

A STUDY OF PRE-HARVEST
SPROUTING TOLERANCE IN TRITICALE
(X TRITICOSECALE WITTMACK)

A Thesis
Submitted to the Faculty
of
Graduate Studies
The University of Manitoba
by
Stanley Plett

In Partial Fulfillment of the
Requirements of the Degree
of

Master of Science
Department of Plant Science
August 1984

A Study of Pre-Harvest
Sprouting Tolerance in Triticale
(X Triticosecale Wittmack)

by

Stanley Plett

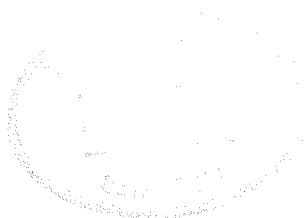
A thesis submitted to the Faculty of Graduate Studies of
the University of Manitoba in partial fulfillment of the requirements
of the degree of

MASTER OF SCIENCE

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Acknowledgements

I wish to express my gratitude to my advisor Dr. E. N. Larter for his guidance during the course of this study and the invaluable comments in the preparation of this thesis.

Grateful acknowledgements are also extended to the members of my advisory committee: Drs. L. J. LaCroix, D. Leisle, and J. S. Noll.

Thanks are due to J. W. Mitchell, M. Fruehm, and B. R. Oree for their assistance throughout the course of this research.

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GENERAL ABSTRACT

PLETT, STANLEY, M.Sc. The University of Manitoba

Title: A STUDY OF PRE-HARVEST SPROUTING TOLERANCE IN TRITICALE
(X Triticosecale Wittmack)

Major Professor: Dr. E. N. Larter

There is a need to improve the tolerance to pre-harvest sprouting in triticale. This study examines the variability for sprouting tolerance existing in the University of Manitoba triticale breeding program and in the accessioned triticales. If only low levels of tolerance are present in local germplasm, new sources must be introduced from elsewhere. The feasibility of introducing tolerance genes from wheat into triticale is also explored.

One hundred and fifteen lines from the University of Manitoba triticale breeding program were evaluated for sprouting tolerance in the winter of 1982. Scoring each progeny line on the basis of rain simulator tests, showed a wide variability in tolerance ranging from very poor, to several lines which were as tolerant as the check wheat, Triticum aestivum L. Em. Thell. cv. 'Glenlea' (94.42%). In the summer of 1982, 18 lines representing a range of scores from 98.45% to 2.14% were further tested. Rankings of scores for the 18 retested lines were similar to those obtained from the initial evaluation. Correlations between yield and tolerance score were low but positive, while those

between peroxidase content and score were consistently low. In the summer of 1983, a further screening of 98 triticales from the University of Manitoba Accession list revealed a wide range of tolerance scores. Three accessions, 6A-187 (T. turgidum / Ae. elongatum), 6A-62 (T. timopheevi / T. persicum // T. sphaerococcum) and 6A-64 (T. dicoccum / S. cereale) were either higher or equal in their sprouting tolerance scores to RL4137, a hexaploid wheat with the highest known tolerance to pre-harvest sprouting.

The effect of stages of grain maturation on sprouting tolerance was studied by sampling kernels weekly from the second to the seventh week post-anthesis. Three triticales lines were used; CD82-45 (M2A / ARM"S" // Bgl), Carman, and CB82-5 (6TA204 // BCO /3/ BVR / TOBI). The wheat cv. 'Glenlea' was used as a control. Sprouting tolerance decreased in kernels from all lines with increasing time after anthesis. Relative rankings among the lines remained constant in samples taken from just before to just after maturity. Maturation by germination temperature interactions were further studied using CB82-9 (Bgl / M2A // Cinnamon), Carman, CB82-5, and RL4137. All interactions were found to be significant. The widest range of scores was found at daytime maturation temperatures of 20 °C and a germination scoring temperature of 25 °C. The most conclusive results were obtained using the two germination temperatures, 17 °C and 25 °C.

Octaploid triticales ($2n = 56$) were derived from crossing the highly tolerant hexaploid wheat, RL4137 with both Otello, a sprouting resistant rye, and with 8301, a susceptible inbred rye. Sprouting tolerance scores from the octaploids were similar

regardless of which rye was involved in the cross. In addition, an octaploid triticale (RL4137 / Unknown Inbred Rye) was used as the donor parent in a cross with a highly productive hexaploid triticale, CA82-8 (Bgl / M2A // Cinnamon), with the objective of obtaining hexaploid derivatives with the sprouting tolerance of the RL4137 wheat line. The resulting F3 plants were compared to the octaploid and hexaploid parents. Scores from F3 progeny ranged from 68% to 100% with most plants having scores approximately equal to the parental lines. RL4137 is the most sprouting tolerant wheat known. Successful incorporation of RL4137 tolerance into triticale would result in a significant increase in sprouting tolerance in triticale.

GENERAL INTRODUCTION

Climatic conditions during the harvesting period are often conducive to pre-harvest sprouting of cereal grains. Cool wet conditions during the fall can promote germination of the kernels in the spikes of standing and swathed grain. Severe losses in both quality and yield can occur in any year when climatic conditions in the fall are such that premature sprouting of the grain is induced (Belderok, 1968). In wheat, yield losses from 10% (Belderok, 1968) to as high as 30-50% (Stoy, 1982) have been estimated to have occurred due to sprouting damage.

The recent development of triticale (X Triticosecale Wittmack) as a cereal crop has stimulated interest in its use as a feed and food crop. In western Canada approximately 10,000 hectares are presently grown (Anonymous). Considerable losses can occur in triticale due to the relative susceptibility of this crop to premature sprouting. In order for triticale to gain general acceptance as a grain crop this problem must be overcome.

Much work has been done on pre-harvest sprouting resistance in wheat; few studies in this problem have been conducted on triticale. This study was initiated to fill that gap and was designed to (1) determine the amount of sprouting tolerance present in the triticale germplasm available at the University of Manitoba (2) determine optimum growth room and germination

temperatures for most accurate ranking of material and (3) demonstrate the transfer of sprouting tolerance from wheat into triticale.

An indication of the existing variability in sprouting tolerance of triticale germplasm now in use can be obtained by testing and the results can be made available for breeding programs for the further development of the species. The first paper of the present study reports a 'screening' procedure to determine the range in sprouting tolerances that exist in the 1981 triticale breeding material as well as in the accessioned triticale germplasm at the University of Manitoba.

Temperature during maturation (Hagemann and Ciha, 1981) affects the amount of dormancy present in cereals at maturity. The expression of this dormancy is affected by the temperature during germination (Saini, 1977). The second paper of this thesis reports sprouting tolerance scores derived from germination of seed at 17 C and 25 C and provides a comparison of these scores with those obtained in a rain simulator. The effects on sprouting of specific temperature regimes administered during the period between post-anthesis and harvest are also reported.

The third section of this thesis is devoted to a discussion of a study designed to transfer tolerance from RL4137, a sprouting tolerant hexaploid wheat, to both octaploid and hexaploid triticale derivatives. Since triticale is an amphiploid derived from wheat-rye hybridization, the most obvious source of genetic tolerance to pre-harvest sprouting for this species would

be from the use of tolerant strains of one or both parental species. For example, the hexaploid wheat line RL4137 contributed sprouting tolerance to the Hard Red Spring wheat cultivar 'Columbus' (Campbell and Czarnecki, 1981) currently recommended for all crop zones in Manitoba.

LITERATURE REVIEW

Losses due to Pre-Harvest Sprouting

Damage due to pre-harvest sprouting of cereal grain can be severe (Belderok, 1968; Stoy, 1983). The damage from premature germination in cereals, though generally restricted to the temperate areas of the world, is a problem whenever cool moist weather conditions prevail during harvest time.

Yield losses in sprouted grain occurs due to removal of the coleoptile and radicle while threshing (Derera, 1980). These yield losses have been estimated to range from 10% (Belderok, 1968) to 30-50% (Stoy, 1983) in years of exceptional damage. In addition to yield losses, the farmer is also faced with a reduced market price for sprouted grain. Sprouted wheat is not desirable for either bread making or for use as seed. Thus the grain can be sold only for feed at a reduced price (Belderok, 1968). It has been estimated that in Australia the annual loss to the farmer due to pre-harvest sprouting is \$18 million (Derera, 1980).

Methods of Scoring for Sprouting Tolerance

The scoring system used in germination studies is based on two values; germination percentage and time to germination. Many schemes have been suggested to combine the two into one unified

expression. Maguire (1962) for example, used germination rate which is the number of seeds germinated per day, ie.

$$\text{Germination rate} = \frac{\sum \text{number germinated}}{\text{days to count}}$$

The sprouting index used by Smith and Millet (1964) is a measure of the number of days until 50% of the seed have sprouted.

$$\text{Sprouting index} = \frac{\sum (\text{days} \times \text{number seed sprouted})}{\text{total number sprouted}}$$

Timson (1965) combined germination percentage with time to germination by calculating the percentage of germinated grains every 24 hours and summing all percentages over a specific number of days. Heydecker (1966), however, proposed that the time required for 25, 50, 75 and 100% germination to be achieved should be used. Germination resistance (GR), a formula to measure the mean germination time, was devised by Gordon (1971) and was expressed as follows:

$$\text{GR} = \frac{\frac{T_1}{2}(N_1) + \frac{T_2 + T_1}{2}(N_2 - N_1) + \dots + \frac{T_i + T_{i-1}}{2}(N_i - N_{i-1}) \text{ hours}}{N_i}$$

A number of germination indices were evaluated by Naylor (1981). He concluded that the best predictions were achieved by those that estimated mean germination time and especially those derived from a germination test.

Goodchild and Walker (1971) reviewed methods of comparing germination curves and concluded that the greatest amount of information could be obtained from a regression model describing

the shape of the germination curve. Mathematical models can be used to describe the germination curve. For wheat germination, a quadratic equation was used by Bould and Abrol (1981). The area under the germination curve can provide a simple and effective measurement to identify genotypic, maternal and environmental controls of seed dormancy (Richter and Switzer, 1982).

The Effect of Maturity on Sprouting Ability

The sprouting ability of a wheat kernel varies with stage of maturation (Wellington and Durham, 1958). Variation in the time to germination among seeds of the same spike may be related to the position of the seed on the spike, and also to the relative maturity of the individual kernels (Hardesty and Elliot, 1956; King and Chadim, 1983). Seeds from the apical floret germinated more rapidly than those from the basal and secondary florets. Seeds from spikelets near the centre of the spike germinated less rapidly than those from the apical or basal portion of the spike.

Triticale maturation rate, as indicated by moisture content and germination potential, resembles that of rye more than wheat (Agrawal, 1977). The weight of water/seed increased until 21-28 days post-anthesis in triticale after which it decreased more rapidly than in wheat. The maximum percentage germination occurred at 35-42 days post-anthesis with some as early as 28 days.

Some confusion exists in the literature as to the best time of sampling material for sprouting tests. A single sampling date if all samples are taken at the same stage of maturity gives

almost as accurate information as a number of sampling dates over a period of time (Weilenmann, 1976). The exact stage of maturity during sampling thus may be of little importance as long as either an extremely early or an extremely late developmental period is avoided (Weilenmann, 1976). In the screening for sprouting resistance of material in a breeding program, a 12-14% grain moisture could be used as a criterion for measuring harvest ripeness (McMaster and Derera, 1976). Pecka (1979) stated that for best results, spikes should be sampled at the end of the 'wax ripe' stage. Monitoring for harvest ripeness will remove confounding variability due to 'period since ripeness' or 'time to ripeness' (Gordon, 1983b).

Relationship of Grain Moisture and Premature Sprouting

A correlation exists between the ability of wheat grains to germinate and their level of moisture (Wellington, 1956). He concluded that the ability to germinate is determined by the length of time after anthesis as well as the amount of water loss that has occurred. Mitchell et al. (1980) found that the drying of a wheat grain induces germinability. A correlation was found between the degree of drying of the pericarp and the onset of germinability. Since the pericarp begins to dry earlier than the rest of the kernel, germinability under field conditions may be initiated before the kernel as a whole has lost its water. Uncertainty exists as to whether the enhancement of sprouting

susceptibility by slow drying results from the longer time period of drying or as a result of a direct effect of the drying rate itself (Gale et al. 1983).

In some grains of barley, wheat, rye, and triticale premature germination may occur as a result of mechanical defects of the seed coat (Gordon, 1970). Splitting of the pericarp occurs regularly while grain moisture is still in excess of 30%. Rupture of the pericarp-testa would allow germination even though a germination test of the intact grain may indicate dormancy is still present. Woodbury and Wiebe (1983) found evidence of cracks appearing in the brush region of the wheat kernel at maturity. They concluded that this was the site of rapid water uptake just prior to germination.

Correlations Between Some Agronomic Traits and Sprouting

The rates of water uptake into ears and grains of wheat are related to the sprouting resistance of the grain (Mares, 1983). Pool and Patterson (1958) concluded that the presence of awns increased the rate of drying in wheat. Clarke (1982), however, from a three-year study found no differences in drying rate of awned versus awnless wheat in either windrowed or standing crops. Faster water uptake and a higher incidence of sprouting was observed in kernels of awned wheat than in awnless lines (King and Chadim, 1983). They concluded that to reduce the problem of pre-harvest sprouting, wheat should be awnless.

Hong (1979) stated that in order to reduce sprouting in wheat, selection should be made for dormant seed, closed florets, low alpha-amylase, early maturity, lax spike, tenacious glume, heavy waxy bloom on spike, red seed coat, and absence of awns.

In a correlation of field sprouting in wheat with yield and test weight, Bhatt et al. (1981) found values of -0.64 and -0.95, respectively. Increased dormancy at maturity may affect germination and seedling vigor (Boyd et al., 1971). A decrease in seedling vigor can cause a reduction in yield (Demirlicakmak et al., 1963). Breeding for increased dormancy therefore, may result in yield reductions (Boyd et al., 1971).

Gordon (1983a & b) found no easily discernable pattern of association between sprouting reaction and either grain color or ripening period in 97 diverse lines of several Triticum spp.. He suggested that while selection for related attributes may be useful, it would be more valuable to screen lines directly on the basis of sprouting resistance.

Presence of Germination Inhibitors

Smith (1948) noted that kernels from threshed wheat spikes germinated more readily than did kernels in intact spikes. Water extracts of the chaff were inconsistently effective in inhibiting germination.

When water is a limiting factor in germination, the glumes may influence the extent of germination (Wellington and Durham, 1958). The glumes may also account for the variation in

germination between unthreshed and threshed grain. Wellington and Durham (1958) could not find a water soluble inhibitor in the glumes and concluded that the inhibition effect on germination was a physical property rather than one of a chemical nature.

Derera et al. (1976) tested a number of wheats in the presence and absence of milled husks. The husk of the variety Kleiber was found to induce a high degree of germination inhibition. Milled husk from the wheat lines RL4137, Park, Thatcher, and Kenya 321 sib resulted in a moderate germination inhibition, while that of Tordo, Timgalen, Gamut, and CT932 resulted in no inhibition.

Water extract from dormant wheat seed was found by Ching and Foote (1961) to inhibit germination of non-dormant seed. They concluded that pre-harvest dormancy in wheat was related to growth inhibitors which are gradually oxidized at or above room temperature, but only very slowly at low temperatures.

Woodbury and Wiebe (1983) found that seeds known to be dormant if germinated on petri plates showed little or no dormancy if germinated in sand with a minimum of water present. They concluded that in petri dish experiments, the rapid water movement under the pericarp transports inhibitors from the pericarp to the embryo. In another experiment in which seeds were placed either embryo or brush end down in sand, dormancy was found only in the latter group. This too, suggested the transportation of an inhibitor substance from the pericarp to the embryo.

Germination of sprouting resistant cultivars was inhibited by about 25% in experiments in which part of the pericarp was left attached to the embryo (Koch et al., 1982). No inhibition due to pericarp effect was noted in susceptible cultivars. This led to the conclusion that sprouting resistance was, at least in part, due to the inhibiting effect of the pericarp.

Genetics of Sprouting Resistance

Red seed coat color was the first genetic trait found to be related to sprouting resistance. Nilsson-Ehle (1914) suggested that the differences in germination capacity of wheat at harvest time was conditioned by hereditary factors, especially those which control red coloration in the testa. This was confirmed by many workers (Harrington, 1932; Hutchenson et al., 1948; Gfeller and Svejda, 1960). McEwan (1976) found no variability for resistance in white wheat and so concluded that in a program to increase sprouting resistance, wheat with a red seed coat should be used.

Gfeller and Svejda (1960) and Freed et al. (1976) concluded that the association between seed coat color and dormancy was due to either very close gene linkage or pleiotropic gene action. In a study of seed coat color, Baker (1981) reported that the three genes governing color act in an additive manner. McEwan (1980) confirmed the three gene model for seed coat color and found that offspring segregating for a single gene for seed color had as much sprouting resistance as their three-gene donor parent. He

noted that gene dosage did not account for the observed variation in sprouting resistance in red-grained wheats and explained it on the basis of an interaction of factors governing grain color and other undefined components of the genetic background.

An 8x8 diallel cross was used by Reitan (1980) to study the genetics of seed coat color and seed dormancy. Segregation patterns suggested the presence of five genes for seed color, with the segregates classifiable into three distinct colour groups. The same three groups were observed for levels of seed dormancy with a distinct relationship between white grain and low level of seed dormancy. Red-seeded wheat exhibited variable amounts of dormancy, unlike white-seeded wheat. Exclusion of white-grained parents from the diallel cross revealed a genetical system of dormancy more or less independent of seed coat color. This confirmed Harrington and Knowles' (1940) conclusion that dormancy itself may be an inherited character.

In a cross between RL4137 and 7722, a white seeded wheat, DePauw and McCaig (1983a and b) found that white-grained F3 segregates exhibited a range in sprouting capacity from fully susceptible to those that were as resistant as the red-seeded control cultivars, Pitic 62, Neepawa, and Glenlea. The percent dormancy of the white-seeded F5 families derived from F3 lines was greater than the mid-parent value with significant differences among the F5 families for their mean dormancy level. This suggested that RL4137 has two genetic mechanisms governing sprouting resistance, one associated with red seed-color, the other unassociated with seed-color.

In the F4 of a cross between Shortim, a non dormant white wheat, and Kenya 321 sib, a relatively dormant white wheat, sufficient variability existed for dormancy levels to establish the potential usefulness of Kenya 321 in a white wheat breeding program (Bhatt and Derera, 1980).

In the progeny from two of three crosses, dormancy in white seeded wheat was found to be controlled by two recessive genes (Bhatt et al., 1983). Modifier genes were suggested as an explanation for the poor fit among progeny of the third cross. A lack of transgressive segregants for dormancy was noted. Large populations with intense selection would be needed therefore in order to incorporate dormancy factors along with genes for other desirable traits into a single line.

Heritability for germination of wheat based on petri-plate germination studies was estimated to be 0.73 by Gfeller and Svejda (1960), while Gordon (1978) established a heritability value of 0.42. A heritability value for germination of wheat in a rain simulator was determined to be 0.92 (Gordon, 1980).

Noll et al. (1982) found that F1 seeds from crosses using RL4137 as the maternal parent were more tolerant to pre-harvest sprouting than seeds from the reciprocal cross. This led to the conclusion that the seed coat and/or endosperm influences dormancy. When RL4137 was the pollen parent, all F1 seeds were significantly more dormant than the non-dormant parent. The embryo component of seed dormancy appeared partially dominant, with the degree of dominance being influenced by the female parent.

The cultivars Kleiber, with a high degree of germination inhibitor in the chaff, and Gamut, lacking a germination inhibitor, were crossed to determine the potential value of glume-induced inhibition in a breeding program (Derera and Bhatt, 1980). In the progeny of the cross Gamut x Kleiber, 13% of both the F3 and F4 segregates were recovered with a high degree of inhibition. In the reciprocal cross, about 15% of F3 lines and 21% of F4 individuals showed a high degree of inhibition.

With the advent of dwarf lines, the effect of the dwarf trait on sprouting resistance has become of interest. Flintham and Gale (1980) examined F3 and F4 lines from a cross between the dwarf wheat, 'Tom Thumb' and two tall cultivars. They found that sprouted grain was reduced in the lines homozygous for the dwarfing gene Gai/Rht3. Mares et al. (1983) concluded that lines containing the gene Gai/Rht3 were resistant to premature sprouting under most conditions. The Norin 10 wheat dwarfing genes, however, did not appear to influence sprouting resistance.

Peroxidase and its Possible Involvement in Grain Sprouting

Peroxidase levels may be related to changes occurring in the kernel. Measurements of peroxidase levels of kernels at different stages of plant growth showed them rising to a peak at 10-20 days post-flowering in amber durum, or at 30 days in hexaploid wheat (Kruger and LaBerge, 1974; Ramantha et al., 1976). Ramantha et al. (1976) found the peroxidase activity curve over time to be very similar in shrivelled triticale to that found in wheat. The

former, however, exhibited a comparatively higher peak and a slower decrease in peroxidase levels with approaching kernel maturity. The peroxidase content of well-filled triticale and rye kernels remained constant to about 25 days post-flowering and then declined.

Gasper et al. (1977) in a study relating peroxidase and germination, found that in isolated embryos of wheat high germination was related to a low peroxidase level. This was not found in the intact grain. The hypothesis advanced was that a sufficiently low peroxidase activity and a minimum threshold auxin level of the embryo are necessary for the onset of germination. In a study comparing the wheat cultivar 'Columbus' with its dormant and non-dormant parents, RL4137 and Neepawa, respectively, Noll (1983) found that kernels of dormant lines had a higher peroxidase level than those of non-dormant lines.

Effect of Maturation Temperature on Sprouting Resistance

Whether or not a specific variety is prone to pre-harvest sprouting in the field depends on the level of dormancy at maturity, and on the weather conditions during the period of maturation and ripening (Greer and Hutchinson, 1945). High temperatures during the ripening period shorten the dormancy period in wheat (Belderok, 1968; Olsson and Mattsson, 1976; Lalluka, 1976). Hagemann and Ciha (1981) noted that while wheat grown at 30 °C lost its dormancy faster than that grown at 24 °C, it also had a higher level of dormancy initially. Grahl and Schroedter (1975) found that dormancy in wheat was related to air

temperature, duration of sunlight, and degree of moisture deficit. These weather factors were studied and ranked in the following order of decreasing influence: moisture deficit > temperature minimum > duration of sunshine > temperature maximum (Schroedter and Grabl, 1978).

Rainfall during the ripening period markedly increased sprouting in wheat while dry weather during this period decreased the germination potential of the grain (Bohac and Ondro, 1978).

Effect of Storage Temperature on Sprouting Resistance

Temperature during grain storage affects the degree of dormancy present at the end of the storage period (Ching and Foote, 1961). Dormancy is commonly broken in cereals by stratification, a low temperature pretreatment of imbibed seeds. Alternating temperatures are also well known as mechanisms for breaking dormancy (Taylorson and Hendricks, 1977). A complete loss of dormancy occurred during storage of wheat at a temperature of 18 °C or higher for a period of one month (Ching and Foote, 1961). At lower temperatures these workers found dormancy to persist over a longer period. For example, wheat stored at 3 °C still retained some dormancy after one month. Noll and Czarnecki (1980) found that grain stored at -15 °C for 4-5 months after harvest, retained a dormancy similar to that at harvest time. In a similar study Mares (1983) noted that wheat, if stored at -15 °C with a moisture content of 12% or less, had a constant germination rate over the period of storage.

Effect of Germination Temperature on Sprouting Resistance

It has been known for some time that the rate of germination of wheat is temperature dependent. Hutchinson et al. (1948) found that differentiation of sprouting resistance was more marked at 23 C than at 15 C. This was verified by George (1967) who reported that the level of dormancy of wheat varieties tested was similar at 10 C, while at 20 C the dormancy period varied from 20-60 days depending on the variety. At 30 C all varieties had a deep persistent dormancy with only three cultivars losing their dormancy after one year.

In triticale it has been found that the percentage germination was highest at 22 C, intermediate at 32 C, and lowest at 15 C (Saini, 1977). Gosling et al. (1981) observed that premature wheat seeds germinate best at temperatures lower than 10 C.

SECTION I

Screening of University of Manitoba Triticale
(X Triticosecale Wittmack) Breeding and
Accession Material for Sprouting Tolerance

ABSTRACT

One hundred and fifteen lines from the University of Manitoba triticales breeding program were evaluated for sprouting tolerance in the winter of 1982. Rain simulator scoring showed a wide variability in tolerance ranging from very poor, to several lines which were as good as the check wheat, Triticum aestivum cv. 'Glenlea'. In the summer of 1982, 18 lines with scores ranging from 98.45% to 2.14% were further tested. Rankings for tolerance generally remained the same as found in the initial screening. Segregation for sprouting tolerance was found to occur in some lines. Correlations between yield and tolerance score were low but positive, while those between peroxidase content and score were uniformly low. In the summer of 1983, a screening of 98 triticales from the accession list revealed a wide range of tolerance scores. The accessions 6A-187 (T. turgidum / Ae. elongatum) and 6A-62 (T. timopheevi / T. persicum // T. sphaerococcum) showed higher sprouting tolerance scores than RL4137, the most tolerant hexaploid wheat known to-date, while 6A-64 (T. dicoccum / S. cereale) had a score about equal to that of RL4137.

INTRODUCTION

Climatic conditions prevalent during the harvesting period of cereal crops in Canada, northern U.S.A. and parts of Europe are conducive to losses due to pre-harvest sprouting of the grain. Wet conditions during the fall can promote the germination of kernels in the spikes of standing crop and/or in grain in the swathed condition. Wheat (Triticum aestivum L. Em. Thell.) and rye (Secale cereale L.) are two crop species that are particularly susceptible to sprouting damage and according to MacKey (1976), Derera (1980) and Stoy (1983), severe losses in both grain quality and yield can occur in any year when climatic conditions in the fall are conducive to premature sprouting of the grain. As a result, the milling and baking quality of our Hard Red Spring wheats can be heavily degraded by induced sprouting, resulting in serious loss of both export and domestic markets.

A large number of our past and present-day wheat cultivars are susceptible to sprouting at the time of harvest. Only recently has progress been made in the development of strains of wheat that possess some degree of tolerance, primarily the result of the initiation of a "screening" program for the evaluation of wheat germplasm as parental material in wheat breeding programs. Today, two Hard Red Spring wheat cultivars available in Canada,

'Leader' and 'Columbus', possess a high level of resistance to pre- and post-harvest sprouting (Campbell and Czarnecki, 1981; DePauw et al., 1982).

The rapid development in recent years of triticale (X Triticosecale Wittmack) as a cereal crop has stimulated interest in its use as a feed and food crop. In western Canada, approximately 10,000 hectares are currently grown for use in the manufacture of bread and bread products (Anonymous). In terms of its tolerance to pre-harvest sprouting, triticale ranks intermediate to its parental species, wheat and rye. Considerable loss in quality can occur in any year, therefore, due to the relative susceptibility of this crop to premature sprouting. As a result, triticale workers have turned their attention to determining the extent to which sprouting tolerant germplasm exists within this new crop species.

The present study was designed to 'screen' both the triticale breeding material and the accessioned germplasm at the University of Manitoba in order to determine the amount of variability in sprouting tolerance existing in this material. In this way, those lines with a sufficiently high level of tolerance could be used as parental stock. This study also investigated yield components in order to determine if selection for yield and sprouting resistance are mutually feasible.

MATERIALS AND METHODS

1. Growth chamber testing of breeding material

Material tested for sprouting tolerance in the winter of 1982 included 115 lines of triticale (X Triticosecale Wittmack) from the 1981 University of Manitoba triticale breeding program. Three wheats (Triticum aestivum L. Em. Thell.) were used as checks: RL4137, a sprout resistant line; Pitic 62, a relatively susceptible cultivar; and Glenlea, a cultivar intermediate to RL4137 and Pitic.

All material was sown under growth chamber conditions using a 16 h photoperiod and an initial day/night temperature of 15/12 °C. A maximum of six seeds per line were sown in three, two-litre milk cartons. The arrangement of cartons was re-randomized every third week to minimize possible variability of temperature and light intensity within the chamber.

Two weeks after seedling emergence, the temperature within the chamber was raised to a day/night temperature regime of 23/15 °C. This temperature relationship was maintained until two weeks post-anthesis at which time a 25/20 °C temperature regime was retained until maturity.

A tag was placed on each spike indicating its date of anthesis and all plants were harvested 30 days post-anthesis. Harvested spikes were stored at -17.0±1.5 °C until analyses could be conducted.

Testing for sprouting tolerance was done in a rain simulator similar to that described by McMaster and Derera (1976). Rainfall was simulated for two hours with the equivalent accumulation of 50mm of moisture. This treatment was followed by seven days at 100% relative humidity (RH) at a temperature of $17 \pm 1^{\circ}$ C. The number of kernels germinated per spike was recorded daily starting on the fourth day. Germination was considered to have occurred when the coleoptile had extended beyond the lemma and palea. After the final count on the seventh day, spikes were removed from the rain simulator and air-dried. The spikes were hand-threshed and the number of kernels per spike was recorded. Using the percent of non-germinated kernels recorded on a daily basis, a linear regression line was calculated for each spike and an estimate of the percent non-germinated seed was derived for the seventh day. This value used as the score for any particular head reflected the rate as well as the level of germination. The sprouting tolerance score for any particular progeny line was the average score of all spikes of that line.

The sprouting tolerance score is an estimate of the percent non germinated kernels on the seventh day of a germination test. Thus a high score represents a more tolerant line than a lower score. Sprouting tolerance scores may be negative. This is due to the fact that the score is an estimate derived using linear regression. A negative score may occur when most of the kernels germinate early during the testing period giving rise to a score that is lower than the actual percent non germinated kernels on

the seventh day. Conversely a score higher than the actual percent non germinated will occur if most of the germination occurs on the seventh day.

2. Field testing of breeding material

A similar screening procedure was used on the 1982 field-grown material which was grown at the two locations in Manitoba, Glenlea and Portage la Prairie. A total of 18 lines was tested which represented repeats from the 1981 testing program. Yield plots were sown at Glenlea on May 12, and at Portage on May 14 and were arranged in a two replicate, randomized complete block design at each location. Plots were 3.96m long, 1m wide with a distance of 0.3m between plots. Climatic conditions during the period of maturation were recorded.

Just prior to harvest, five spikes were collected at random from each plot at Glenlea for peroxidase analysis and five for rain simulation, and five at Portage for rain simulation. All material was stored at $-17.0 \pm 1.5^{\circ}$ C awaiting analyses. For yield determination plots were mechanically harvested by small-plot combine.

Five spikes of each plot were subjected to rain simulation conditions whereby they were maintained at 100% RH for seven days at $16.5 \pm 1.0^{\circ}$ C. Germinated seed counts were begun on the third day and scoring was done in a similar manner to that described above for material grown in the growth chamber. At the same time, total kernel number per spike was recorded, as well as spike length, awn length, and the spikelet number per spike. Correlations were calculated comparing sprouting score with yield, number of

kernels per spike, awn length, spike length, numbers of spikelets per spike, spikelets per centimeter, kernels per centimeter, and kernels per spikelet.

Statistical analysis included the derivation of ANOVA'S for each location, and tests of significance conducted on differences of sprouting tolerances both among lines and among selections within lines. Furthermore, overall ANOVA'S were computed to compare rankings of lines scored for sprouting tolerance in each of the two years, 1981-1982.

Peroxidase levels in the grain of all lines sampled from the Glenlea location were assayed using seed from five spikes per plot sampled specifically for this purpose. Two extracts from each plot sample were prepared for the assay by grinding ten seeds (two seeds from each of the five spikes) with a mortar and pestle. Grinding was followed by extraction with 10 ml of 10% sucrose solution. After a 30 minute extraction period, samples were centrifuged (10,000xg, for 10 min) and filtered. The filtered supernatants were assayed for peroxidase activity.

Peroxidase activity was assayed according to the method described in the Worthington Enzyme Manual (Anonymous, 1972). One unit of peroxidase activity was defined as the amount of enzyme that consumes 1 u mole of hydrogen peroxide per minute at 25 C. Correlations were conducted between peroxidase activity and sprouting scores for all triticales lines analyzed.

3. Testing of accessioned triticales lines

Tests for sprouting tolerance in accessioned material included 85 hexaploid triticales of diverse origin and 24

triticales in which the ploidy level was not known. Eleven lines tested the previous year were included as checks. These were seeded May 2, 1983 at the University of Manitoba in single row plots. Each plot was 2.44m long with plots 0.3m apart. Plots were arranged in a completely randomized design. Anthesis occurred during the last week of June and the first week in July. Climatic conditions during the period prior to harvest were recorded.

Early maturing lines were harvested on August 12 and the late maturing lines on August 19. Ten spikes were picked at random from each line and immediately placed in a rain simulator. Rain simulation procedure and scoring were done in a manner similar to that used for the screening of material from the breeding program and lines were ranked in descending order of their sprouting tolerance.

RESULTS AND DISCUSSION

1. Growth chamber testing of breeding material

The scores obtained from testing of the experimental lines from the 1981 University of Manitoba triticale breeding program ranged from 100% non-sprouted grains for the line RL4137 to 1.6% non-sprouted kernels for YA81-26 (Alleycat/Beagle) (Appendix 1). Five triticale lines were found with a higher score than the wheat cv. Glenlea which rated a score of 94.42% (Table 1).

Table 1: Pedigree and score of lines with a higher sprouting tolerance score than Glenlea.

| Line | Pedigree | Score |
|---------|---------------------------|-------------------------|
| YF81-6 | 6TA204/PPV13//YOREME | 98.45 _± 2.72 |
| BC81-26 | M2A/ARM"S"//BEAGLE | 97.96 _± 3.61 |
| 101-134 | PANTHER"S"/Octo Bulk BUSH | 95.81 _± 6.34 |
| YH81-13 | 6TA204/PPV13//WELSH | 95.45 _± 6.43 |
| YJ81-25 | FS3972-10M-ON//6TA204/BCO | 95.00 _± 6.43 |

The commercial triticale cultivar Carman rated a score of 69.66%. A total of 35 lines of triticale had a score higher than Carman, while the other 79 lines had a score lower than Carman.

Three of the five lines with the highest score had '6TA204' in their parentage and two of these had 'PPV13'. However, when the parentage of lines with low scores were examined, the same or

similar pedigrees were found. For example:

YG81-10 (6TA204/PPV13//CIN/3/72UM2006) had a score of 27.86%

YB81-24 (6TA204/PPV13//FS1897) had a score of 35.62%

Therefore, '6TA204' and 'PPV13' can be found in both high and low scoring lines.

Variability for sprouting tolerance exists in the University of Manitoba triticale breeding material used in this study. Chojnacki et al. (1976) found a wide range of variability in sprouting resistance in triticale. Similarly in the present study lines were found equal to or higher in score than Glenlea wheat, with the majority ranking lower than the check cultivar. Selection within triticale populations for improved sprouting tolerance score therefore should prove valuable.

2. Field testing of breeding material

Climatic conditions during the period of maturation were recorded as shown in Table 2.

Table 2: Temperature and rainfall data from Glenlea and Portage for the months of July and August, 1982

| <u>Glenlea:</u> | Temperature (°C) | | Rainfall (mm) | |
|-----------------|------------------|--------|---------------|--------|
| | July | August | July | August |
| Maximum | 25.9 | 23.6 | 82.6 | 30.5 |
| Minimum | 13.0 | 9.6 | | |
| Average | 19.5 | 16.6 | | |
| <u>Portage:</u> | | | | |
| Maximum | 25.6 | 23.0 | 183.6 | 46.5 |
| Minimum | 13.7 | 10.4 | | |
| Average | 19.7 | 16.7 | | |

Average overall scores obtained during the summer of 1982 were higher for field grown material than for material tested in the growth chamber (Table 3). The average field score rose due to environmental influence. In general, however, rankings remained the same. Four lines deviated quite markedly depending upon where they were grown; YJ81-25 (FS3972-10M-ON//6TA204/BCO), which had a score of 95.00% in the growth chamber, scored an average of 66.77% in the field. In contrast, CP81-7 scored 21.70% in the growth chamber and averaged 82.12% in the field. The highest scores obtained in the field were 91.78% and 90.42% for lines YJ81-3 (6TA204#83 / KOALA3) and BB81-2 (BGL / M2A // CINNAMON), respectively, while in the growth chamber these same two lines rated 57.34% and 59.90%, respectively.

Within-line segregation was noted in some of the lines studied. Lines BC81-26 and YM81-4 (Table 4) exhibited significant differences among selections at both locations (Glenlea and Portage). Lines CB81-8 and YJ81-8 showed significant differences among selections at Glenlea only, while YF81-6 had significant selection differences only at Portage. No significant differences for sprouting tolerance were found in either location for selections within the lines YJ81-25, YK81-10, YJ81-6, BB81-2, YM81-14, and YG81-10 (Appendix 2). In all lines with significant differences, the highest and/or lowest scoring selections were common at both locations. This relationship held only for lines that had significant differences among selections at one or both

Table 3: Comparisons of pre-harvest sprouting tolerance scores, 1982

| Line | Growth Chamber | Field | | |
|---------|----------------|-------------|-------------|-------------|
| | | Glenlea | Portage | Average |
| YF81-6 | 98.45+ 2.72 | 85.79+10.61 | 88.09+ 7.64 | 86.94+ 8.60 |
| BC81-26 | 97.45+ 3.61 | 82.84+17.37 | 91.42+10.53 | 87.13+11.40 |
| YJ81-25 | 95.00+ 4.89 | 57.29+19.69 | 76.25+15.26 | 66.77+16.91 |
| GLENLEA | 94.42+ 6.83 | 90.80+ 6.73 | 90.38+ 7.43 | 90.59+ 6.48 |
| YM81-4 | 94.30+ 7.64 | 75.18+17.46 | 90.38+16.49 | 82.78+16.08 |
| YK81-10 | 87.27+11.58 | 87.47+14.07 | 85.42+13.41 | 86.45+13.37 |
| YH81-7 | 69.60+16.82 | 60.88+16.51 | 66.41+16.66 | 63.64+16.83 |
| CARMAN | 69.56+44.72 | 76.91+10.76 | 80.57+13.57 | 78.74+12.76 |
| CB81-8 | 60.69+24.09 | 50.24+28.54 | 56.00+26.87 | 53.12+25.26 |
| BB81-2 | 59.90+23.14 | 89.66+10.75 | 91.18+10.53 | 90.42+11.24 |
| YJ81-4 | 57.64+28.23 | 57.88+18.90 | 60.90+25.95 | 59.39+19.40 |
| YJ81-3 | 57.34+22.06 | 100.00+ 0.0 | 83.57+16.88 | 91.78+12.66 |
| YJ81-6 | 55.67+ 8.01 | 54.90+22.00 | 58.81+27.18 | 56.70+25.64 |
| YM81-14 | 48.06+34.30 | 57.47+18.06 | 73.87+19.26 | 65.67+18.61 |
| YG81-10 | 27.86+14.66 | -5.56+20.21 | 17.23+36.88 | 5.83+30.24 |
| CP81-7 | 21.70+62.11 | 82.75+19.72 | 81.75+10.85 | 82.12+16.26 |
| YJ81-8 | 10.64+17.54 | 40.97+31.19 | 43.31+28.01 | 42.14+25.42 |
| YB81-4 | 2.14+35.69 | 17.18+12.23 | 41.69+31.71 | 29.53+23.30 |
| AVERAGE | 61.54 | 64.59 | 70.96 | 67.76 |

Table 4: Pre-harvest sprouting scores between selections within triticale lines BC81-26 and YM81-4

| Line | Selection | Glenlea | | Portage | | Average | | | | |
|---------|-----------|---------|--------|---------|-------|---------|-----|-------|--------|----|
| BC81-26 | CD82-100 | 90.88 | +12.91 | a1 | 98.77 | + 3.32 | a2 | 94.83 | +10.03 | a |
| BC81-26 | CD82-45 | 94.88 | + 7.48 | a | 98.29 | + 1.73 | a | 96.42 | + 5.62 | a |
| BC81-26 | CD82-9 | 95.39 | + 8.47 | a | 98.21 | + 2.06 | a | 96.80 | + 6.17 | a |
| BC81-26 | CD82-30 | 87.83 | +12.46 | a | 95.06 | + 7.21 | ab | 91.44 | +10.58 | a |
| BC81-26 | CD82-40 | 94.55 | + 3.36 | a | 93.06 | + 5.47 | abc | 93.81 | + 4.48 | a |
| BC81-26 | CD82-103 | 70.16 | +22.00 | b | 88.03 | + 9.57 | bcd | 79.10 | +18.88 | b |
| BC81-26 | CD82-95 | 68.61 | +20.60 | b | 85.83 | +14.69 | bcd | 77.22 | +19.53 | b |
| BC81-26 | CD82-87 | 72.10 | +13.65 | b | 84.21 | +10.68 | cd | 78.15 | +13.44 | b |
| BC81-26 | CD82-84 | 71.45 | +13.11 | b | 81.33 | +12.23 | d | 76.39 | +13.78 | b |
| YM81-4 | BD82-55 | 77.91 | +15.19 | ab | 97.16 | + 3.56 | a | 87.53 | +14.59 | a |
| YM81-4 | BD82-10 | 84.58 | +10.08 | a | 94.26 | + 7.42 | a | 89.42 | + 9.94 | a |
| YM81-4 | BE82-21 | 61.48 | +21.37 | b | 87.58 | +19.13 | ab | 74.53 | +23.85 | b |
| YM81-4 | BD82-40 | 76.76 | +14.64 | ab | 82.54 | +24.48 | b | 79.65 | +19.86 | ab |

1. Scores followed by the same letter are not significantly different

2. Separate Duncan's Multiple Range Values were calculated for each line at each location

locations. This agrees well with Nedel and Baier (1982) who reported segregation for sprouting resistance in triticale lines otherwise considered uniform.

Simple correlations of yield and yield parameters to sprouting tolerance scores were calculated (Table 5). No high r values from simple correlations between various plant characters and sprouting tolerance scores were found; however, due to the large sample sizes many of the correlations were significant. Both spike length and number of spikelets per spike were significantly and positively correlated with sprouting tolerance. These correlations explained 5.2% and 7.6% of the variation in sprouting tolerance scores, respectively.

Kernel number per spike was closely correlated with sprouting tolerance score at the Glenlea location but not at the Portage site. Spikelets per cm of spike and grain yield had low positive correlations with sprouting tolerance scores at Glenlea only. No significant correlation between kernels per cm of spike and sprouting tolerance score was found. Yield and yield components were generally positively correlated with tolerance scores, while awn length, the only non yield parameter measured, was negatively correlated.

Although correlations of yield and yield parameters to sprouting tolerance score were not high, the trends were such that selection for yield should not interfere with selection for sprouting tolerance. Similar trends in wheat were reported by Bhatt et al. (1981).

Table 5: Correlations between pre-harvest sprouting tolerance scores and certain plant characteristics

| Location | Kernels/spike | Awn length (cm) | Spike length (cm) | No. Spikelets per Spike |
|----------|--------------------|-----------------|-------------------|-------------------------|
| Glenlea | .1891 .0001***2 | -.014 .737 | .220 .0001*** | .315 .0001*** |
| Portage | .057 .181 | -.105 .013** | .193 .0001*** | .204 .0001*** |
| Overall | .147 .0001*** | -.058 .054* | .227 .0001*** | .275 .0001*** |

| | Spikelets per cm | Kernels per cm | Kernels per Spikelet | Yield |
|---------|------------------|----------------|----------------------|----------------|
| Glenlea | .096 .023** | .069 .104 | .003 .942 | .198 .037** |
| Portage | .023 .592 | -.058 .169 | -.095 .025** | .049 .605 |
| Overall | .055 .064* | .019 .517 | -.027 .371 | .110 .101 |

1-first number is r value second is P>R

2- *, **, *** significance at 1, 5, 10% respectively

Multiple Range Test rankings of lines for sprouting tolerance score and peroxidase levels revealed no obvious relationship (Table 6). This was confirmed by the finding of a non significant correlation between these two parameters with a r value of 0.086. Correlations of tolerance scores and peroxidase levels within most lines were found to be non-significant. A significant positive relationship between peroxidase level and sprouting tolerance score was detected only in one line, YF81-6. This, however, was probably due to chance alone. These results indicate that it would be of little value to use peroxidase levels as a criterion in the appraisal of resistance to pre-harvest sprouting. In wheat Noll (1983) found a correlation between peroxidase levels and dormancy. This does not appear to be the case in triticales tested.

3. Testing of accessioned triticales lines

Climatic conditions during the period prior to harvest are shown in Table 7.

Testing of the accessioned triticales revealed lines with tolerance scores equal to that of RL4137's score of 97.85%. Scores ranged from 98.93% to -11.99% (Appendix 3). Most of the lines with scores higher than 90.00% contained Aegilops sp. or other wild relatives of wheat in their pedigrees.

Table 6: Comparison of pre-harvest sprouting tolerance score and peroxidase levels

| 1 Line | Score | | 2 Peroxidase | |
|-----------|-------------|-----|-----------------|-------|
| YJ81-3 | 100.00+ 0.0 | a3 | 1.98+0.15 | j |
| GLENLEA | 93.69+ 4.81 | ab | 2.79+0.10 | ghi |
| BB81-2 | 91.12+ 8.33 | ab | 3.07+0.58 | efghi |
| YK81-10 | 86.14+12.85 | abc | 2.81+0.48 | ghi |
| YF81-6 | 81.43+11.85 | bc | 3.29+0.69 | efg |
| BC81-26 | 78.66+19.66 | bc | 4.41+1.16 | bc |
| YM81-4 | 77.05+18.45 | bcd | 4.35+1.28 | bc |
| CARMAN | 76.90+10.77 | bcd | 5.96+0.76 | a |
| COOP81-7 | 72.09+20.79 | cde | 3.89+0.23 | cd |
| YJ81-4 | 61.29+14.72 | def | 3.14+0.17 | efgh |
| YH81-7 | 58.64+13.77 | ef | 3.55+2.52 | de |
| YM81-14 | 58.10+20.29 | ef | 2.89+0.39 | fghi |
| YJ81-25 | 57.11+22.97 | ef | 4.67+1.47 | b |
| YJ81-6 | 51.09+21.06 | fg | 2.60+0.72 | hi |
| CB81-8 | 45.26+30.49 | fg | 2.37+0.97 | ij |
| YJ81-8 | 36.36+35.01 | g | 3.09+0.69 | efgh |
| YB81-4 | 14.91+13.17 | h | 2.86+0.18 | ghi |
| YG81-10 | 2.90+15.60 | h | 3.50+1.18 | def |

1-Replicate one only of Glenlea 1982

2-peroxidase expressed in units per kernel

3-scores with same letters are not significantly different

Overall correlation of score to peroxidase

$r=0.086$ $\text{prob}>r=.202$ ns

Table 7: Temperature data for the months of
July and August, 1983

| | July | August |
|---------|------|--------|
| maximum | 28.1 | 29.7 |
| minimum | 16.3 | 15.2 |
| average | 22.2 | 22.5 |

Lines with high sprouting tolerance were found in the University of Manitoba accessions. Several lines with a durum x rye pedigree, for example 6A-190 (STEWART / PROLIFIC) and 6A-618 (JNK-6T-192), with scores of 95.89% and 94.05% respectively, were almost equal to that of RL4137, the most tolerant of all wheat lines studied to date. These could readily be employed in a breeding program. The more distantly related 6A-187 (T. turgidum / Ae. elongatum) and 6A-62 (T. timopheevi / T. persicum // T. sphaerococcum) with scores of 98.93% and 98.92% respectively, exhibited resistance equal to that of RL4137 with a score of 97.85%. Because of their more distant genetic relationship with wheat (T. aestivum), 6A-187 and 6A-62 may be more difficult to incorporate into a breeding program. Larger populations with more rigorous selection would be needed to obtain the desired plant types if these lines were used.

The apparent tolerant reaction of Aegilops-based accessions deserves further comment. Some of the sprouting tolerance in the Aegilops lines may not be a characteristic of the seed, but rather an influence exerted by the glumes. This hard waxy glume makes threshing of the grain very difficult. These lines have a

very hard waxy glume which slows water movement into the seed, thus decreasing germination rate. The high sprouting tolerance noted in these lines, therefore, may not be a useful resistance for incorporation into a commercial variety of triticale.

With three exceptions, all material analyzed from the 1983 populations exhibited a decrease in sprouting tolerance relative to those analyzed the previous year (Table 8). The overall average tolerance score decreased from 83.3% in 1982 to 69.3% in 1983. The exceptions, lines BD-37 (6TA204 / PPV13 // YRE) and CD-84 (M2A / ARM"S // BGL), had constant scores, while CB-5 (6TA204 // BCO /3/ BUR / TOBI) exhibited a score increase from 42.31% in 1982 to 73.07% in 1983.

Lalluka (1976) reported that in wheat high temperatures in the period just prior to ripening shortened the dormancy period. The lower tolerance scores in 1983 relative to those obtained in the summer of 1982 may be due to the hot dry weather during the pre-harvest period in 1983. A similar relationship between lower scores and higher temperatures was noted between the growth chamber and field testing of the breeding material. In the growth chamber, the score was an average of 61.54% as compared to 70.96% in the field. Temperatures just prior to maturity were 25/20 °C in the growth chamber and an average of 16.7 °C in the field (Table 2). This agrees with Saini (1977) who found that germination rate of triticale increased as the temperature during the maturation period increased.

Table 8: Comparison of 1982 and 1983 pre-harvest sprouting tolerance scores

| Line | 1982 | 1983 |
|---------|--------------------------|--------------------------|
| CD-45 | 96.42 ₊ 5.62 | 84.72 ₊ 16.89 |
| CB-9 | 92.65 ₊ 10.58 | 79.62 ₊ 26.57 |
| BA-14 | 91.78 ₊ 14.35 | 67.76 ₊ 16.23 |
| GLENLEA | 90.59 ₊ 6.90 | 58.39 ₊ 20.92 |
| BD-31 | 89.98 ₊ 9.31 | 77.10 ₊ 21.76 |
| BA-78 | 89.98 ₊ 11.55 | 66.37 ₊ 22.00 |
| BD-55 | 87.53 ₊ 14.59 | 54.04 ₊ 11.89 |
| BD-37 | 83.07 ₊ 13.14 | 87.11 ₊ 7.72 |
| BD-40 | 79.65 ₊ 19.86 | 51.43 ₊ 13.66 |
| CARMAN | 78.74 ₊ 12.07 | 55.61 ₊ 26.78 |
| CD-84 | 76.39 ₊ 13.78 | 75.80 ₊ 13.74 |
| CB-5 | 42.31 ₊ 28.01 | 73.07 ₊ 19.21 |
| AVERAGE | 83.26 | 69.25 |

The two test sites, Glenlea and Portage recorded similar average temperatures in 1982, consequently, something other than temperature must be involved in creating differences in sprouting tolerance scores noted between these two stations.

Wellington (1956) reported that in wheat, germination ability was related to the amount of water present in the seed. Bohac and Ondro (1978) found that rainfall during the ripening period increased the level of pre-harvest sprouting in wheat. Mitchell et al. concluded that the amount and rate of drying prior to maturity was related to sprouting resistance. Rainfall levels at Glenlea and Portage differed both in July and in August, 1982 (Table 2). This rainfall difference could explain why the average tolerance scores of material grown at these stations were dissimilar.

A problem encountered during testing of the University of Manitoba triticale breeding material was the limited number of spikes produced per line. The large difference in sprouting tolerance scores of CP81-7 from the growth chamber compared to those from the 1982 field (Table 3) was probably due to the small sample size in the growth chamber. Of the six seeds sown in the growth chamber only two spikes developed. These had sprouting scores of -22.22% and 65.63% for an average score of 21.70% with a standard deviation of 62.11%. With this magnitude of variability, scoring with any degree of reliability was impossible. The scores from the 1982 summer analyses suggest that a more accurate score for CP81-7 in the growth chamber should have been approximately 65% rather than 21%.

Standard deviations were large throughout this study. One of the tasks facing future research in this area must be to reduce the error levels. Relative ranking of sprouting tolerance scores appeared to be stable from one period of testing to the next. Significant differences noted between selections in the summer of 1982 were still present in 1983. Thus in spite of the magnitude of the standard deviations, useful sprouting tolerance scores could still be obtained.

SECTION II

Sampling Times and Temperature Effects
on Pre-harvest Sprouting Tolerance in
Triticale (X Triticosecale Wittmack)

ABSTRACT

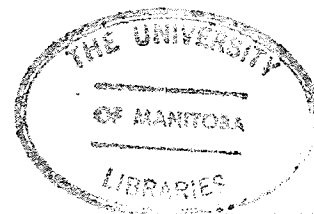
The effects of sampling times during maturation on pre-harvest sprouting tolerance were studied on the triticale lines, CD82-45 (M2A/ARM"S"//Beagle), Carman, and CB82-5 (6TA204//BC0/3/BVR/TOBI) from the University of Manitoba breeding program. The wheat (Triticum aestivum L. Em. Thell.) cv., 'Glenlea' was used as a control. Sprouting tolerance decreased in all lines with time after maturity. Relative rankings between the lines remained constant in samples taken from just before to just after maturity. Sprouting tolerance scores obtained from petri-dish germination at 17 C most closely resembled rain simulator scoring in magnitude. Maturation-germination temperature interactions were further studied using CB82-9 (Bgl/M2A//Cinnamon), Carman, CB82-5, and RL4137. All interactions were found to be significant. The widest range of scores were found at daytime maturation temperatures of 20 C and a germination scoring temperature of 25 C. The most conclusive results were obtained using the two germination temperatures, 17 C and 25 C.

INTRODUCTION

Germination temperatures and sampling times influence the expression of dormancy in wheat and triticale (Hutchinson et al., 1948; Saini, 1977; Gordon, 1983b). The optimum time of sampling for the evaluation of pre-harvest sprouting tolerance varies according to the objectives of the study. For plant breeding purposes, sampling should be done at harvest ripeness (McMaster and Derera, 1976). Pecka (1979) claims the most accurate sprouting tolerance scores are obtained if sampling is done at the end of the 'wax ripe' stage. The conclusion reached by Wielenman (1976) was that time of sampling is not critical for accurate results as long as it is neither very early nor very late during the ripening period.

Wheat (Triticum aestivum L. Em. Thell.) has a shorter dormancy period if grown at temperatures of 24 C or higher compared to lower temperatures (Belderok, 1968; Olsson and Mattsson, 1976; Lalluka, 1976; Hagemann and Ciha, 1981).

Germination temperatures have an influence on the expression of dormancy in wheat, with an increased level of dormancy being expressed at higher temperatures (Hutchinson et al., 1948; George, 1967). Saini (1977) found that in triticale the period of time required to germinate was higher at either 22 C or 32 C than at 15 C.



The present study was designed to study maturity and temperature effects on pre-harvest sprouting tolerance. The effects of temperature differences during maturation and germination were investigated to determine the optimal temperatures for use in testing for sprouting tolerance.

MATERIALS AND METHODS

1. Kernel Development in Relation to Sprouting Tolerance

This phase of the study was conducted using wheat (T. aestivum L. Em. Thell.) cv. Glenlea and three triticale (Triticosecale Wittmack) lines germinated in both petri dishes and in the rain simulator. The triticale lines included experimental entries CD82-45 (M2A/ARM"S"//Beagle), CB82-5 (6TA204//BCO/3/BVR/TOBI) and the commercial cv. 'Carman'. From each line, 170 seeds were sown in 85 two-litre milk cartons and grown under greenhouse conditions in the spring of 1983. At anthesis, a tag was placed on each spike indicating the date of initiation of pollen dissemination. Starting two weeks post-anthesis, 15 spikes per line per week were harvested for germination tests in petri dishes.

For germination studies, the primary and secondary kernels of each spikelet were sampled from each spike. Two layers of paper towelling were placed in the bottom of each germination dish and 25 kernels were placed crease down in each dish. Ten ml of distilled water was added to each. Five dishes were placed in a germination cabinet operating at 17 C while another five were tested in a second cabinet at 25 C. The percent of ungerminated kernels was recorded daily from the third through to the seventh day.

A linear regression for germination in each dish was obtained from the daily readings and was used to estimate the percent non-germinated kernels on the seventh day. This value used as the score for any particular dish reflected the rate as well as the level of germination. The estimate obtained for each sample was recorded as the sprouting tolerance score for each. The average score for the five samples within a line was used as the sprouting tolerance evaluation at each of the two temperature regimes.

The sprouting tolerance score is an estimate of the percent non germinated kernels on the seventh day of the germination test. Thus a high score represents a more tolerant line than a lower score. Sprouting tolerance scores may be negative. This is due to the fact that the score is an estimate derived using linear regresssion. A negative score may occur when most of the kernels germinate early during the testing period giving rise to a score that is lower than the actual percent non germinated kernels on the seventh day. Conversely a score higher than the actual percent non germinated will occur if most of the germination occurs on the seventh day.

Starting at the fourth week post-anthesis, an additional ten spikes were harvested each week from each line and were stored at $-17.0 \pm 1.5^{\circ} \text{C}$ until the final date of sampling. Sampling was terminated in the seventh week for Glenlea and Carman and in the eighth week for CD82-45 and CB82-5. For germination studies, the frozen spikes were arranged in the rain simulator and given two hours of simulated rain for the equivalent of 50 mm of

precipitation. They were then maintained at 100% relative humidity and 15.5 ± 0.5 °C for seven days. The number of germinated seeds per head was recorded daily commencing on the third day. Germination was considered to have occurred when the coleoptile was extruding beyond the lemma and palea. After each daily reading, simulated rain was applied for ten minutes to compensate for the drying that occurred during the recording period. Using the daily percent of non-germinated kernels, a sprouting tolerance score was calculated as for the petri dish tests.

2. Comparison of Germination Patterns

The lines RL4137, Carman, CB82-9 (Bgl/M2A//Cinnamon), and CB82-5 were used to measure the effect of temperature during maturation on germinability. The plants were grown in a growth room with 16 h daylength and day/night temperatures of 20/15 °C until one week post-anthesis. At that time, one third of the plants of each line were transferred to a growth chamber with a day/night temperature regime of 30/25 °C, another third to one with 25/20 °C temperatures, while the third population remained in the 20/15 °C regime.

At heading, each plant was tagged for date of anthesis. At maturity, the earliest spike of each line was sampled and the grain analyzed for moisture content. When the moisture level of the grain reached 13%, all spikes of the same post-anthesis period within a line were harvested and the kernels were immediately placed in petri-dishes for germination studies. The technique for germination and scoring was similar to that described above.

RESULTS AND DISCUSSION

1. Kernel Development in Relation to Pre-harvest Sprouting Tolerance

Maturity occurred between three and four weeks post-anthesis in all cultivars tested. All cultivars matured at approximately the same rate. For triticales, the sprouting tolerance score at 17 C germination temperature (GT) dropped rapidly between three and four weeks post-anthesis (Figures 1 to 4; Appendix 4). Weilenmann (1976) reported that in wheat the amount of sprouting increased as time after anthesis increased. At 25 C GT, the germination pattern varied according to genotype. For CB82-5, its tolerance fell rapidly during the 3-4 week period while the value of Carman (Fig. 2) declined at a more gradual rate. Glenlea and CD82-45 had a constant high score at 25 C (Fig. 3 & 4). The rain simulator scores most nearly resembled in magnitude the 17 C GT score from petri dishes. Correlations (Table 9) were significant for the rain simulator score and the 17 C GT score in both CD82-45 and CB82-5. Only the overall correlation between the rain simulator score and the 25 C GT score was significant (P=0.01).

It should be noted that for rain simulation, harvesting commenced on the fourth week post-anthesis to avoid possible reductions due to freezing at high moisture levels (Mares, 1983).

Figure 1: Comparison of germination dish scores at 25°C and 17°C and rain simulator scores on line CB82-5

Legend: ●—● 25°C Germination temperature
▲—▲ 17°C Germination temperature
■—■ rain simulator

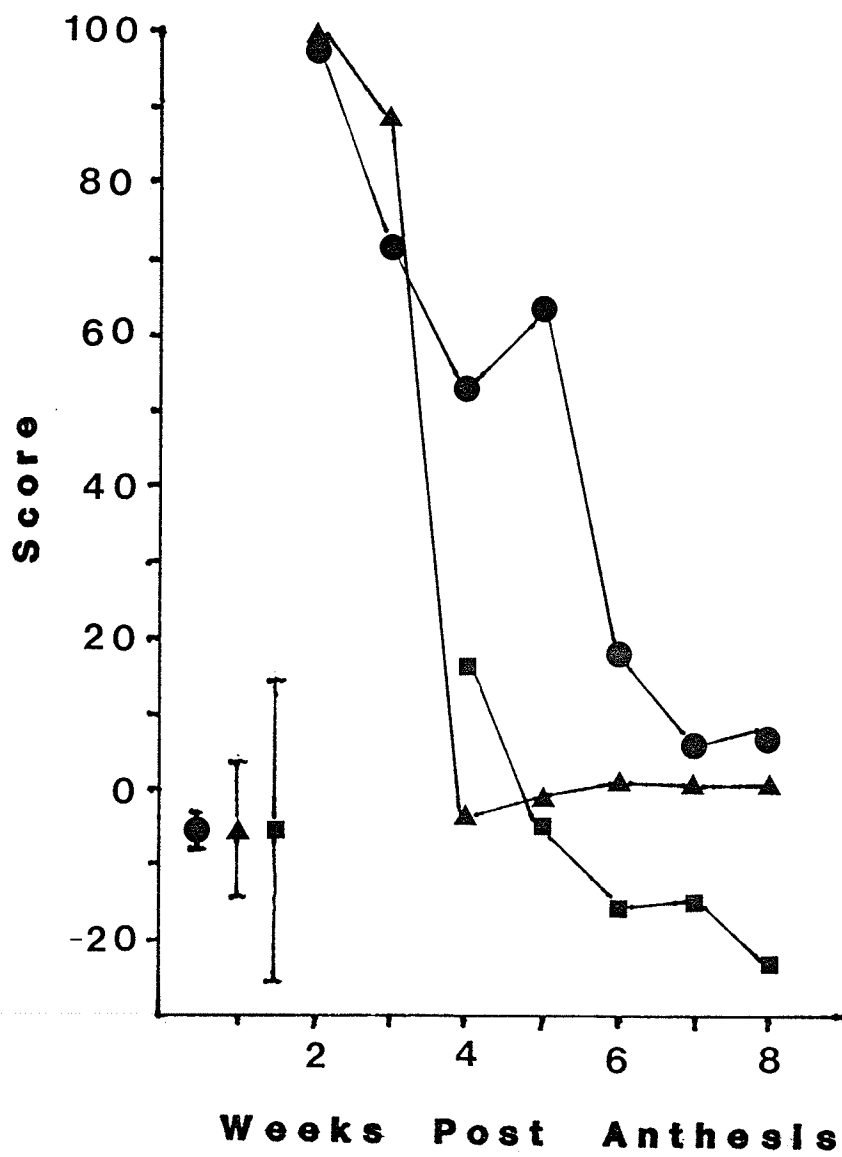


Figure 2: Comparison of germination dish scores at 25°C and 17°C and rain simulator scores on cv.

Carman

Legend: ●—● 25°C Germination temperature
▲—▲ 17°C Germination temperature
■—■ rain simulator

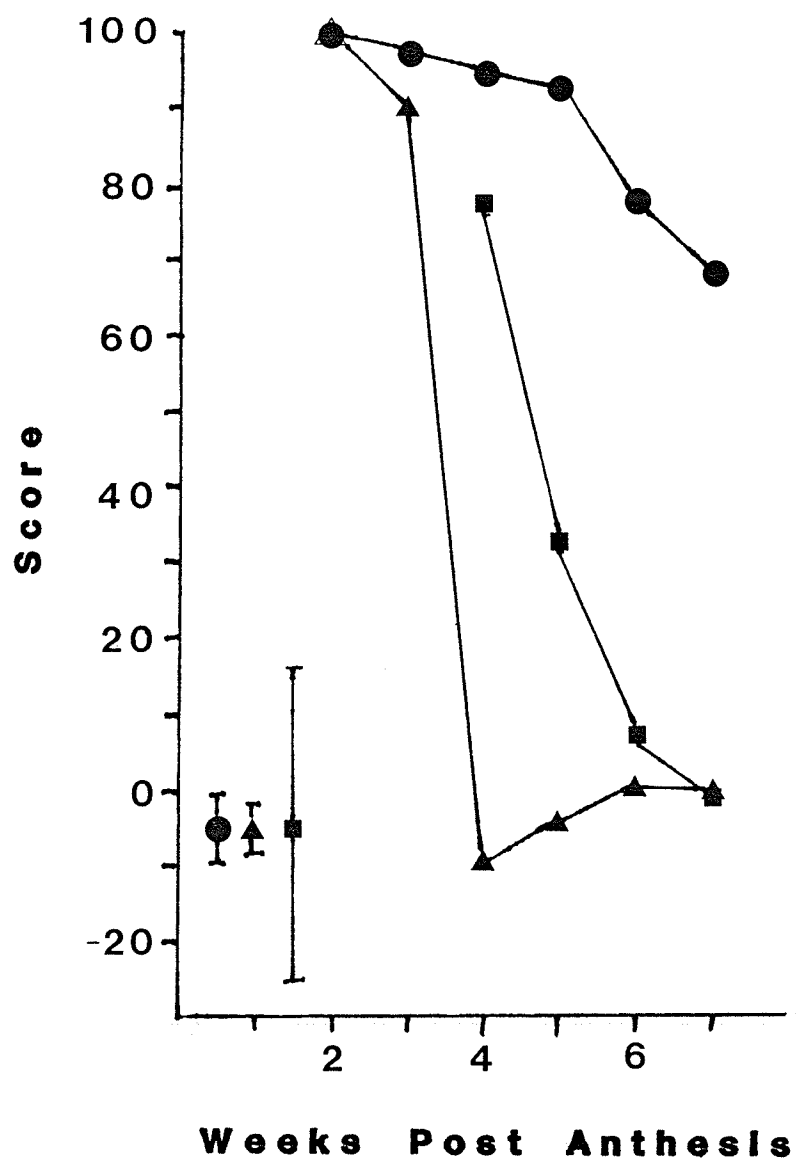


Figure 3: Comparison of germination dish scores at 25°C and 17°C and rain simulator scores on line CD82-45

Legend: ● — ● 25°C Germination temperature
▲ — ▲ 17°C Germination temperature
■ — ■ rain simulator

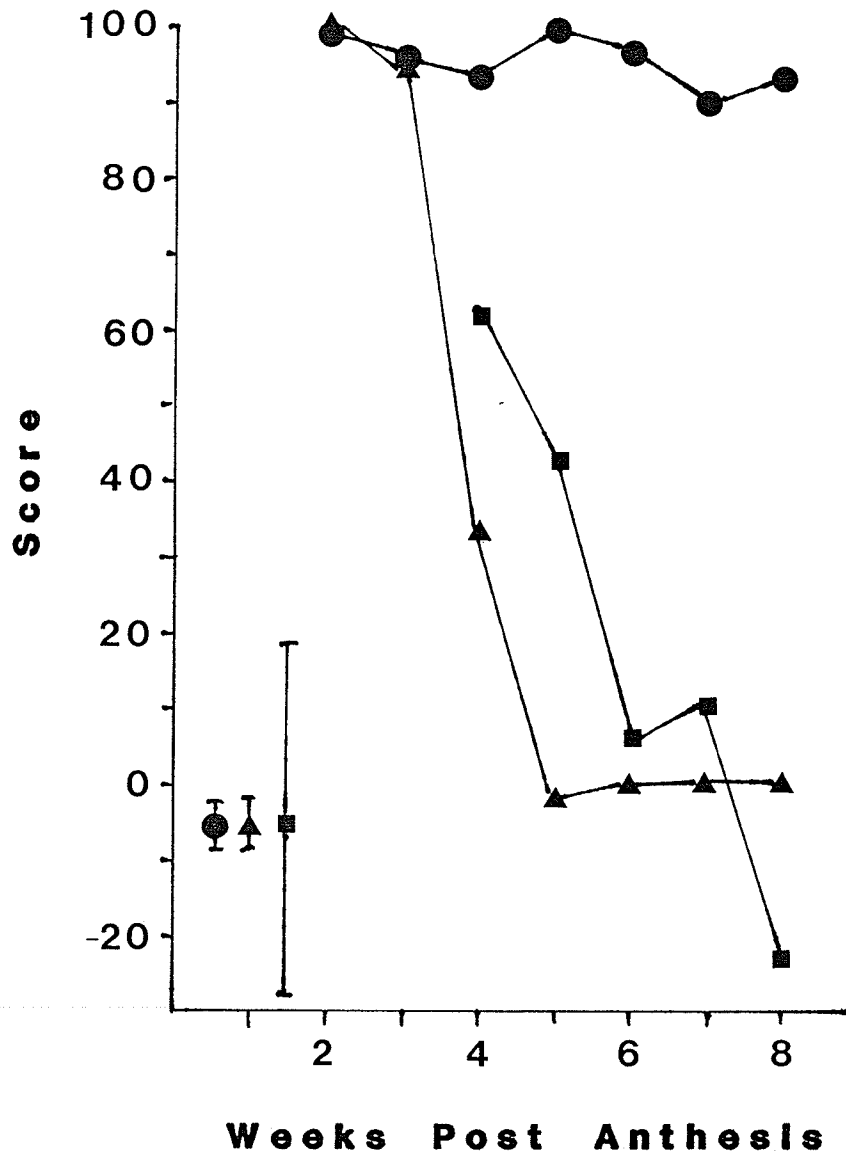
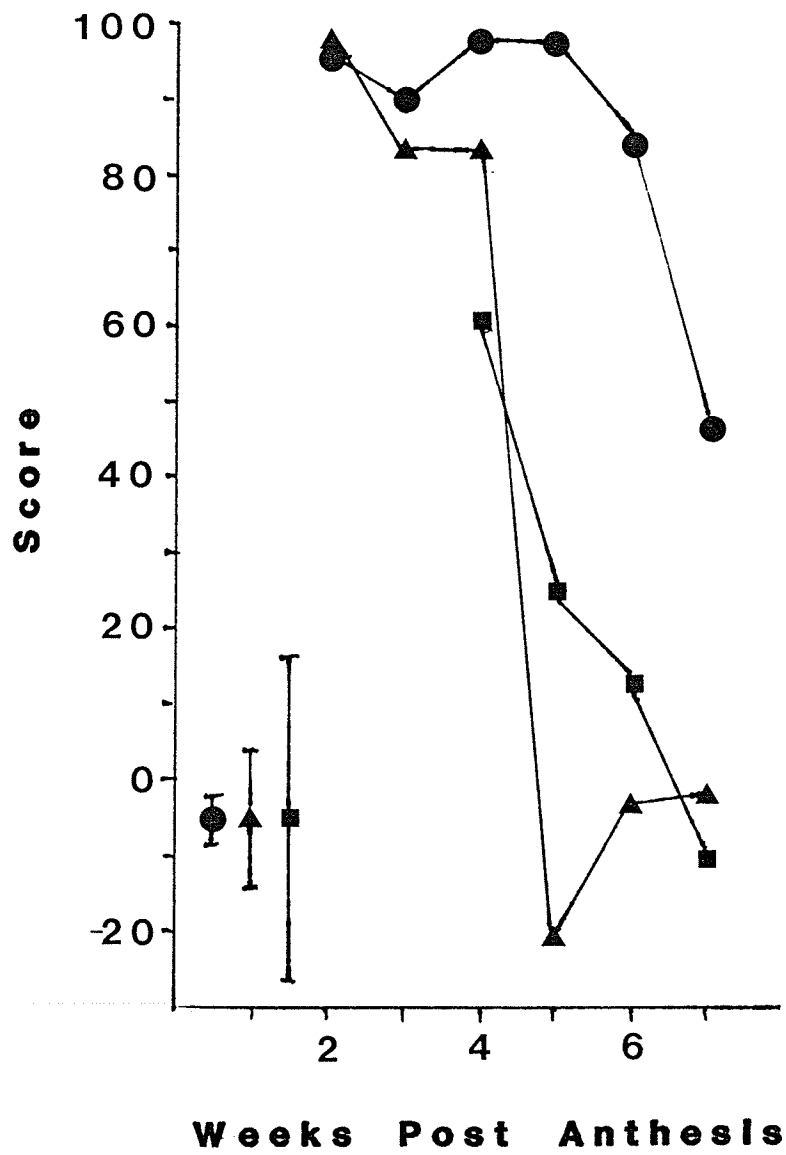


Figure 4: Comparison of germination dish scores at 25°C and 17°C and rain simulator scores on cv. Glenlea

Legend: ● — ● 25°C Germination temperature
▲ — ▲ 17°C Germination temperature
■ — ■ rain simulator



Much of the reduction in score had already occurred at 17^o C GT by the fourth week.

Germination dish testing for sprouting tolerance may be a viable alternative where small sample sizes make the use of a rain simulator impractical. If only one germination temperature

Table 9: Correlation between pre-harvest sprouting tolerance scores from rain simulator experiments and those from germination at 17^oC and 25^oC

| | | 25 ^o C Germination | Rain Simulator |
|----------------------------------|---------|----------------------------------|-------------------|
| 17 ^o C Germination | Glenlea | .426 | .769 |
| | Carman | .580 | -.991***1 |
| | CD82-45 | .328 | .663 |
| | CB82-5 | .755** | -.904** |
| | Overall | .397** | .387 |
| 25 ^o C Germination | Glenlea | | .845 |
| | Carman | | .887 |
| | CD82-45 | | .315 |
| | CB82-5 | | .768 |
| | Overall | | .661*** |

1. significance ***,** at 1 & 5% respectively

can be used, the higher one (25 °C), is recommended. For maximum accuracy, however, at least two temperatures during germination scoring should be used, for example: 17 °C and 25 °C.

Changes in tolerance scores occur rapidly during kernel ripening, therefore, all experimental material should be harvested at approximately the same stage of development. The exact time of harvest of wheat may not be crucial if all materials were sampled at comparable stages of maturity (Weillenman, 1976), a condition that also seems to apply to triticale.

2. Comparison of Germination Patterns

Overall ranking of the material in the temperature studies showed that RL4137 had the highest average sprouting tolerance score of 56.43%, while the triticale CB82-5 had the lowest score of -0.45%. CB82-9 and Carman had similar tolerance scores of 35.09% and 33.44%, respectively (Figure 5).

Time to maturity increased from 28-30 days at 30 °C maturation temperature (MT) to 43-49 days at 20 °C MT (Table 10). Agrawal (1977) states that under normal conditions triticale will be mature at 35-42 days post-anthesis and occasionally as early as 28 days.

Figure 5: Average tolerance scores of four lines;
RL4137, CB82-9, Carman and CB82-5

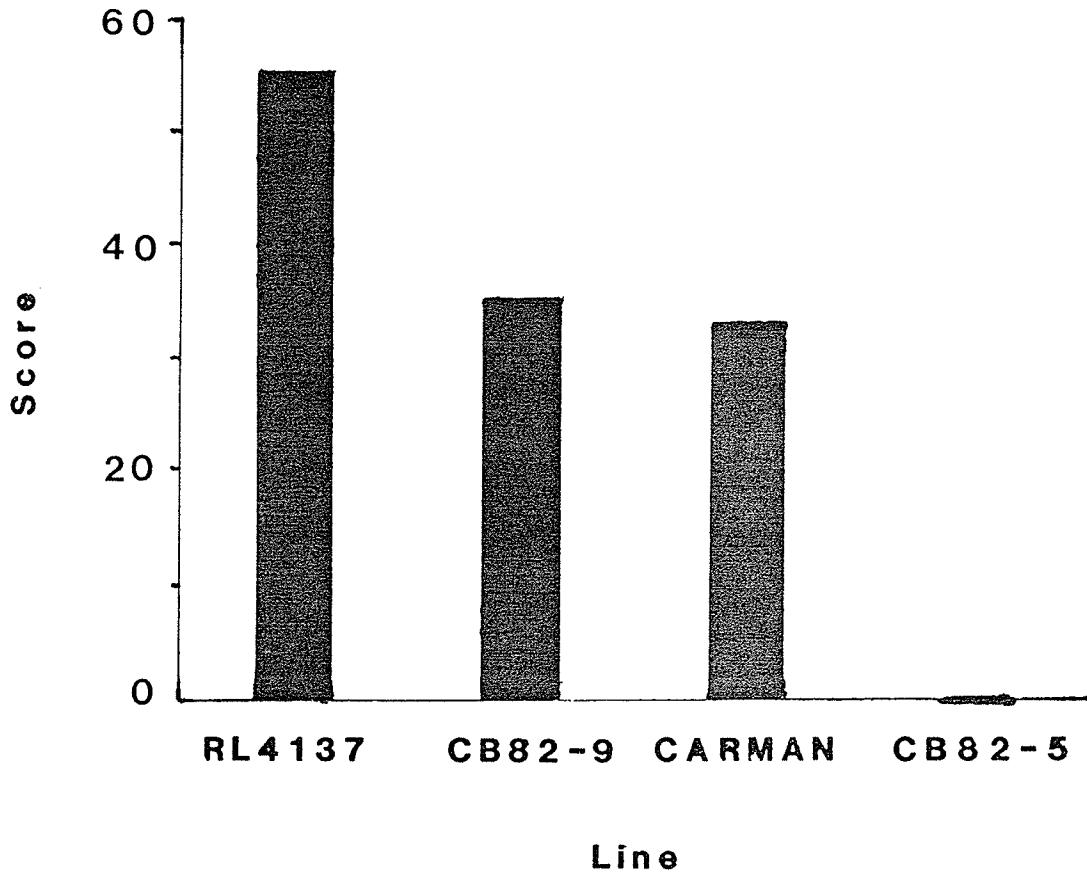


Table 10: Number of Days Post Anthesis to Harvest

| Variety | Temperature (°C) | | |
|---------|------------------|-------|-------|
| | 30/25 | 25/20 | 20/15 |
| RL4137 | 28 | 30 | 43 |
| CB82-9 | 29 | 29 | 49 |
| Carman | 30 | 30 | 45 |
| CB82-5 | 29 | 33 | 48 |

Average tolerance scores decreased as temperatures during maturation increased. Overall average scores of 38.73% at 20°C MT, 30.90% at 25°C MT, and 23.77% at 30°C MT were noted (Figure 6). The triticale CB82-5 deviated markedly in its germination pattern relative to the other genotypes in that it exhibited an increase in tolerance score with an increase in maturation temperature (Figure 7). High temperatures during maturation have been noted by several authors to shorten the dormancy period in wheat (Belderok, 1968; Olsson and Mattsson, 1976; Lalluka, 1976). This study verified the opinion that in this respect triticale reacts like wheat.

Germination temperature changes resulted in tolerance scores that were proportional to temperature. At the higher temperature of 25°C an average score of 55.63% was observed while an average score of 6.63% was recorded at the lower germination temperature of 17°C (Figure 6).

An examination of germination temperature x line interactions reveals that CB82-5 was the only exception to the

Figure 6: Average tolerance scores at three maturation
and two germination temperatures

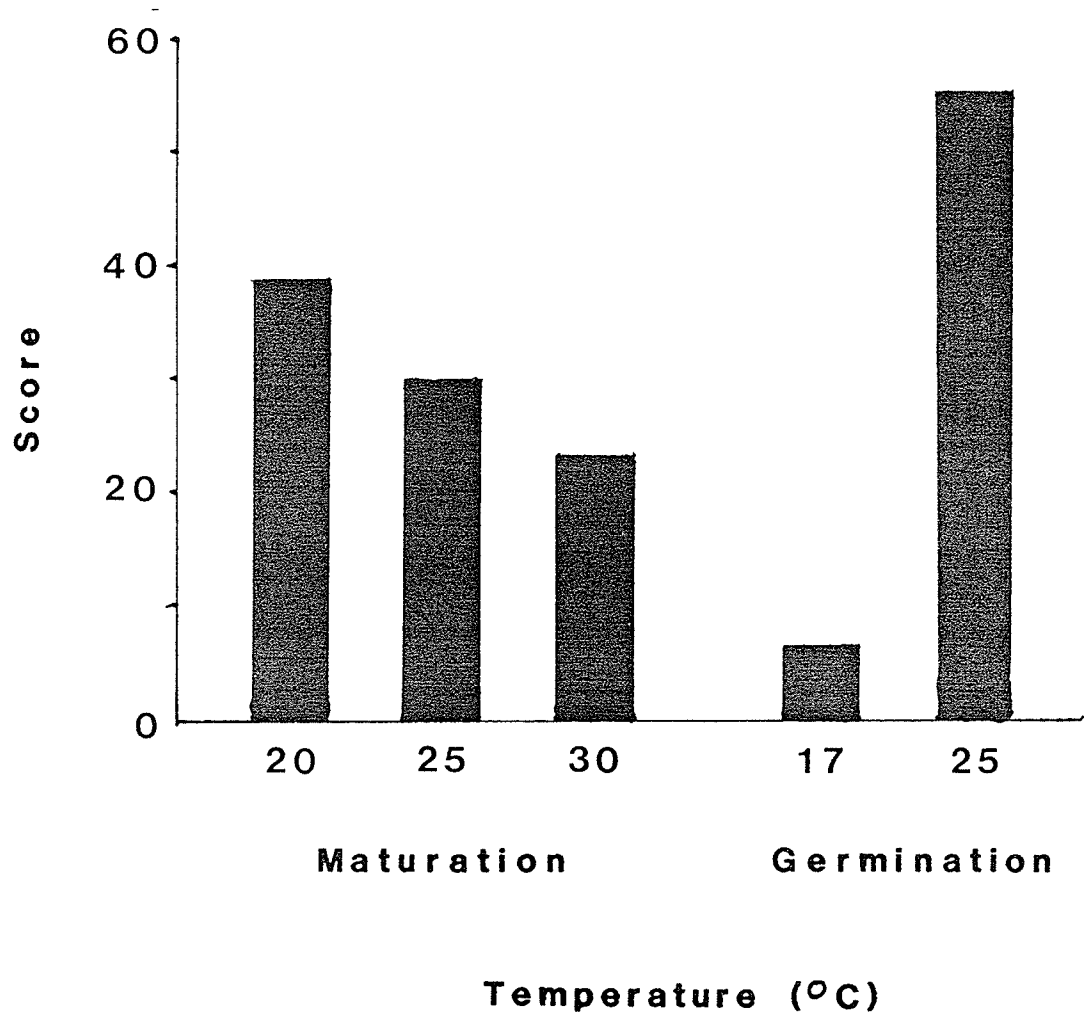
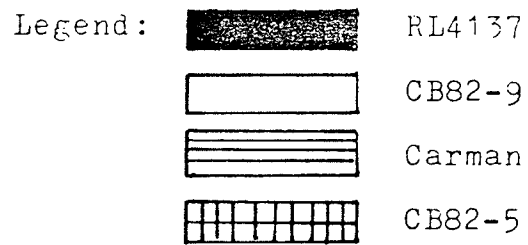


Figure 7: Temperature during maturation by progeny
line interactions



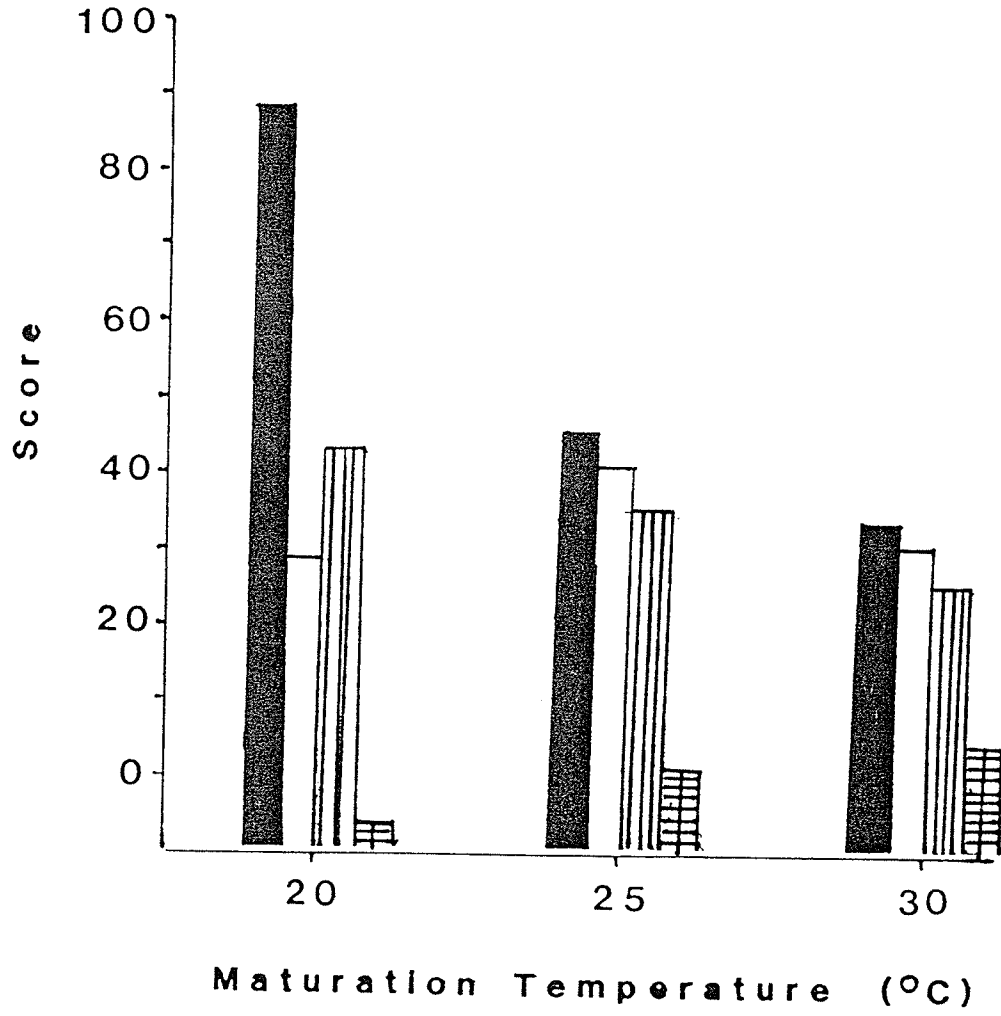

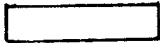
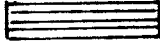

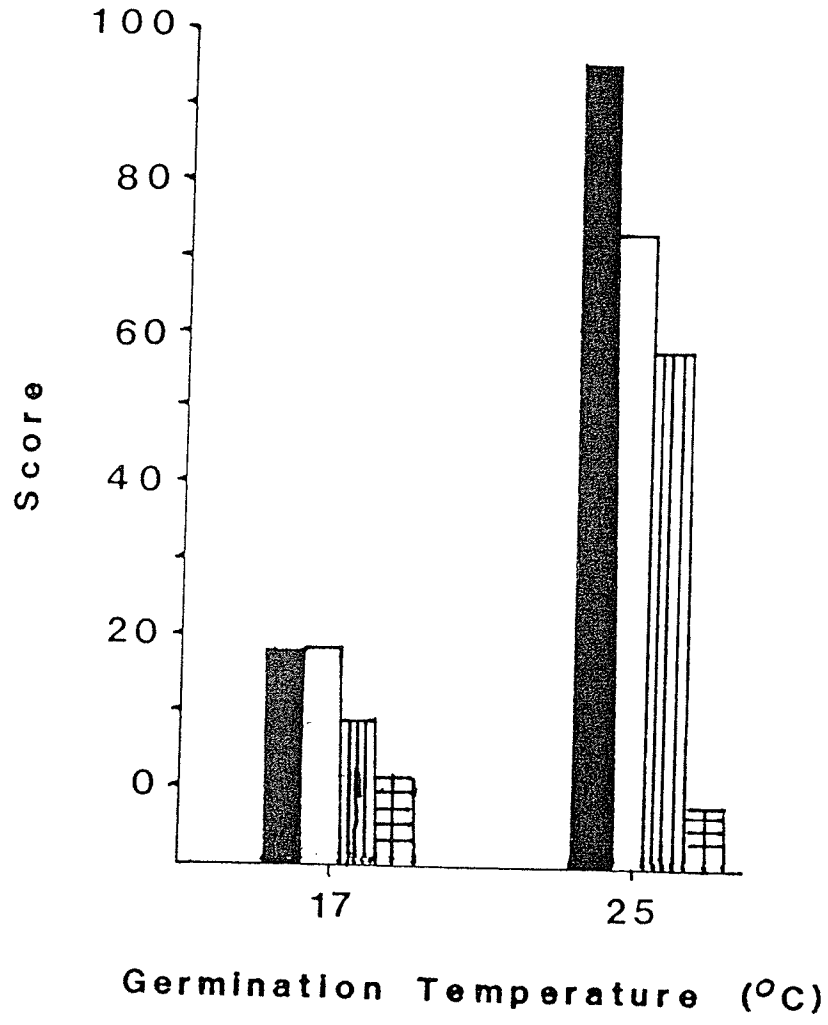


Figure 8: Germination temperature by progeny
line interactions

Legend:  RL4137
 CB82-9
 Carman
 CB82-5



general marked increase in score obtained at the 25 C GT as compared to 17 C GT (Figure 8). CB82-5 instead of showing an increase in tolerance score, maintained a very low score at both 17 C GT and 25 C GT.

The tolerant wheat line RL4137, as well as the triticales CB82-9 and Carman, appear to react in a similar way to temperatures during maturation and germination. CB82-5 on the other hand, responds in a completely different manner. This may be due to it having little or no sprouting tolerance relative to the other lines tested. Olsson and Mattsson (1976) reported definite cultivar differences in the response of wheat to high temperatures during the maturation period.

The largest differences between lines were noted at the maturation temperature of 20 C (Figure 7). In wheat, Hutchinson et al. (1948) and George (1967) found that at a germination temperature of 23 C differentiation of sprouting resistance was more marked than at 15 C. Similar results were obtained in this study with better differentiation shown at 25 C than at 17 C (Figure 8). Therefore, in order to differentiate between lines on the basis of sprouting tolerance, a maturation temperature of 20 C and a germination temperature of 25 C is recommended. However, due to the germination pattern of CB82-5, it would seem advisable to germinate the material at two temperatures (17 C and 25 C) in order to obtain the best possible differentiation of relative rankings.

SECTION III

Pre-Harvest Sprouting Tolerance of Octaploid and
Hexaploid Triticale (X Triticosecale Wittmack)
Derivatives of RL4137

ABSTRACT

A study was made of the sprouting tolerance of two octaploid triticales ($2n = 56$) derived from crossing a sprouting resistant hexaploid wheat (Triticum aestivum L. Em. Thell.) (RL4137), to both a sprouting resistant rye (S. cereale L.) (Otello), and a susceptible inbred rye (8301). The sprouting tolerance of both octaploids were identical; viz. 69.6% for RL4137/Otello and 69.2% for RL4137/8301. Crosses were made between the octaploid derived from the hexaploid wheat RL4137 and a hexaploid triticale (BGL/M2A//CIN) in an attempt to derive hexaploid progeny ($2n = 42$) possessing pre-harvest sprouting tolerance. Sprouting tolerance scores ranged from 68% to 100% in the F3 progenies, with most plants having scores approximately equal to the parental lines. With the availability of the superior sprouting tolerance of RL4137 as a parental source, this approach appears to be a practical method of increasing sprouting tolerance in hexaploid triticale.

INTRODUCTION

Triticale (X Triticosecale Wittmack) generally lacks pre-harvest sprouting tolerance. Thus one of the priorities of triticale breeding programs must be to increase the amount of sprouting resistance, either through the exploitation of genetic variability already existing within present populations of triticale germplasm, or from the synthesis of new sprouting tolerant amphiploids.

Since triticale successfully hybridizes with wheat, genes residing in either the A,B or D genomes of hexaploid wheat (T. aestivum L. Em. Thell.) can be transferred to a hexaploid triticale background. Alternately hexaploid wheat can be used to create a primary octaploid triticale ($2n = 56$) which when crossed to a suitable hexaploid triticale will result in secondary hexaploids ($2n = 42$) that contain the desired trait.

The line RL4137 is the most sprouting tolerant strain of hexaploid wheat known and has been successfully used as a sprouting resistance donor in producing the bread wheat cultivar 'Columbus' (Campbell and Czarnecki, 1981). RL4137, therefore, would be a potentially valuable parent for use in a breeding program designed to transfer sprouting tolerance from wheat into triticale.

The first section of the present study was conducted in an attempt to answer the question, "does a derived octaploid triticale containing the entire genetic complement of RL4137 have a sprouting tolerance similar to that of RL4137?" Two octaploid amphidiploids containing RL4137 were synthesized and evaluated in comparison with the two parental lines, RL4137 and a sprouting tolerant rye 'Otello' (Persson, 1976). In addition a susceptible inbred rye, University of Manitoba accession '8301', was also used in the comparison.

Since most of the breeding and production of triticale involves the use of the hexaploid type ($2n = 42$), the second part of this study is devoted to an investigation of secondary hexaploid triticales derived from an octaploid in which the sprouting tolerant line 'RL4137' constituted the wheat parent.

Materials and Methods

1. The RL4137 derived octaploid triticale

Crosses were made between RL4137 wheat (T. aestivum L. Em. Thell.) and Otello (S. cereale L), as well as between RL4137 and 8301, a sprouting susceptible rye from the University of Manitoba accessions. The chromosome number in the resulting hybrids was doubled by immersion of roots in a colchicine solution as described by Winkle and Kimber (1976). At maturity all kernels were harvested and sown in two-litre milk cartons with one plant per carton. These were placed in a growth room with a 20/15 C day/night temperature regime and a 16 h photoperiod. The parental lines RL4137, Otello, and 8301 were sown with the new amphidiploids for purposes of comparison.

All plants of a line were harvested on the same date. Two layers of paper towelling were placed in the bottom of germination dishes and 25 kernels per line were placed crease down in each dish to which ten ml of distilled water was added. Ten dishes of each line were placed in a germination cabinet operating at 17 C while another ten were tested in a second cabinet at 25 C. The percent of ungerminated kernels was recorded daily from the third through to the seventh day.

A linear regression for germination in each dish was obtained from daily readings and was used to estimate the percent non-germinated kernels on the seventh day. This value used as the score for any particular dish reflected the rate as well as the

level of germination. The average score for the ten dishes within a line was used as the sprouting tolerance evaluation at each of the two temperature regimes. The sprouting tolerance score is an estimate of the percent non germinated kernels on the seventh day of the germination test. Thus a high score represents a more sprouting tolerant line than a lower score.

2. The RL4137 derived hexaploid triticales

The octaploid triticales from RL4137/Unknown Inbred Rye was crossed with the hexaploid triticales line, CA82-8 (Bgl/M2A//Cin). CA82-8, a sprouting resistant line in the 1982-83 crossing program at the University of Manitoba, has a high test weight, high yield and a good seed type. Six F1 kernels were obtained. Of these, only one germinated and 13 F2 kernels were harvested from the single F1 plant. Seven F2 seedlings were successfully grown to maturity from which two kernels of each spike were planted in a growth room operating at a 20/15 °C temperature regime. The rest of the F2 seeds were tested for sprouting tolerance in petri dishes at a germination temperature of 25 °C. The octaploid and hexaploid triticales parental lines were also included in the population. In the F3 generation, only four plants produced a sufficient number of seeds to permit a germination test to be conducted. Each of these plants was individually scored in petri dishes at a germination temperature of 25 °C and compared to the parental lines. Germination and scoring was done in a manner similar to that described above.

The octaploid parents contained the A, B, D, and R genomes while the hexaploid parent contained the A, B, and R genomes. It was assumed that the fertile offspring had lost the D genome such that by the F3 most plants would be hexaploids ($2n = 42$).

RESULTS AND DISCUSSION

Differences in sprouting tolerances between the parental ryes, Otello and 8301 were not reflected in the sprouting reaction of their octaploid triticales derivatives (Table 11). At a 17 C germination temperature (GT), Otello and 8301 scored 65.72% and 5.60%, respectively. However, the derived amphiploids (RL4137/Otello and RL4137/8301) at this temperature respectively scored 50.93% and 54.27%. At 25 C the difference in tolerance between Otello and 8301 was less marked with scores of 95.08% and 75.85%, while their amphiploids (RL4137/Otello and RL4137/8301) at this temperature scored 88.27% and 84.02%, respectively. The sprouting tolerance scores of the octaploid RL4137/8301 were intermediate to its parental values at both temperatures. RL4137/Otello had scores which were lower than the scores of either of its parents.

The primary octaploid triticales synthesized in this study did not have sprouting tolerance scores which reflected the difference in scores of their respective rye parents. For example, the score of the octaploids RL4137/8301 and RL4137/Otello are non-significantly different from one another at both 17 C GT and 25 C GT. On the other hand Otello the tolerant rye parent, had a consistently higher score at both temperatures compared to 8301, the susceptible parent. The tolerance scores of

the octaploids appeared to be independent of those of the parental rye lines. Further research is needed, however, to verify these results.

Table 11: Pre-harvest sprouting scores of octaploid triticales and their parental lines

| Line | Germination Temperature | |
|---------------|--------------------------|--------------------------|
| | 17 °C | 25 °C |
| RL4137 | 99.48 _± 1.64 | 98.24 _± 2.85 |
| RL4137/8301 | 54.27 _± 13.28 | 84.02 _± 11.20 |
| 8301 | 5.60 _± 5.51 | 75.85 _± 6.40 |
| RL4137/Otello | 50.93 _± 11.50 | 88.27 _± 8.97 |
| Otello | 65.72 _± 13.09 | 95.08 _± 4.35 |

DePauw and McCaig (1983a) hybridized RL4137 with an experimental white wheat line 7722, and were successful in transferring some of RL4137's dormancy into white-seeded offspring. Similarly in the present cross, RL4137/8301, some of RL4137's sprouting tolerance seems to have been transferred to the octaploid triticales derivative. This did not appear to have occurred in the case of RL4137/Otello since its score was lower than either of its parental lines.

The octaploid triticales line, RL4137/unknown Inbred Rye, used as a parent in deriving secondary hexaploid triticales, had an average score of 88.80% with the hexaploid triticales parent,

CA82-8, scoring 93.56% (Table 12). Duncan's Multiple Range Test **showed these to be** non-significantly different from one another. The four F3 progeny plants tested (plants 1, 2, 3 and 4, Table 12) scored 85.55%, 90.54%, 68.00% and 100.00%, respectively. Plants 1 and 2 were non-significantly different from either parent while plants 3 and 4 were significantly lower and higher, respectively, than either of the parent lines. The average score of a total of seven F2 plants tested was 68.00%, while the lowest scoring F3 (plant 3) had the same score.

Table 12: Pre-harvest germination scores of octaploid and hexaploid triticales and selected secondary triticales progeny

| Line | Score | |
|-------------------------------|--------------------------|-----|
| RL4137/Inbred Rye (octaploid) | 88.80 _± 0.85 | bc1 |
| CA82-8 (hexaploid) | 93.56 _± 0.67 | bc |
| F3 plant #1 | 85.55 _± 1.63 | c |
| F3 plant #2 | 90.54 _± 0.55 | bc |
| F3 plant #3 | 68.00 _± 2.10 | d |
| F3 plant #4 | 100.00 _± 0.00 | a |
| F2 plants | 68.00 _± 9.92 | d |

1. Scores followed by the same letter are not significantly different at P=.05

Only four of the twelve F3 plants grown were tested. The total variation in the F3's therefore, was probably not represented. With the high level of resistance present in CA82-8 it is not certain that this resistance noted in the F3 plants is of RL4137 origin. The fact, however, that one of the four plants examined (Table 12), exhibited a high level of sprouting tolerance, indicates promise for deriving resistant hexaploid secondary triticales from octaploid and hexaploid crosses of this species.

A lack of transgressive segregation was noted by Bhatt et al. (1983) in their study of sprouting resistance inheritance in wheat. Segregation in the present study occurred beyond the upper and lower scores of the two parental lines with a large percent being below that of the low scoring parent. This may be a result of the unknown genotype of the rye parent used in the original synthesis of the octaploid triticales parent.

GENERAL DISCUSSION

Sprouting tolerance scores in the triticale germplasm handled in this study were found to decrease as temperature during maturation increased. Belderok (1968) stated that high temperatures during the ripening period shorten the dormancy period in wheat. This was later confirmed by Olsson and Mattsson (1976) as well as by Lalluka (1976).

Differences in sprouting tolerance scores were noted in the summer of 1982 between material grown at the Portage and Glenlea sites which could not be accounted for on the basis of differences in mean temperatures alone. Bohac and Ondro (1978) noted that rainfall during the ripening period markedly increased sprouting in wheat while dry weather during this period decreased the level of sprouting. In the present study, the Glenlea site as compared to Portage received a higher amount of rainfall both in July (101 mm) and August (16 mm) (Table 1). Water availability may thus have been a factor involved in the sprouting differences noted.

Mitchell et al. (1980) found that the moisture content of the seed at the time of harvest has an effect on its germinability. Since the test plots at the Portage site were slower to mature than those at Glenlea, average moisture levels of harvested seed from the two experimental sites could have differed. This could explain in part why the triticale grown at Portage had a higher score than that grown at Glenlea even though temperatures were similar at the two sites.

Plarre (1980) described a breeding method for the improvement of sprouting resistance in rye. This involved crosses within S. cereale, using in addition to Otello, an introduction from the wild species S. silvestre. A breeding program along a similar approach could prove useful in improving the sprouting tolerance of triticale germplasm. The present study indicated the presence of variability in material now available. Selection for lines with high tolerance scores within the breeding program, along with a system of crosses made to the more tolerant accessioned germplasm, could result in an increased level of pre-harvest sprouting tolerance in future commercial varieties. The present study with RL4137 revealed that it may be possible to use this source of tolerance in a manner similar to that described by Plarre (1980) in his use of S. silvestre.

In a breeding program for sprouting tolerance it would be recommended to first test and select for higher sprouting tolerance within lines presently being used. By crossing the best available lines to superior accessioned germplasm, then selecting for desired agronomic traits and sprouting tolerance improvement in tolerance should be achieved. By crossing RL4137 to a sprouting tolerant rye, then backcrossing to a sprouting tolerant hexaploid triticale, improved secondary hexaploid triticales could be produced.

Bhatt et al. (1981) found a correlation of -0.64 between yield and field sprouting in wheat. A similar relationship was found in triticale in the present study. Thus it should be possible to select for both high yield and sprouting tolerance simultaneously. Selection for increased dormancy may result in

reduced seedling vigor, leading to a reduction in yield (Boyd et al., 1971). The plant breeder therefore, when selecting for increased dormancy must make sure that seedling vigor is not reduced simultaneously.

A number of schemes have been suggested for the scoring of sprouting tolerance. Smith and Millet (1964) used the number of days to 50% germination as a basis for measuring tolerance. Gordon (1971) used germination resistance, a formula deriving the mean germination time. Area under the germination curve was suggested as useful for the measurement of differences in sprouting tolerance of grain by Richter and Switzer (1982). Goodchild and Walker (1971) after comparing a number of methods of comparing germination curves, concluded that the greatest amount of information could be obtained from a regression model describing the shape of the germination curve. Bould and Abrol (1981) used a quadratic equation to describe the germination pattern of wheat. For the present study, a linear regression equation was used to estimate the percent non-germinated seed on the seventh day. This method was chosen as it is relatively easy to use and will result in a tolerance score that reflects both time to germination and percent non-germination.

Strand (1980) states that in sprouting resistance tests based on germination, the standard error is theoretically lowest at the extremes of germination percentages and that the differentiation between lines is expressed more definitively in the 10-70% germination range. In the present study standard errors were generally large but were smallest for material

exhibiting a high score for sprouting tolerance. Since relative rankings remained constant from one testing period to another, this scoring method was useful in evaluation of material for pre-harvest sprouting tolerance.

Strand (1980) suggests that for screening populations and testing of large numbers of selections, a method of testing based on seed dormancy is advantageous. Gordon (1983b) recommended that testing for sprouting resistance be based directly on sprouting of the grain. In the case of large numbers, the use of a rain simulator as described by McMaster and Derera (1976) would be advised. Small scale tests are often conducted on filter paper in petri-plates using a standard germination testing procedure (Bhatt and Derera, 1980). In the present study, a comparison of tolerance scores based on germination obtained either on petri-plates or in the rain simulator revealed that scores were generally lower on the basis of petri-plate germination. Nevertheless, relative rankings of triticale lines remained the same for both methods.

In testing for sprouting tolerance it may not always be feasible or possible to use a rain simulator. Petri dishes may be used instead. In the present study it was found that scores derived from petri dish germination at 17 °C most nearly resembled scores from a rain simulator in magnitude over a range of maturity levels. However, for best differentiation between cultivars germination in petri dishes at a germination temperature of 25 °C was recommended since at this germination temperature dormancy is expressed for a longer period after maturity.

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Appendix 1: Screening of the University of Manitoba 1981
triticale breeding program

| | Score | Pedigree |
|-----------|--------------|--------------------------------|
| RL4137 | 100.00+ 0.00 | |
| YF81-6 | 98.45+ 2.72 | 6TA204/PPV13//YOREME |
| BC81-26 | 97.96+ 3.61 | M2A/ARM"S"//BEAGLE |
| 101-134 | 95.81+ 6.34 | PANTHER"S"/OCTO BULK-BUSH |
| YH81-13 | 95.45+ 6.43 | 6TA204/PPV13//WELSH |
| YJ81-25 | 95.00+ 4.89 | FS3972-10M-ON//6TA204/BCO |
| GLENLEA | 94.42+ 6.83 | |
| YM81-4 | 94.30+ 7.64 | BEAGLE/M2A |
| YM81-23 | 91.92+11.43 | UM9/MY64//FS381 |
| 101-116 | 90.72+ 8.86 | NAVOJOA/LINCE |
| YK81-7 | 88.47+12.23 | M2A"S" |
| YB81-23 | 88.33+20.58 | 6TA204/PPV13//FS1897 |
| YK81-10 | 87.27+11.58 | TCCXI |
| YB81-15 | 86.78+17.53 | 73UM8518/BEAGLE |
| 101-167 | 86.67+29.81 | W74.103-ADDA/BEAGLE"S"-M2AxIRA |
| BB81-10 | 86.60+14.27 | DRIRA/SORGO |
| COOP81-1 | 86.46+18.37 | 7431A-36B2 |
| YB81-22 | 85.86+16.09 | BEAGLE/WELSH |
| 101-173 | 83.70+11.31 | SETTER-PANDA"S" |
| ITYN81-20 | 81.82+ 9.25 | BONITO"S" |
| YK81-21 | 80.95+12.26 | M2A/SETTER |
| YM81-6 | 80.38+14.36 | BEAGLE M2A/CINNAMON |
| COOP81-12 | 80.13+19.73 | 7634-163F2C |
| YE81-19 | 79.89+21.78 | 8A761/WELSH |

(continued)

Appendix 1: continued

| | Score | Pedigree |
|-----------|--------------------------|-----------------------------|
| 101-366 | 78.89 ₊ 17.28 | FS1781-NV |
| YM81-5 | 78.82 ₊ 27.20 | BEAGLE/M2A |
| YB81-21 | 78.29 ₊ 15.41 | BEAGLE/WELSH |
| COOP81-6 | 78.06 ₊ 25.95 | 7634-423F4D |
| COOP81-16 | 77.99 ₊ 25.31 | 7431C-56D5 |
| YE81-15 | 77.95 ₊ 18.16 | 6A1093/DRIRA |
| COOP81-3 | 77.78 ₊ 14.21 | 7634-246E2D |
| YK81-15 | 73.47 ₊ 38.27 | CINUEM/IRA |
| 101-19 | 72.69 ₊ 21.70 | MUSKOX 32 |
| 101-359 | 72.42 ₊ 15.67 | TJ-BEAGLE"S" |
| YA81-8 | 70.23 ₊ 28.62 | BGL/4/8A95/RNR/3/HARI//ARM |
| YB81-12 | 70.18 ₊ 29.62 | VT75-229/BEAGLE |
| 101-169 | 70.05 ₊ 30.05 | W74.103-ADDAX/BEAGLE"S"-M2A |
| CARMAN | 69.66 ₊ 44.79 | |
| 101-273 | 68.66 ₊ 31.87 | IA-KLAXCAL/BEAGLE |
| PITIC 62 | 68.56 ₊ 12.63 | |
| COOP81-2 | 68.49 ₊ 12.52 | 74UM8819 |
| 101-219 | 68.38 ₊ 29.61 | PANTHER"S"/M1A |
| YG81-21 | 67.99 ₊ 17.24 | 6TA204/BCO//72UM2006 |
| 101-142 | 67.83 ₊ 39.82 | PANTHER"S"/OCTO BULK BUSH |
| 101-60 | 67.04 ₊ 42.44 | FS1795-LINCE |
| CB81-8 | 66.78 ₊ 17.40 | 6TA204//BCO/3/BVR/TOBI |
| 101-35 | 66.72 ₊ 32.88 | CIN-P162xPATO/BEAGLE |
| 101-183 | 66.67 ₊ 34.83 | PANTHER"S"/GAZELLE"S" |
| YE81-25 | 66.29 ₊ 26.73 | 6A715/WELSH |

(continued)

Appendix 1: continued

| | Score | Pedigree |
|-----------|---------------------|------------------------------|
| 101-49 | 66.15+ <u>44.66</u> | POLAR"S" |
| WELSH | 65.28+ <u>20.28</u> | |
| YH81-3 | 64.98+ <u>18.11</u> | 6TA204/BCO//CINNAMON |
| 101-102 | 64.17+ <u>27.11</u> | SETTER |
| ITYN81-36 | 63.89+ <u>20.49</u> | NACUZARI 76 |
| 101-361 | 63.73+ <u>51.30</u> | DRIRA-KANG |
| 101-74 | 63.67+ <u>24.08</u> | BEAGLE"S"/ADDAX |
| YH81-7 | 63.52+ 8.74 | 6TA204/BCO//72UM2013 |
| 101-362 | 62.62+ <u>25.71</u> | PG"S"-CENT.BULKxABN |
| YJ81-7 | 61.96+ <u>33.40</u> | KGR//MTE20/P/4/BVR/3/ARM |
| YG81-11 | 61.40+ <u>19.42</u> | 6TA204/PPV13//CIN/3/72UM2006 |
| COOP81-8 | 60.76+ <u>29.47</u> | 7634-294A2D |
| YD81-10 | 60.57+ <u>27.88</u> | LEO-10W-2W-0W/WELSH |
| BC81-25 | 60.27+ <u>28.58</u> | BEAGLE"S">//M2A/CINNAMON |
| CB81-9 | 60.23+ <u>21.66</u> | SZALKAS//6TA204/ARM"S" |
| BB81-2 | 59.90+ <u>23.14</u> | BGLxM2A/CINNAMON |
| COOP81-9 | 59.13+ <u>30.46</u> | 7634-423A2A |
| YJ81-4 | 57.65+ <u>28.23</u> | M2A/6TA204 |
| 101-44 | 57.53+ <u>20.39</u> | JUANILLO 90 |
| YJ81-3 | 57.34+ <u>22.05</u> | 6TA204 #83/KOALA-3 |
| YE81-23 | 56.94+ <u>18.65</u> | GA714/WELSH |
| YB81-19 | 56.89+ <u>61.74</u> | 73UM8518/BEAGLE |
| YJ81-6 | 55.67+ 8.01 | M2A/6TA204 |
| 101-230 | 55.45+ <u>40.53</u> | PANDA"S"/RAHUM |
| YA81-10 | 54.70+ <u>19.25</u> | TCXIII/BGL |
| YG81-4 | 54.36+ 2.08 | 6TA204/PPV13//CIN/3/WELSH |

(continued)

Appendix 1: continued

| | Score | Pedigree |
|-----------|---------------------|-------------------------------|
| YB81-16 | 53.80+ <u>36.37</u> | 73UM8518/BEAGLE |
| CB81-4 | 53.44+ <u>45.62</u> | UM9//ILS3.1P/HD//KGRUM9 |
| YH81-26 | 52.75+ <u>24.45</u> | FS4395-5M-0N/WELSH |
| YJ81-1 | 52.67+ <u>36.72</u> | 6TA204 #83/KOALA-3 |
| YK81-12 | 51.85+ <u>51.22</u> | 6TA204/PPV13 |
| BC81-1 | 51.53+ <u>33.18</u> | M2A/6TA204 |
| BB81-13 | 51.50+ <u>29.62</u> | M2A* |
| YB81-20 | 50.07+ <u>38.60</u> | 73UM8518/BEAGLE |
| YK81-16 | 50.00+ <u>70.71</u> | MUNTXING/M2A |
| 101-132 | 48.37+ <u>41.00</u> | FS1781/NAVOJOA |
| YM81-14 | 48.06+ <u>34.30</u> | IRA/BEAGLE |
| YL81-8 | 47.90+ <u>8.20</u> | TCCXI |
| YM81-13 | 46.95+ <u>21.75</u> | IRA/BEAGLE |
| CB81-11 | 44.12+ <u>26.20</u> | 6TA204/PPV13//CINNAMON/3/M2A |
| COOP81-5 | 43.27+ <u>27.12</u> | 7431D-42G1 |
| 101-266 | 42.83+ <u>53.19</u> | NV-M2A(2)/CUYOxOCTO BULK BUSH |
| YF81-26 | 42.57+ <u>32.17</u> | BEAGLE/TERRIER |
| YH81-4 | 42.44+ <u>13.52</u> | 6TA204/BCO//72UM2013 |
| YG81-5 | 42.22+ <u>26.94</u> | 6TA204/PPV13//CIN/3/WELSH |
| 101-373 | 41.99+ <u>28.94</u> | JUANILLO 555 |
| BB81-11 | 40.65+ <u>41.53</u> | MAYA-ARMIDILLO-108 |
| YM81-3 | 39.41+ <u>33.85</u> | BGC/T171 |
| 101-188 | 38.89+ <u>31.74</u> | PANDA"S"/OCTO BULK BUSH |
| ITYN81-28 | 38.71+ <u>1.23</u> | IRR-BEAGLE |
| YH81-18 | 36.80+ <u>33.84</u> | 6TA204/PPV13//72UM2006 |

(continued)

Appendix 1: continued

| | Score | Pedigree |
|-----------|---------------------|------------------------------|
| YB81-24 | 35.62+ <u>43.62</u> | 6TA204/PPV13//FS1897 |
| 101-137 | 35.45+ <u>54.43</u> | PANTHER"S"/OCTO BULK BUSH |
| COOP81-14 | 35.05+ <u>41.08</u> | 7634-225G4A |
| 101-255 | 34.98+ <u>29.13</u> | IRA-BUNNY/FS477 |
| 101-120 | 34.95+ <u>19.18</u> | BCM"S"/IA |
| COOP81-11 | 34.87+ <u>42.27</u> | 7634-225G3C |
| 101-223 | 31.89+ <u>35.44</u> | PANDA"S"/RAHUM |
| YA81-24 | 29.80+ <u>27.18</u> | RNR(G--)/TSS9(4--) |
| YG81-10 | 27.86+ <u>14.66</u> | 6TA204/PPV13//CIN/3/72UM2006 |
| COOP81-7 | 21.70+ <u>62.12</u> | 7431A-68E4 |
| YF81-24 | 21.64+ <u>11.20</u> | 6TA204/PPV21//WELSH |
| 101-232 | 11.25+ <u>33.59</u> | PANDA"R"/ARABIAN |
| YJ81-8 | 10.63+ <u>17.54</u> | KGRUM9/3/PC//VD6391/MY64 |
| 101-243 | 5.56+ <u>23.83</u> | PANDA"R"/ARABIAN |
| 101-122 | 2.95+ <u>15.48</u> | BACUM"S"-IA |
| YB81-4 | 2.14+ <u>35.69</u> | M2A/CML//DRIRA(EE) |
| YA81-26 | 1.67+ <u>21.84</u> | ALLEYCAT/BEAGLE |

Appendix 2: Score by selection within progeny lines

| Line | Selection | Glenlea | Portage | Average |
|---------|-----------|----------------------------|----------------------------|----------------|
| YF81-6 | BD82-31 | 88.33+10.57 a ¹ | 91.63+ 8.07 a ² | 89.98+ 9.31 a |
| YF81-6 | BD82-67 | 84.82+ 5.95 a | 90.42+ 2.94 abc | 87.62+ 5.39 ab |
| YF81-6 | BD82-61 | 88.53+ 6.67 a | 85.64+ 6.33 bc | 87.08+ 6.50 ab |
| YF81-6 | BD82-37 | 81.47+16.09 a | 84.67+ 9.99 c | 83.04+13.14 b |
| BC81-26 | CD82-100 | 90.88+12.91 a | 98.77+ 3.32 a | 94.83+10.03 a |
| BC81-26 | CD82-45 | 94.88+ 7.48 a | 98.29+ 1.73 a | 96.42+ 5.62 a |
| BC81-26 | CD82-9 | 95.39+ 8.47 a | 98.21+ 2.06 a | 96.80+ 6.17 a |
| BC81-26 | CD82-30 | 87.83+12.46 a | 95.06+ 7.21 ab | 91.44+10.58 a |
| BC81-26 | CD82-40 | 94.55+ 3.36 a | 93.06+ 5.47 abc | 93.81+ 4.48 a |
| BC81-26 | CD82-103 | 70.16+22.00 b | 88.03+ 9.57 bcd | 79.10+18.88 b |
| BC81-26 | CD82-95 | 68.61+20.60 b | 85.83+14.69 bcd | 77.22+19.53 b |
| BC81-26 | CD82-87 | 72.10+13.65 b | 84.21+10.68 cd | 78.15+13.44 b |
| BC81-26 | CD82-84 | 71.45+13.11 b | 81.33+12.23 d | 76.39+13.78 b |
| YM81-4 | BD82-55 | 77.91+15.19 ab | 97.16+ 3.56 a | 87.53+14.59 a |
| YM81-4 | BD82-10 | 84.58+10.08 a | 94.26+ 7.42 a | 89.42+ 9.94 a |
| YM81-4 | BE82-21 | 61.48+21.37 b | 87.58+19.13 ab | 74.53+23.85 b |
| YM81-4 | BD82-40 | 76.76+14.64 ab | 82.54+24.48 b | 79.65+19.86 ab |
| YJ81-25 | BA82-61 | 48.94+14.08 a | 82.91+15.38 a | 65.93+22.57 a |
| YJ81-25 | BA82-10 | 65.44+ 7.73 a | 77.36+13.57 a | 71.40+16.54 a |
| YJ81-25 | BA82-79 | 47.80+20.83 a | 72.83+16.16 a | 60.31+22.23 a |
| YJ81-25 | BB82-15 | 66.97+19.44 a | 71.91+15.59 a | 69.44+17.34 a |
| YK81-10 | BB82-7 | 92.96+ 4.89 a | 83.69+13.98 a | 88.33+11.25 a |
| YK81-10 | BA82-42 | 90.73+14.36 a | 81.33+14.64 a | 86.03+14.91 a |
| YK81-10 | BA82-78 | 85.03+13.02 a | 94.94+ 7.58 a | 89.98+11.55 a |
| YK81-10 | BA82-68 | 81.17+19.02 a | 81.72+13.19 a | 81.44+15.94 a |
| CB81-8 | CA82-82 | 78.39+13.86 a | 71.82+21.45 a | 75.11+17.89 a |
| CB81-8 | CB82-18 | 53.09+23.38 ab | 51.22+19.48 a | 52.16+20.97 b |
| CB81-8 | CB82-16 | 50.80+30.23 ab | 51.29+39.50 a | 51.04+34.23 b |
| CB81-8 | CA82-64 | 41.18+22.59 b | 48.75+26.22 a | 44.97+24.13 b |
| CB81-8 | CB82-5 | 27.73+26.98 b | 56.90+21.36 a | 42.31+28.01 b |
| YH81-7 | BA82-3 | 66.67+20.27 a | 60.94+20.37 a | 63.80+20.00 a |
| YH81-7 | BA82-34 | 59.51+ 9.11 a | 67.56+11.57 a | 63.54+10.95 a |
| YH81-7 | BA82-14 | 56.46+17.97 a | 70.73+17.04 a | 63.59+18.55 a |

(continued)

Appendix 2: continued

| Line | Selection | Glenlea | Portage | Average |
|-----------|-----------|---------------|---------------|---------------|
| YJ81-4 | BA82-24 | 60.52+17.72 a | 43.50+25.17 a | 52.01+22.92 b |
| YJ81-4 | BB82-17 | 55.23+20.60 a | 78.31+10.72 a | 66.77+19.89 a |
| YJ81-6 | BB82-2 | 57.35+18.84 a | 58.39+21.63 a | 57.87+19.75 a |
| YJ81-6 | BA82-76 | 52.44+25.57 a | 58.62+33.04 a | 55.53+29.93 a |
| BB81-2 | CB82-1 | 91.22+ 7.12 a | 85.82+17.39 a | 88.52+13.23 a |
| BB81-2 | CA82-59 | 89.65+10.69 a | 88.22+11.14 a | 88.93+10.65 a |
| BB81-2 | CB82-9 | 89.47+13.61 a | 95.83+ 5.36 a | 92.65+10.58 a |
| BB81-2 | CB82-8 | 88.30+12.08 a | 94.84+ 5.99 a | 91.57+ 9.87 a |
| YM81-14 | BA82-64 | 65.14+18.21 a | 66.02+18.47 a | 65.58+17.85 a |
| YM81-14 | BA82-32 | 58.12+14.26 a | 77.60+21.15 a | 67.86+20.20 a |
| YM81-14 | BA82-18 | 54.73+12.98 a | 78.90+17.62 a | 66.82+19.51 a |
| YM81-14 | BA82-49 | 51.88+24.52 a | 72.96+19.88 a | 62.42+24.27 a |
| YG81-10 | BA82-66 | -4.73+19.62 a | 23.54+37.21 a | 9.41+32.38 a |
| YG81-10 | BA82-63 | -6.40+21.82 a | 10.91+37.40 a | 2.26+31.09 a |
| YJ81-8 | BB82-20 | 60.93+34.60 a | 60.09+25.14 a | 60.51+29.44 a |
| YJ81-8 | BB82-8 | 48.46+25.17 a | 45.41+20.37 a | 46.94+22.34 a |
| YJ81-8 | BB82-17 | 46.12+23.41 a | 44.22+21.06 a | 45.18+21.69 a |
| YJ81-8 | BB82-28 | 8.35+11.00 b | 23.53+34.00 a | 15.94+25.80 b |
| YJ81-3 | | 100.00+ 0.00 | 83.57+16.88 | 91.78+14.35 |
| GLENLEA | | 90.80+ 6.73 | 90.38+ 7.43 | 90.59+ 6.90 |
| COOP81-10 | | 82.75+19.72 | 81.48+10.85 | 82.12+15.51 |
| CARMAN | | 76.91+10.76 | 80.57+13.57 | 78.74+12.07 |
| YB81-4 | | 17.18+12.23 | 41.69+31.71 | 29.43+26.55 |

1. scores followed by the same letter are not significantly different

2. separate duncans were run for each line at each location

Appendix 3: Screening of the University of Manitoba Triticale
Accessions

| Accession number | Score | Pedigree |
|---------------------|--------------------------|--|
| 6A-187 | 98.93 ₊ 1.22 | T.TURGIDUM/AE.ELONGGATUM |
| 6A-62 | 98.92 ₊ 1.79 | T.TIMOPHEEVI/T.PERSICUM//T.SPHAEROCOCCUM |
| RL4137 | 97.85 ₊ 3.40 | |
| 6A-64 | 97.37 ₊ 5.17 | T.DICOCCUM/S.CEREALE |
| 6A-190 | 95.88 ₊ 5.94 | STEWART/PROLIFIC |
| 6A-32 | 95.40 ₊ 7.64 | T.TIMOPHEEVI/AE.BICORNIS |
| 6A-149 | 94.83 ₊ 2.79 | T.TIMOPHEEVI/AE.ELONGATUM |
| 6A-48 | 94.83 ₊ 4.49 | T.DURUM (COERULESCENS)/AE.SQUARROSA |
| 6A-54 | 94.23 ₊ 10.18 | T.TIMOPHEEVI/AE.COMOSA |
| 6A-618 | 94.05 ₊ 8.97 | JNK-6T-192 |
| 6A-46 | 93.35 ₊ 5.19 | AE.LONGISSIMA/T.PERSICUM |
| 6A-51 | 92.33 ₊ 6.38 | T.TIMOPHEEVI/AE.SQUARROSA |
| 6A-43 | 91.84 ₊ 13.74 | AE.LONGISSIMA/T.DICOCCUM |
| OA-1428 | 90.76 ₊ 20.34 | TURGIDUMxMANITOU/CENTENO |
| 6A-600 | 90.32 ₊ 11.82 | FLAMINGO"S"/SNOOPY |
| 6A-44 | 90.20 ₊ 15.09 | AE.LONGISSIMA/T.DURUM (KUBANKA) |
| 6A-418 | 89.80 ₊ 9.65 | HERCULES/2D197 |
| 6A-943 | 89.56 ₊ 14.85 | PELLISSIER/CENTENO |
| 6A-205 | 89.44 ₊ 9.49 | T.TIMOPHEEVI/AE.UMBELLULATA |
| 6A-53 | 89.31 ₊ 9.48 | T.TIMOPHEEVI/AE.LONGISSIMA |
| OA-1424 | 88.59 ₊ 19.83 | PITICxDURUM/CENTENO |
| 6A-1454 | 87.90 ₊ 12.08 | MAL/UC-90 |
| OA-1439 | 87.46 ₊ 4.90 | MAN/HB110 |
| 6A-404 | 87.29 ₊ 21.56 | UM70/LOST TAG RYE |

(continued)

Appendix 3: continued

| Accession | Score | Pedigree |
|-----------|----------------------|-----------------------------------|
| 6A-580 | 87.21 <u>+</u> 11.20 | JORI/UC-90 |
| BD82-37 | 87.11 <u>+</u> 7.72 | 6TA204/PPV13//YRE |
| | 86.88 <u>+</u> 10.35 | RL4137/INBRED RYE |
| 6A-390 | 86.88 <u>+</u> 26.25 | STEWART 63/PROLIFIC |
| 6A-412 | 86.00 <u>+</u> 15.99 | RD75/ZOAPILA |
| 6A-353 | 85.86 <u>+</u> 9.40 | T.DICOCCUM (VERNAL) /AE.SQUARROSA |
| 4B-1185 | 85.28 <u>+</u> 20.04 | DORMANT RED TETRAPLOID |
| OA-1449 | 84.89 <u>+</u> 11.13 | C.S.5D/8143 (INBRED RYE) |
| 6A-356 | 84.74 <u>+</u> 13.41 | T.PERSICUM/AE.SQUARROSA |
| CA82-25 | 84.72 <u>+</u> 16.89 | M2A/ARM'S'//BGL |
| 6A-357 | 84.71 <u>+</u> 8.50 | T.ORIENTALE/AE.SQUARROSA |
| 6A-699 | 83.99 <u>+</u> 10.29 | JORI/2D117 |
| 6A-589 | 82.64 <u>+</u> 15.26 | ROME 137/MERCED |
| OA-1426 | 82.52 <u>+</u> 12.55 | TURGIDUMxPITIC/CENTENO |
| 6A-417 | 82.20 <u>+</u> 12.93 | HY118 (INDIA) /2D201 |
| 6A-354 | 82.11 <u>+</u> 7.69 | T.DURUM/AE.SQUARROSA |
| 6A-530 | 81.93 <u>+</u> 10.86 | COCORIT/UC-90 (TRIPLE DWARF) |
| 6A-640 | 81.16 <u>+</u> 21.87 | TETRA THATCHER/2D289 |
| 6A-49 | 81.13 <u>+</u> 10.55 | T.TURGIDUM/AE.SQUARROSA |
| 6A-37 | 80.58 <u>+</u> 11.38 | T.PYRAMIDALE/T.AEGILOPOIDES |
| OA-1441 | 80.39 <u>+</u> 13.89 | MANITOU/T.ORIENTALE |
| OA-1422 | 80.00 <u>+</u> 14.40 | MANITOU-ORIENTALE/CENTENO |
| 6A-66 | 79.67 <u>+</u> 18.01 | T.DICOCCOIDES/S.CEREALE |
| 6A-52 | 79.63 <u>+</u> 16.25 | T.TIMOPHEEVI/T.MONOCOCCUM |
| CB82-9 | 79.62 <u>+</u> 26.57 | UM9//ILS3.1P/HD//KGRUM9 |
| 6A-35 | 78.83 <u>+</u> 11.26 | T.DICOCCOIDES/T.MONOCOCCUM |

(continued)

Appendix 3: continued

| Accession | Score | Pedigree |
|-----------|----------------------|----------------------------|
| OA-1440 | 78.21 <u>+</u> 15.31 | 4B110/MAN |
| 6A-203 | 77.88 <u>+</u> 8.52 | T.PERSICUM/AE.SQUARROSA |
| BA82-81 | 77.10 <u>+</u> 21.76 | 6TA204/PPV13//YRE |
| CD82-84 | 75.80 <u>+</u> 13.74 | M2A/ARM"S"//BGL |
| 6A-33 | 75.48 <u>+</u> 17.47 | T.DICOCCUM/T.MONOCOCCUM |
| 6A-58 | 74.97 <u>+</u> 6.87 | STEWART/AE. ELONGATUM |
| 6A-530 | 74.86 <u>+</u> 20.71 | COCORIT/UC-90 |
| 6A-1351 | 74.62 <u>+</u> 20.80 | COCORIT/S.AFRICANUM |
| 6A-271 | 73.92 <u>+</u> 34.42 | T.DURUM/SPRING PETKUS RYE |
| OA-1437 | 73.33 <u>+</u> 24.32 | 233/PITIC |
| CB82-5 | 73.07 <u>+</u> 19.21 | 6TA204//BCO/3/BVR/TOBI |
| 6A-1367 | 72.55 <u>+</u> 16.69 | T.PERSICUM-3/BULK RYE |
| 4B-1183 | 71.86 <u>+</u> 14.40 | MED.DORMANCY DURUM |
| 6A-1479 | 71.37 <u>+</u> 25.02 | T.DICOCCOIDES/PROLIFIC |
| 6A-583 | 71.01 <u>+</u> 14.00 | JNK6T206B/73TP77 |
| 6A-698 | 70.10 <u>+</u> 25.39 | JORI/PROLIFIC |
| 6A-590 | 69.94 <u>+</u> 26.93 | ISN49/TOLUCA |
| OA-1425 | 68.12 <u>+</u> 22.39 | PITICxTURGIDUM/CENTENO |
| BA82-4 | 67.76 <u>+</u> 16.23 | 6TA204/BCO//72UM2013 |
| 6A-393 | 66.50 <u>+</u> 26.31 | T4N/PROLIFIC |
| 6A-34 | 66.44 <u>+</u> 17.08 | T.DICOCCUM/AE.CAUDATA |
| BA82-78 | 66.37 <u>+</u> 22.00 | TCC XI |
| 6A-26 | 65.82 <u>+</u> 11.92 | TUMILLO/AE.SQUARROSA |
| 6A-1421 | 64.88 <u>+</u> 27.11 | CAMARA/HERCULES |
| OA-1434 | 64.88 <u>+</u> 29.45 | PITICx110/CENTENO |
| 6A-1407 | 63.94 <u>+</u> 24.51 | T701-2 (MATHESON) /COORONG |

(continued)

Appendix 3: continued

| Accession | Score | Pedigree |
|-----------|--------------------------|--|
| 4B-1184 | 63.89 ₊ 20.29 | DORMANT RED TETRAPLOID |
| 6A-1466 | 63.76 ₊ 18.53 | T.DICOCCUM/2141 (PETKA) |
| 6A-306 | 63.69 ₊ 28.74 | TRITICALE VILLAX MARIA |
| OA-1423 | 62.75 ₊ 29.62 | DURANxPITIC/CENTENO |
| 6A-27 | 62.08 ₊ 20.60 | T.DICOCCUM (VERNAL) /AE.SQUARROSA |
| 6A-272 | 61.87 ₊ 20.05 | T.DURUM (SHARK) /S.KUPRIJANOVI |
| 6A-1421 | 61.36 ₊ 21.79 | CAMARA/HERCULES |
| 6A-1475 | 61.08 ₊ 10.53 | T.DICOCCUM/2141 |
| OA-1430 | 61.07 ₊ 24.78 | PITICx110/CENTENO//KKO PITIC/CENTENO |
| 6A-68 | 60.84 ₊ 18.80 | T.ORIENTALE/S.AFRICANUM |
| 6A-1471 | 60.35 ₊ 17.74 | JORI/2121 (S.F.S. PROLIFIC) |
| 6A-151 | 58.73 ₊ 30.01 | T.DICOCCUM/T.MONOCOCCUM |
| GLENLEA | 58.39 ₊ 20.92 | |
| 6A-359 | 58.12 ₊ 17.99 | T.PERSICUM/T.MONOCOCCUM |
| OA-1431 | 57.64 ₊ 24.34 | 4B110xPITIC/CENTENO//PITICx110/CENTENO |
| 6A-45 | 57.00 ₊ 18.35 | AE.LONGISSIMA/T.DICOCCOIDES |
| 6A-830 | 56.91 ₊ 37.45 | CML/PATO//PITIC 62 |
| 6A-639 | 56.81 ₊ 24.29 | TETRA THATCHER/PROLIFIC |
| 6A-711 | 56.40 ₊ 15.98 | T.POLONICUM/S.MONTANUM |
| 6A-1480 | 55.93 ₊ 23.06 | T.DICOCCOIDES/2380 |
| CARMAN | 55.61 ₊ 26.78 | |
| OA-1442 | 54.15 ₊ 37.24 | T.ORIENTALE/MANITOU |
| BD82-55 | 54.04 ₊ 11.89 | BGL/M2A |
| OA-1444 | 53.16 ₊ 14.48 | MANITOU/T.ORIENTALE//CENTENO |
| BD82-40 | 51.43 ₊ 13.66 | BGL/M2A |
| 6A-865 | 51.33 ₊ 11.22 | JORI/INBRED 194 |

(continued)

Appendix 3: continued

| Accession | Score | Pedigree |
|-----------|--------------|------------------------------------|
| 6A-1473 | 47.05+36.79 | TETRA PRELUDE/PROLIFIC |
| 6A-20 | 46.47+17.78 | CARLETON/S.CEREALE |
| 6A-1131 | 45.21+32.24 | ROMANIA TF3 TRITICALE |
| OA-1443 | 44.70+13.64 | T.ORIENTALE/MANITOU//CENTENO |
| 6A-271 | 44.64+22.92 | T.DURUM/SPRING PETKUS RYE |
| 6A-895 | 42.98+17.06 | T.POLONICUM-BRANT/SNOOPYx23001 OY |
| OA-1432 | 40.60+19.60 | MANx110/CENTENO//110xMAN/CENTENO |
| OA-1433 | 39.71+27.42 | 4B110xMAN/CENTENO//MANx110/CENTENO |
| OA-1446 | 36.20+25.16 | 4B110/MANITOU//CENTENO |
| 6A-1468 | 35.93+32.29 | JORI/2141 (PETKA RYE) |
| 6A-709 | 35.34+34.15 | KUBANKA/SYMKO (WINTER RYE) |
| OA-1435 | 35.28+26.63 | 4B110xPITIC/CENTENO |
| 6A-1474 | 31.63+36.10 | TETRA PRELUDE/2076 |
| 6A-391 | 28.70+14.25 | P4N-30/PROLIFIC |
| 6A-1032 | 25.23+25.02 | COCORIT/SNOOPY |
| OA-1448 | 25.03+39.65 | T.DURUM/PITIC//CENTENO |
| 6A-250 | 24.66+32.28 | T.PERSICUM/S.CEREALE |
| 6A-644 | 15.39+31.02 | TETRA PRELUDE/PROLIFIC |
| OA-1445 | 14.01+11.83 | MANITOU/4B110//CENTENO |
| OA-1438 | 12.84+13.36 | PITIC/233 |
| 6A-1504 | 6.34+14.94 | CLERCAL |
| OA-1427 | 5.87+28.51 | MANITOUxTURGIDUM/CENTENO |
| 6A-445 | -3.07+13.66 | TRITICALE TURGIDUM |
| 6A-638 | -11.18+17.94 | TETRA THATCHER/2D-289 |
| 6A-1368 | -11.99+12.09 | TETRA PRELUDE/2D289 |

Appendix 4: Comparison during maturation of germination
at 17°C and 25°C, and rain
simulator data

| Week | 17°C | | 25°C | | Rain simulator | |
|-----------------|---------|-------|---------|-------|----------------|-------|
| GLENLEA: | | | | | | |
| 2 | 98.96+ | 2.33 | 96.48+ | 3.70 | - | - |
| 3 | 83.68+ | 7.27 | 90.16+ | 5.66 | - | - |
| 4 | 83.52+ | 4.82 | 98.88+ | 2.50 | 61.61+ | 22.62 |
| 5 | -21.44+ | 4.24 | 98.72+ | 1.75 | 25.74+ | 21.49 |
| 6 | -3.53+ | 2.31 | 84.18+ | 12.06 | 13.76+ | 23.82 |
| 7 | -2.23+ | 2.46 | 46.40+ | 28.98 | -11.67+ | 19.03 |
| CARMAN: | | | | | | |
| 2 | 100.00+ | 0.00 | 100.00+ | 0.00 | - | - |
| 3 | 90.80+ | 5.51 | 97.04+ | 2.93 | - | - |
| 4 | -10.00+ | 4.58 | 95.12+ | 2.63 | 77.38+ | 15.38 |
| 5 | -4.96+ | 4.50 | 92.00+ | 3.66 | 32.56+ | 18.19 |
| 6 | 0.00+ | 0.00 | 78.88+ | 3.68 | 7.74+ | 30.84 |
| 7 | 0.48+ | 0.36 | 69.20+ | 9.12 | -1.72+ | 23.42 |
| CD82-45: | | | | | | |
| 2 | 100.00+ | 0.00 | 99.36+ | 1.43 | - | - |
| 3 | 95.04+ | 3.49 | 96.00+ | 2.48 | - | - |
| 4 | 33.04+ | 20.70 | 94.48+ | 5.98 | 62.60+ | 28.34 |
| 5 | -2.40+ | 1.62 | 100.00+ | 0.00 | 43.50+ | 22.69 |
| 6 | 0.00+ | 0.00 | 97.52+ | 2.37 | 7.54+ | 18.15 |
| 7 | -0.96+ | 1.43 | 89.44+ | 7.59 | 11.97+ | 26.80 |
| 8 | 0.00+ | 0.00 | 93.60+ | 5.58 | -23.50+ | 25.94 |
| CB82-5: | | | | | | |
| 2 | 100.00+ | 0.00 | 98.72+ | 2.86 | - | - |
| 3 | 89.76+ | 4.21 | 72.40+ | 8.06 | - | - |
| 4 | -4.32+ | 7.66 | 53.12+ | 11.69 | 16.69+ | 36.53 |
| 5 | -0.64+ | 0.88 | 64.32+ | 11.93 | -5.07+ | 21.72 |
| 6 | 1.60+ | 2.19 | 17.84+ | 20.14 | -16.93+ | 15.92 |
| 7 | 0.00+ | 0.00 | 5.77+ | 7.13 | -15.70+ | 11.03 |
| 8 | 0.00+ | 0.00 | 7.45+ | 6.61 | -23.93+ | 12.95 |

Appendix 5: Effect of temperature during maturation
on sprouting tolerance scores

| Maturation temp (°C) | Line | Germination temp (°C) | Score |
|-------------------------|--------|--------------------------|--------------------------|
| 20 | RL4137 | 17 | 86.52 _± 6.52 |
| 20 | RL4137 | 25 | 91.20 _± 7.58 |
| 20 | CB-9 | 17 | 10.76 _± 5.42 |
| 20 | CB-9 | 25 | 76.08 _± 11.96 |
| 20 | CARMAN | 17 | 12.72 _± 5.69 |
| 20 | CARMAN | 25 | 45.72 _± 11.37 |
| 20 | CB-5 | 17 | -6.52 _± 5.05 |
| 20 | CB-5 | 25 | -6.68 _± 5.73 |
| 25 | RL4137 | 17 | -7.32 _± 11.87 |
| 25 | RL4137 | 25 | 98.72 _± 1.65 |
| 25 | CB-9 | 17 | -1.04 _± 6.40 |
| 25 | CB-9 | 25 | 72.36 _± 9.44 |
| 25 | CARMAN | 17 | 17.20 _± 7.44 |
| 25 | CARMAN | 25 | 64.80 _± 6.34 |
| 25 | CB-5 | 17 | 0.56 _± 3.69 |
| 25 | CB-5 | 25 | 1.88 _± 10.87 |
| 30 | RL4137 | 17 | -28.48 _± 7.20 |
| 30 | RL4137 | 25 | 97.94 _± 3.01 |
| 30 | CB-9 | 17 | -16.24 _± 3.97 |
| 30 | CB-9 | 25 | 68.68 _± 17.91 |
| 30 | CARMAN | 17 | -2.96 _± 8.19 |
| 30 | CARMAN | 25 | 63.16 _± 17.62 |
| 30 | CB-5 | 17 | 14.36 _± 4.88 |
| 30 | CB-5 | 25 | -6.28 _± 21.57 |