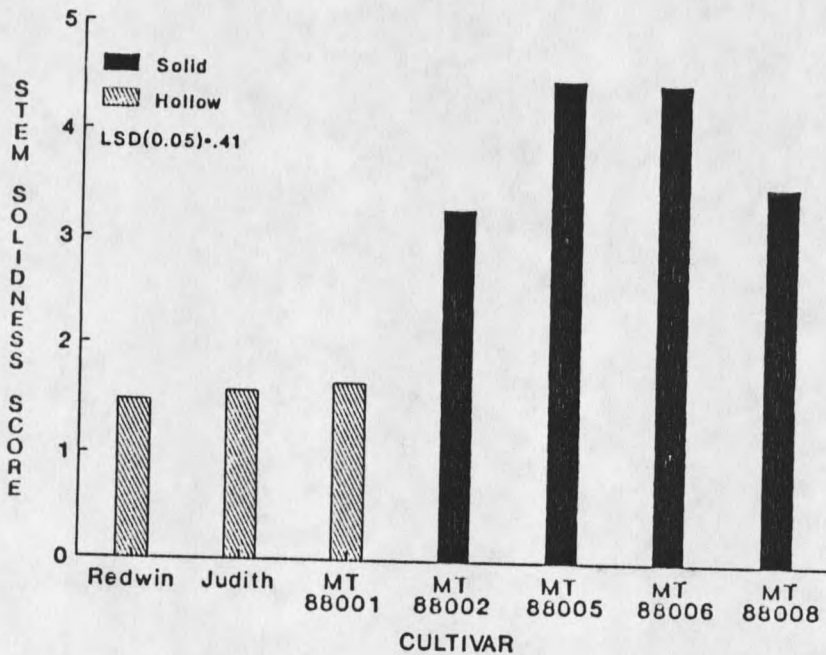


Figure 6. Mean stem-solidness scores for each of the cultivars at internode 5 (N5).

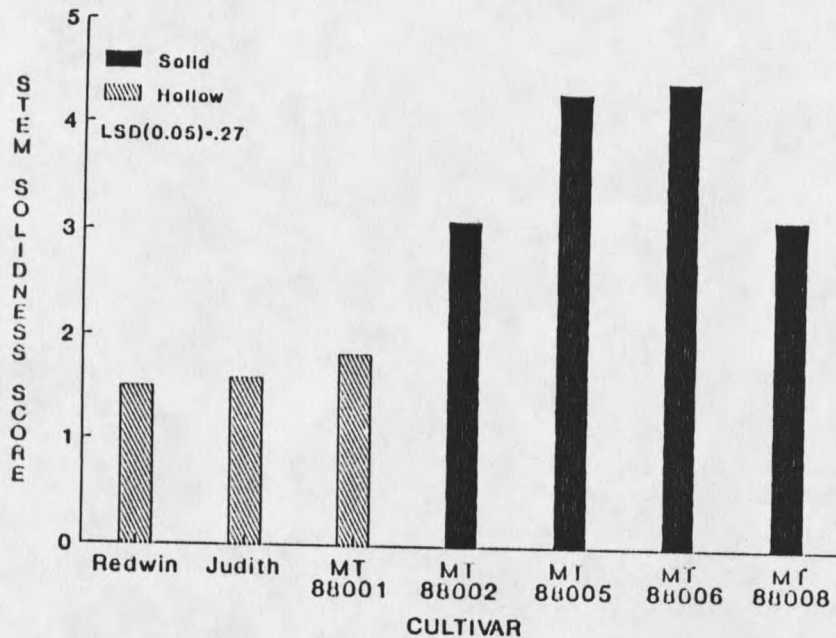


Figure 7. Mean stem-solidness scores for each of the cultivars for NAVG.

The response of the other hollow-stemmed cultivar, MT 88001 (Figure 10), for NAVG was more variable over locations. It ranged from 1.05 to 2.40. At most of the locations it could not be differentiated statistically from Redwin and Judith for the SSS variables (Tables 15 through 19). A similar phenotypic response for these three hollow-stemmed cultivars is to be expected since their pedigrees have no known source of solid-stemmed genes (Table 1). The three hollow-stemmed cultivars were always statistically different from the four solid-stemmed cultivars for all SSS variables (Tables 15 through 19). The consistency of Redwin and Judith compared

to MT 88001 may have resulted because the investigator had preconceived notions as to the scores that should have been assigned to Redwin and Judith. The investigator may have been inclined to give scores of 1 or 2 to the "known" hollow-stemmed cultivars (Redwin and Judith), but may have been more discerning when scoring the "unknown" MT 88001. The variation may also have been a result of selection of immature tillers in MT 88001 and not Redwin or Judith. Or, the variation could have been caused by genetic differences in stem wall thickness and not to differences in pith thickness. The lack of substantial amounts of pith observed in hollow stems made it difficult to distinguish between pith and stem wall, therefore, a score of 2 may have been assigned to a stem that had no pith, but had a thick stem, and a score of 1 may have been assigned to a stem that had some pith, but had a thin stem wall.

The mean SSSs at N1, N2, N4, N5, and NAVG varied within the solid-stemmed group at all locations (Tables 16 through 19 and 15, respectively). The lowest mean SSS for the solid-stemmed group for NAVG was 3.14 at location 2 and the highest was 4.20 at location 1. The ranges for the other SSS variables were 2.22 to 3.42 for N1, 2.84 to 4.08 at N2, 3.14 to 4.19 at N4, and 3.23 to 4.60 for N5. There were no apparent trends in the variation.

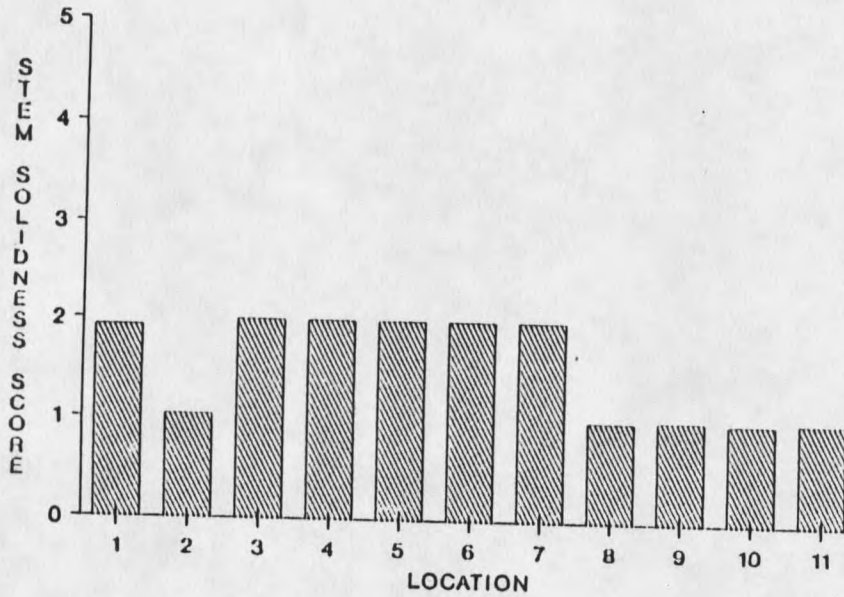


Figure 8. NAVG stem-solidness scores for the cultivar Redwin (1 = hollow, 5 = solid).

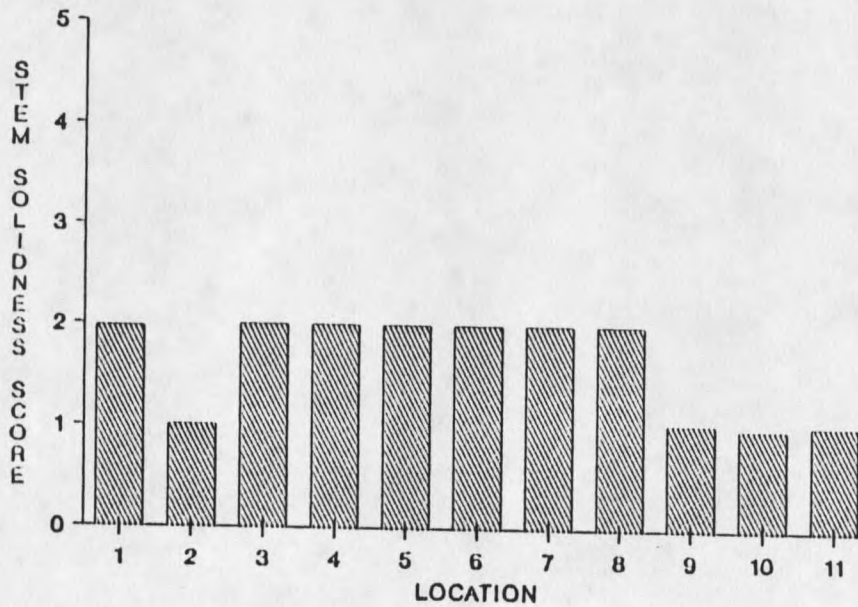


Figure 9. NAVG stem-solidness scores for the cultivar Judith (1 = hollow, 5 = solid).

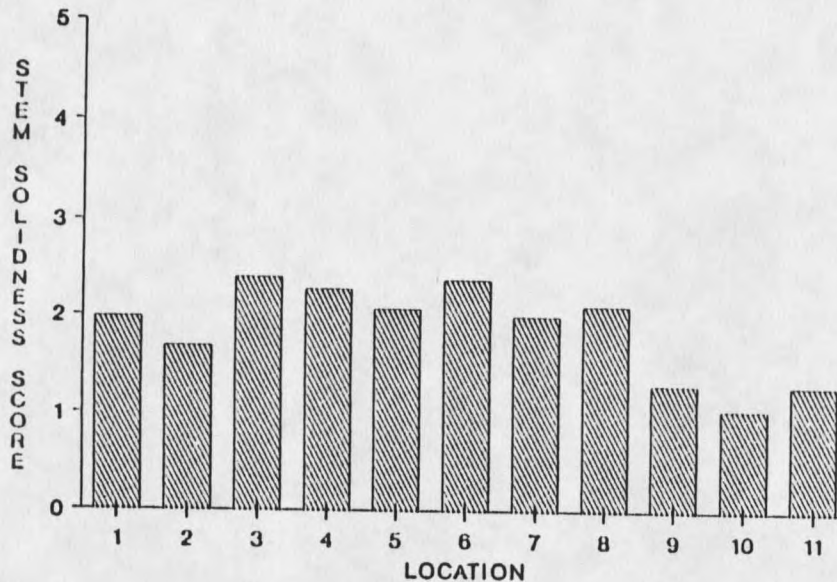


Figure 10. NAVG stem-solidness scores for the cultivar MT 88001 (hollow = 1, solid = 5).

Generally, MT 88005 and MT 88006 had similar mean SSSs for the five SSS variables. MT 88005 was most often significantly different from all other cultivars, but frequently it was not statistically different from MT 88006. MT 88005 always differed significantly from Redwin, Judith, MT 88001, MT 88002, and MT 88008, except at location 3 for N1, and location 1 for N5. MT 88006 was always significantly different from Redwin, Judith, MT 88001, MT 88002, and MT 88008, except at location 1 for N5, and it usually did not differ from MT 88005. The similar SSS reactions of MT 88005 and MT 88006 to the locations (Figures 11 and 12) may have been a result of these two lines being selections from the same cross (Table 1).

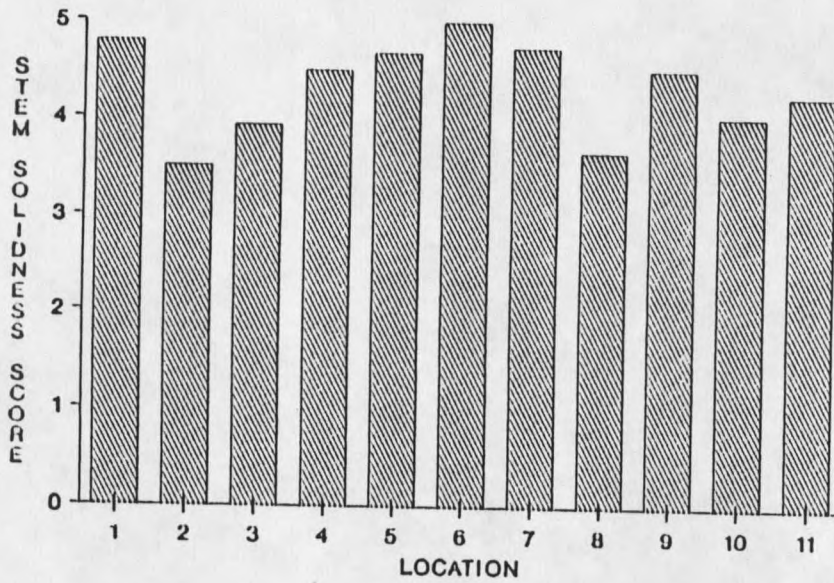


Figure 11. NAVG stem-solidness scores for the cultivar MT 88005 (1 = hollow, 5 = solid).

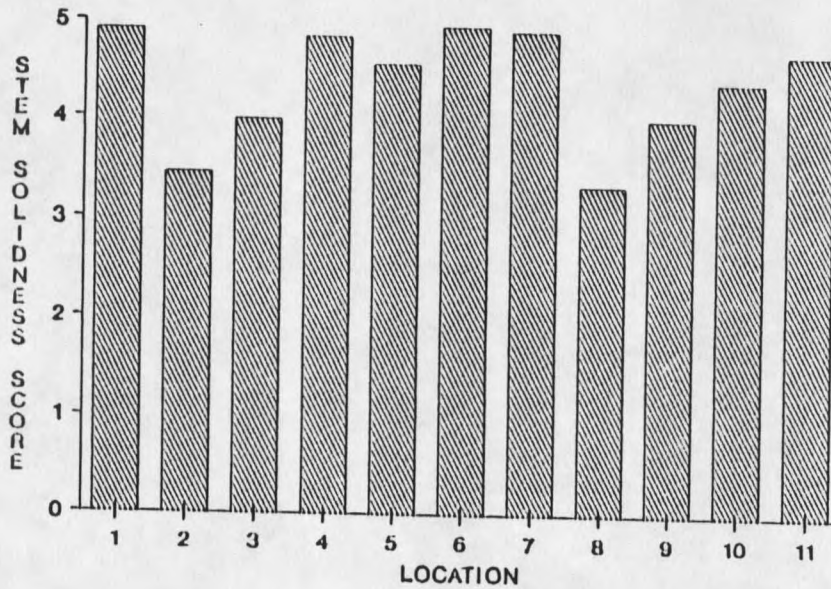


Figure 12. NAVG stem-solidness scores for the cultivar MT 88006 (1 = hollow, 5 = solid).

MT 88002 and MT 88008 were similar in the mean SSSs for the SSS variables (Tables 15 through 19). MT 88002 was always significantly different from Redwin, Judith, MT 88001, and MT 88006. MT 88008 was always significantly different from Redwin, Judith, MT 88001, MT 88005, and MT 88006, except at location 3 for N1, and location 1 for N5. MT 88002 was usually not different from MT 88008. The similarities in SSS reaction to the environment noted in MT 88002 and MT 88008 (Figures 13 and 14) cannot be explained by the parentage of these two cultivars because they are different (Table 1). In fact, the pedigree of MT 88008 is more like MT 88005 and MT 88006 than it is like MT 88002.

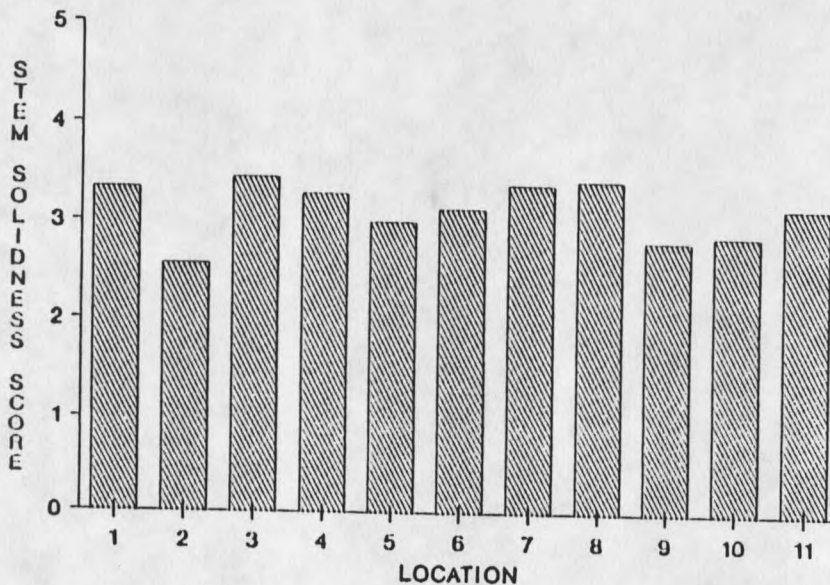


Figure 13. NAVG stem-solidness scores for the cultivar MT 88002 (1 = hollow, 5 = solid).

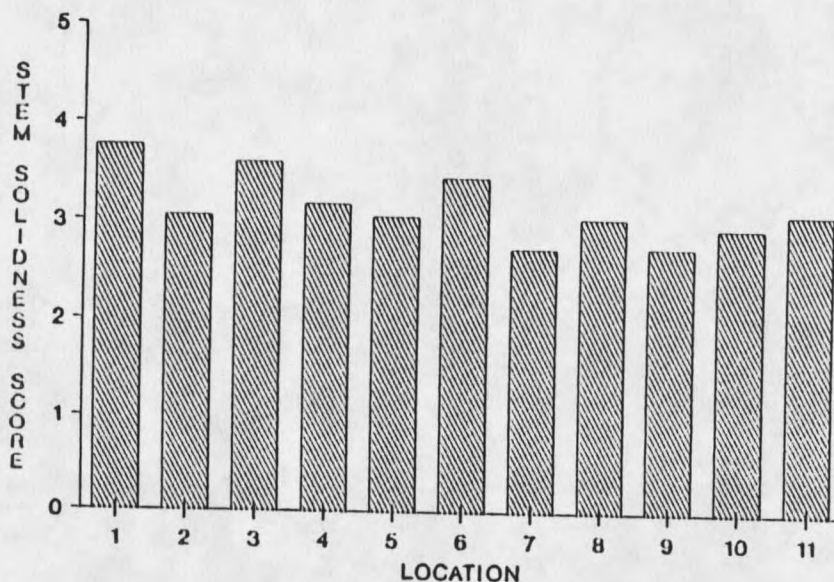


Figure 14. NAVG stem-solidness score for the cultivar MT 88008 (1 = hollow, 5 = solid).

The mean SSSs for each cultivar were similar for the five SSS variables (Tables 15 through 19). The variable that reacted most unlike the others was N5 where the SSSs of the solid-stemmed group were higher than for the other SSS variables.

Total Number of Internodes

Lersten (1987) reported that all wheat cultivars have five to seven nodes. In this study, the cultivars varied from 3.23 to 3.83 for the mean total number of above ground internodes per stem (NTOT) (Figure 15). The cultivars with the fewest internodes were MT 88001 (3.23) and MT 88002 (3.30) (Table 14). Since these are both relatively short

wheats, it is possible that the lower internodes of these cultivars were very short and were located below ground level, hence, they were not taken when stem samples were gathered. Variation in NTOT may also have been a result of the difficulty in distinguishing main stems from late tillers. Late tillers would have had less developed bottom internodes that may have been left when samples were taken. The cultivars were equally exposed to the factors that may have caused environmental variation. Therefore, it is likely that the number of nodes is under genetic control. Other factors that may have accounted for the variation in NTOT include differences over the locations in type of planter used, planting depth, and moisture conditions at the time of planting.

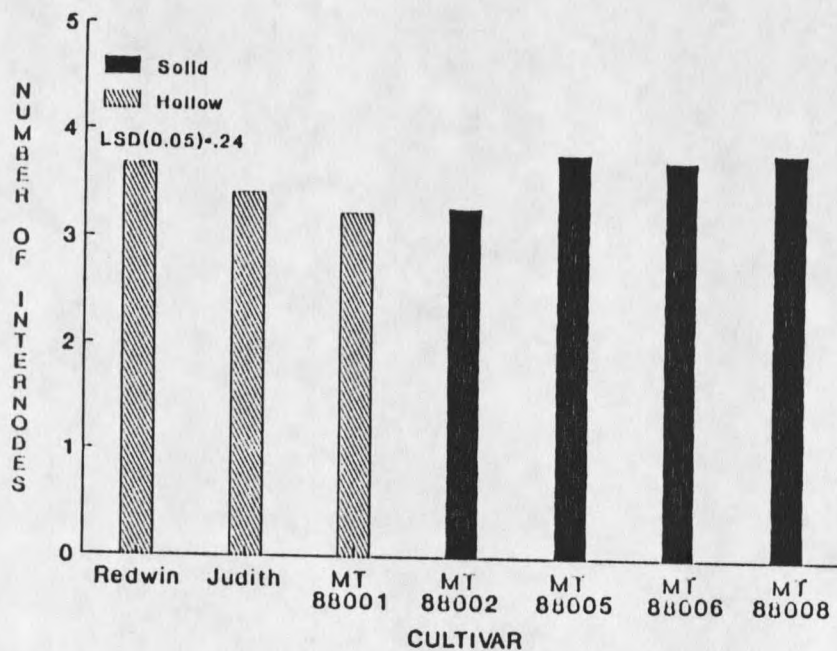


Figure 15. Mean total number of above ground internodes (NTOT) for each of the cultivars.

Predictability of Stem-Solidness
Score and Total Number of Internodes

Regression analysis indicated that Redwin and Judith had higher r^2 values, and were more predictable in their response to environment than the other cultivars (Table 20). The r^2 s for the SSSs of Redwin at N1, N2, N4, N5, and NAVG were 0.79, 0.87, 0.92, 0.54, and 0.90 respectively, which indicated that more than half of the variation in the SSSs of Redwin was accounted for by a linear model. The r^2 values for Judith were 0.72 for N1, 0.77 for N2, 0.81 for N4, 0.25 for N5, and 0.72 for NAVG. The r^2 values for the SSS variable N5 were lower than the other variables for all the cultivars. In most instances the solid-stemmed cultivars had a poorer fit (lower r^2) than the hollow-stemmed cultivars.

Regression of cultivar performance on the mean of all cultivars forces the mean of the b values to be 1.0. Nearly all the b values were not statistically different from the mean response of 1.0. The only exceptions were MT 88002 and MT 88008 for N2, and Redwin for NAVG. The lack of precision for detecting slopes different from the mean response of 1.0 was to be expected for the hollow-stemmed group, since the analysis of variance (Tables 6 through 10) showed interactions with locations were not important. The location x cultivar interaction observed in the analysis of variance for the solid-stemmed group was not explained by

Table 20. Regression statistics from the regression of cultivar mean on location mean for stem-solidness variables and total number of internodes.

Cultivar	Slope (b value)						r ²					
	N1n†	N2n	N4a‡	N5a	NAVG	NTOT	N1n	N2n	N4a	N5a	NAVG	NTOT
Hollow												
Redwin	1.15	1.26	1.20	1.34	1.37*	0.91	0.79	0.87	0.92	0.54	0.90	0.63
Judith	1.03	1.13	1.10	0.90	1.17	0.77	0.72	0.77	0.81	0.25	0.72	0.85
MT 88001	0.81	0.86	1.17	0.93	1.02	0.78	0.45	0.62	0.74	0.26	0.61	0.75
Solid												
MT 88002	0.78	0.50*	0.96	0.22	0.56	1.01	0.60	0.45	0.57	0.03	0.47	0.91
MT 88005	1.03	1.29	0.80	0.72	0.92	1.18*	0.44	0.63	0.45	0.19	0.46	0.99
MT 88006	1.39	1.50	1.12	2.00	1.11	1.13	0.69	0.74	0.68	0.60	0.45	0.91
MT 88008	0.75	0.44*	0.64	0.82	0.56	1.21*	0.60	0.38	0.38	0.16	0.38	0.98

* Statistically different from 1.0 at the 0.05 probability level, using the student's t test.

† Normal data

‡ Adjusted data

differential response of cultivars to the environmental index. The interaction appeared to be a result of random, unpredictable associations with the environments. The differential response of the solid-stemmed cultivars may have been due to their interaction with other environmental variables such as temperature and light intensity.

The regression results for NTOT were different from those for the SSS variables (Table 20). Redwin had the lowest r^2 ($r^2 = 0.63$) for NTOT. More than 90% of the variation in NTOT of the solid-stemmed cultivars could be accounted for by a linear model. The NTOT b values for MT 88005 and MT 88008 were statistically different from 1.0, which indicated that these two cultivars responded to environment differently than the mean response.

Proportions

The location mean values did not necessarily reflect individual cultivar SSS responses to the environments. A location mean SSS of 3.0 could have been a result of the solid-stemmed cultivars each having had SSSs of about 5.0 and each of the hollow-stemmed cultivars having had SSSs of 1.0, or, the solid-stemmed cultivars could have had SSSs of 4.0 and the hollow-stemmed cultivars could have had SSSs of around 2.0. It was necessary to examine cultivar mean values at individual locations as cultivar x location interactions were evident for all traits.

Evaluation of the location means of N1, N2, N4, N5, and NAVG, indicated that these seven winter wheat cultivars separated into three groups as determined by the LSD test ($P \leq 0.05$). The groups were subsequently defined as hollow-stemmed (H), which included MT 88001, Redwin, and Judith, intermediate solid-stemmed (I), which included MT 88002 and MT 88008, and solid-stemmed (S), which included MT 88005 and MT 88006.

In order to verify this assignment it was decided to determine the proportion of the total number of stems of each cultivar that fell into each group. The SSSs at each internode and the NAVG SSSs were evaluated for both the normal and adjusted data. Proportional analyses made it possible to examine the SSSs of N3, N4, and N5 (adjusted data; N1, N2, and N3), which had not previously been possible because all stems did not have the same number of internodes.

The proportional data indicated that the cultivars separated into distinct categories for each internode and for NAVG (Tables 21 and 22). A value of 0.70 was arbitrarily chosen as the lowest value a cultivar could have to be classified into a specific category.

Redwin, Judith, and MT 88001 fell into the H category at all reading sites for both normal and adjusted data. MT 88005 was classified as S at all reading sites except N1 for the adjusted data where the value for S was 0.66. MT 88006

Table 21. Proportion of stems of each cultivar that were in the hollow (H), intermediate solid (I), and solid (S) stemmed categories for the normal data.

Cultivar	N1			N2				N3				
	Loc†	H	I	S	Loc	H	I	S	Loc	H	I	S
MT 88001	11	0.82	0.17	0.00	11	0.91	0.09	.000	10	0.94	0.05	0.01
MT 88002	11	0.13	0.60	0.27	11	0.14	0.73	0.13	11	0.23	0.63	0.14
MT 88005	11	0.08	0.18	0.75	11	0.08	0.16	0.76	11	0.08	0.19	0.73
MT 88006	11	0.09	0.10	0.81	11	0.07	0.11	0.82	11	0.07	0.17	0.76
MT 88008	11	0.23	0.64	0.13	11	0.16	0.70	0.14	11	0.20	0.61	0.19
Redwin	11	0.99	0.01	0.00	11	1.00	0.00	0.00	11	1.00	0.00	0.00
Judith	11	0.99	0.01	0.00	11	1.00	0.00	0.00	11	1.00	0.00	0.00

Cultivar	N4			N5				NAVG				
	Loc	H	I	S	Loc	H	I	S	Loc	H	I	S
MT 88001	6	1.00	0.00	0.00	2	1.00	0.00	0.00	11	0.85	0.15	0.00
MT 88002	5	0.12	0.40	0.48	2	0.00	0.25	0.75	11	0.06	0.78	0.16
MT 88005	6	0.04	0.15	0.82	5	0.04	0.07	0.89	11	0.07	0.12	0.81
MT 88006	6	0.09	0.26	0.65	5	0.08	0.03	0.89	11	0.05	0.08	0.87
MT 88008	6	0.22	0.43	0.35	5	0.15	0.16	0.68	11	0.09	0.69	0.21
Redwin	6	1.00	0.00	0.00	5	1.00	0.00	0.00	11	1.00	0.00	0.00
Judith	6	1.00	0.00	0.00	3	1.00	0.00	0.00	11	1.00	0.00	0.00

† Number of locations (Locs) that had at least one stem with a score for the listed internode.

‡ For N1, N2, N3, N4, and N5; $1.0 \leq H \leq 2.0$, $I = 3.0$, $4.0 \leq S \leq 5.0$:
for NAVG; $1.0 \leq H \leq 2.33$, $2.34 \leq I \leq 3.66$, $3.67 \leq S \leq 5.0$)

Table 22. Proportion of stems of each cultivar that were in the hollow (H), intermediate solid (I), and solid (S) stemmed categories for the adjusted data.

Cultivar	N1			N2			N3					
	Loc†	H	I	S	Loc	H	I	S	Loc	H	I	S
MT 88001	2	0.90	0.10	0.00	6	0.91	0.08	0.00	10	0.79	0.20	0.01
MT 88002	2	0.59	0.41	0.00	5	0.19	0.60	0.21	11	0.12	0.54	0.34
MT 88005	5	0.09	0.25	0.66	6	0.05	0.23	0.73	11	0.09	0.17	0.75
MT 88006	5	0.10	0.17	0.74	6	0.09	0.10	0.81	11	0.07	0.11	0.82
MT 88008	5	0.34	0.58	0.08	6	0.26	0.60	0.13	11	0.16	0.68	0.16
Redwin	5	1.00	0.00	0.00	6	0.97	0.03	0.00	11	0.99	0.01	0.00
Judith	3	1.00	0.00	0.00	6	0.97	0.03	0.00	11	1.00	0.00	0.00

Cultivar	N4			N5			NAVG					
	Loc	H	I	S	Loc	H	I	S	Loc	H	I	S
MT 88001	11	0.86	0.14	0.00	11	0.94	0.05	0.01	11	0.85	0.15	0.00
MT 88002	11	0.22	0.60	0.18	11	0.06	0.65	0.29	11	0.06	0.78	0.16
MT 88005	11	0.08	0.13	0.80	11	0.08	0.09	0.83	11	0.07	0.12	0.81
MT 88006	11	0.09	0.09	0.83	11	0.07	0.12	0.81	11	0.05	0.08	0.87
MT 88008	11	0.19	0.61	0.20	11	0.13	0.47	0.39	11	0.09	0.69	0.21
Redwin	11	1.00	0.00	0.00	11	1.00	0.00	0.00	11	1.00	0.00	0.00
Judith	11	1.00	0.00	0.00	11	1.00	0.00	0.00	11	1.00	0.00	0.00

† Number of locations (Loc) that had at least one stem with a score for the listed internode.

‡ For N1, N2, N3, N4, and N5; $1.0 \leq H \leq 2.0$, $I = 3.0$, $4.0 \leq S \leq 5.0$: for NAVG; $1.0 \leq H \leq 2.33$, $2.34 \leq I \leq 3.66$, $3.67 \leq S \leq 5.0$)

was classified as S at all reading sites except N4 for the normal data where the S value was 0.65.

MT 88002 and MT 88008 were much more variable than the other cultivars. MT 88002 was classified as I at normal N2 and NAVG, and as S at normal N5. It was not classified as I at normal N1, N3, or N4, or at any of the adjusted reading sites. MT 88008 reacted in much the same way as MT 88002. It too was classified as I at normal N2, and NAVG, and was close to being S at normal N5. It was not classified as I at normal N1, N3, or N4, or at any of the adjusted reading sites.

The proportional data supported the assignment of these cultivars into three categories. MT 88001, Redwin, and Judith were hollow-stemmed, MT 88002 and MT 88008 were intermediate solid-stemmed, and MT 88005 and MT 88006 were solid-stemmed. The intermediate solid-stemmed group was more variable than the other groups.

Resistance Criteria

The amount of pith required for a spring wheat to be resistant to the wheat stem sawfly has been investigated by Wallace et al. (1973). They scored the top four internodes of 14 spring wheats for solidness and found a score of 15 (NAVG = 3.75) would reduce stem cutting by the sawfly to approximately 8%, which they considered to be resistant.

The mean percent cutting of the Montana cultivars by sawflies (three location/years) was: MT 88001, 10.33; MT 88002, 15.66; MT 88005, 18.66; MT 88006, 9.33; MT 88008, 30.33; Check, 49.33 (G.D. Kushnak, 1988 and 1989, and M. Weiss, 1989, personal communication). Redwin and Judith were included in a general cutting score for susceptible cultivars and were not reported as separate entries. If the Montana winter wheat cultivars were judged on mean NAVG scores (Table 15) using Wallace et al.'s (1973) criteria, MT 88001, Redwin, Judith, MT 88002 and MT 88008 would be susceptible cultivars, and MT 88005 and MT 88006 would be resistant cultivars. Because of differences in the amount of data and how it was gathered, application of their criteria to the winter wheats studied should be done with caution. They evaluated the resistant spring wheats for nine years and obtained values that ranged from 0.00 to 36.25% cutting among the seven resistant wheats. Our cutting data included only three location/years, and was gathered on winter wheat. There are no data that indicate the same SSSs in winter wheat and spring wheat would insure the same level of resistance in both.

The author assumed a winter wheat cultivar was resistant if the mean sawfly cutting was less than 25%. The data from Conrad, Montana and Williston, North Dakota indicated that Redwin, Judith and MT 88008 were susceptible to sawfly damage, but MT 88001, MT 88002, MT 88005, and MT

88006, may have been resistant. Further study on the minimum stem-solidness required in winter wheat for resistance to the wheat stem sawfly, and a definition of the maximum percent cutting allowed in a resistant cultivar, is needed to enhance the development of resistant cultivars. This may increase the likelihood that resistant wheats with good agronomic and baking and milling characteristics will be found.

CHAPTER 5

DISCUSSION

As mentioned before, sampling techniques may have contributed to variation in SSSs. Main stems were chosen and cut off at ground level. It is possible that late tillers were chosen and the lower internodes were not elongated as much in these as in more mature stems so the short internodes were not taken with the stem during sampling. The variation may have been caused by a genotype that produced a phenotype with very short bottom internodes that were below ground and not taken with the samples. Or, the sampler may have been inclined to give biased evaluations because some of the cultivars could be visually identified.

Suggestions to limit the variation caused by sampling practices are:

1. Cut 15 stems per plot and score the ten tallest with the greatest stem diameter to insure that only main stems are chosen.
2. Cut down into the soil when collecting stems to insure that all the internodes are taken with the sample.

3. Insure that the identity of the cultivar remains unknown while scoring samples.
4. When evaluating advanced lines, determine the number and characteristics (i.e. short and below ground) of the internodes in order to analyze stability accurately.

In this study all locations were sampled in the same manner, and although there was variation caused by sampling methods, the amount of this variation should have been fairly constant over all the locations.

The analysis of variance indicated that a large amount of the cultivar variation in the SSS variables was attributed to the solid-stemmed group, and that approximately 50% of the variation in location x cultivar interactions for N1, N2, N4, and NAVG was due to variation in the solid-stemmed group.

The evaluation of the SSS variables of the individual cultivars at all locations resulted in the conclusions that Redwin and Judith reacted similarly across the locations, as did MT 88002 and MT 88008. MT 88005 and MT 88006 responded to the locations in the same manner. MT 88001 did not react like any of the cultivars, but was most similar to Redwin and Judith.

The SSSs for N1 and N2 were similar to those for NAVG. It may be necessary to score only the bottom two internodes for solidness to determine if the wheat is solid-stemmed.

This would involve less labor than the present method of scoring all available internodes. Wallace and McNeal (1967) reported that the two bottom internodes are the most important to sawfly resistance because the larvae must pass through them before girdling the stem. This also suggests that selection on the basis of the SSSs of the two bottom internodes would yield sawfly resistant lines.

The regression analysis did not indicate that any of the cultivar SSS reactions could be predicted precisely by a linear model. This suggested that the mean of all cultivars was not a suitable independent variable to use in regression analysis. Some other environmental variable(s) might better explain the differential cultivar response to environments.

The generation of the seed of MT 88001, MT 88002, MT 88005, MT 88006, and MT 88008 used for the study was not known. Proportional analyses indicated that MT 88002 and MT 88008 were the most difficult to classify because some stems fell into each of the three categories. This may have been a result of these two cultivars segregating for stem-solidness. Or, the variation may have been due to their having fewer, or different, solidness genes than MT 88005 and MT 88006.

McNeal and Wallace (1967) evaluated the stem-solidness stability of spring wheat by comparing the difference of the largest and smallest SSSs of each cultivar among locations. They used the score of N2 as the score for N1 if N1 was

missing. This could have been misleading when the data were analyzed because the bottom internode may be more solid or more hollow than the second internode from the bottom. This practice arose from use of a scoring scale based on readings at five internodes instead of a scale based on the exact number of above ground internodes per stem. The use of a computer has made it convenient to use the latter method.

Because the winter wheat data in this study were gathered somewhat differently than McNeal and Wallace's (1967), and because the proportional analyses allowed the investigator to determine the actual number of internodes and stems that fell into each group, it was more appropriate to evaluate the stem-solidness stability of the seven winter wheat cultivars by comparing the proportion of stems in the hollow, intermediate solid, and solid-stemmed categories.

Two methods of analyzing the data were used. It was difficult to distinguish if either method was more valid than the other. Although the adjusted data method was the more conventional of the two analyses (i.e. comparison of corresponding internodes), the first method of analysis should not be disregarded. It is not clear if internodes that are very short and remain underground are as important in resistance to the sawfly as bottom internodes that are longer and all or part of which are above ground level. This distinction could be critical when considering the

release of a sawfly resistant cultivar that has the short internode trait.

The proportional data indicated that these seven winter wheat cultivars should be divided into three groups. The hollow-stemmed group should include Redwin, Judith, and MT 88001. The intermediate solid-stemmed group should include MT 88002 and MT 88008. The solid-stemmed group should include MT 88005 and MT 88006.

The intermediate solid-stemmed cultivars, MT 88002 and MT 88008, were more variable in their SSS reaction to the environments than the hollow-stemmed or the solid-stemmed groups. It seems likely that the intermediate solid-stemmed cultivars have fewer genes modifying the solid-stemmed phenotype than do the solid-stemmed cultivars. It is possible that the two to four minor modifying genes that McNeal (1956) reported to be present in spring wheat may also be found in winter wheat. These modifying genes may not only confer solidness to stems, but may also play a role in stabilizing the solidness. Perhaps there is a regulation system that overrides the stability gene(s) when stress conditions such as too little or too much moisture, or low light intensity, occur. If this hypothesis were true, it would lead to the assumption that a truly solid-stemmed cultivar would remain stable for solidness over a range of "normal" environmental conditions.

All locations in this study, except location 8, were considered to be representative of "normal" environmental conditions in Montana. The materials at location 8 were considered to have been exposed to water stress. Under these conditions the truly solid-stemmed cultivars MT 88005 and MT 88006 had scores similar to the intermediate solid-stemmed cultivars. The stress induced modification of the expression of some of the solidness genes, and pith formation may have been sacrificed for seed production. It should be noted that in the extreme conditions that were encountered at location 8 the formation of pith would not be necessary for sawfly resistance since sawfly mortality is high under drought conditions (Platt and Farstad, 1946).

CHAPTER 6

CONCLUSIONS

Significant differences in the stem-solidness scores of the cultivars were found for all measured variables. Significant location x cultivar interactions were also noted although the hollow-stemmed group did not appear to interact with the environment.

Use of either the adjusted or the normal method in analyzing stem-solidness data is appropriate since both methods gave similar results for the stem-solidness score variables.

Proportional analyses are useful in interpreting stem-solidness data for stability as it allows the investigator to evaluate each internode when the total number of internodes varies among and within the cultivars.

The proportional analyses and evaluation of the location means of the stem-solidness score variables indicated that the seven winter wheat cultivars studied should be separated into three groups. The hollow-stemmed group includes Redwin, Judith, and MT 88001. The intermediate solid-stemmed group includes MT 88002 and MT 88008. The solid-stemmed group includes MT 88005 and MT 88006.

The proportional analyses indicated that the intermediate solid-stemmed group was more variable than the solid-stemmed group, because the intermediate solid-stemmed group usually had less than 70% of the stems in any one category. Of the seven winter wheat cultivars studied MT 88005 and MT 88006 were most stable for solid stems.

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APPENDIX

YIELD AND TEST WEIGHT TABLES

Table 23. Yield and test weight of the hollow-stemmed cultivars at seven Montana locations, and the location means of the seven cultivars studied.

Location Year	<u>MT 88001</u>		<u>Redwin</u>		<u>Judith</u>		<u>Mean of 7 Locations</u>	
	Yield kg/ha	Test Wt kg/m ³	Yield kg/ha	Test Wt kg/m ³	Yield kg/ha	Test Wt kg/m ³	Yield kg/ha	Test Wt kg/m ³
Conrad 1989	4395.1	804.4	3689.4	803.1	4233.8	809.5	4190.6	804.7
Bozeman 1989	5067.1	777.3	4428.7	801.8	4670.6	754.2	4273.2	768.9
Havre 1989	2204.2	711.7	2237.8	769.6	2399.1	725.9	2303.1	735.1
Moccasin 1989	2573.9	755.5	2694.8	782.5	3360.1	743.9	2790.8	760.6
Geraldine 1989	3709.6	776.1	4670.6	794.1	3884.3	731.0	3722.0	755.3
Highwood 1989	4361.4	813.4	4912.5	787.6	4710.9	795.4	4383.5	794.5
Denton 1989	3709.6	790.2	4200.2	800.5	4327.8	798.0	3613.6	788.6
Mean	3717.3	775.5	3833.4	791.3	3940.9	765.4	3611.0	772.5

LSD (0.05) for yield = 497.48; LSD (0.05) for test weight = 19.28

Table 24. Yield and test weight of the solid-stemmed cultivars at seven Montana locations.

Location Year	<u>MT 88002</u>		<u>MT 88005</u>		<u>MT 88006</u>		<u>MT 88008</u>	
	Yield kg/ha	Test Wt kg/m ³	Yield kg/ha	Test Wt kg/m ³	Yield kg/ha	Test Wt kg/m ³	Yield kg/ha	Test Wt kg/m ³
Conrad 1989	4905.8	778.6	4388.3	813.4	3655.8	792.8	4065.8	831.4
Bozeman 1989	6021.4	729.7	3272.8	769.6	3178.7	761.9	3272.8	787.6
Havre 1989	2412.6	677.0	2197.5	742.6	2305.0	740.0	2365.5	778.6
Moccasin 1989	2997.2	719.4	2762.0	755.5	2674.7	755.5	2473.1	811.8
Geraldine 1989	3696.1	719.4	3050.7	689.8	3501.3	773.5	3541.6	803.1
Highwood 1989	4448.8	767.1	4381.6	790.2	3770.1	791.5	4099.4	816.0
Denton 1989	3622.2	772.2	3400.5	782.5	3010.7	772.2	3024.1	804.4
Mean	4014.9	737.6	3350.5	763.4	3156.6	769.6	3263.2	804.7

LSD (0.05) for yield = 497.48; LSD (0.05) for test weight = 19.28

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