EFFECT OF WEATHERING DURING DELAYED HARVEST ON TEST WEIGHT AND OTHER GRADING AND QUALITY FACTORS OF WHEAT

(*Triticum aestivum* L.)

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EDWARD MATTHEW CZARNECKI

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ABSTRACT

Czarnecki, Edward. M.Sc., The University of Manitoba, October, 1980. Effect of Weathering During Delayed Harvest on Test Weight and Other Grading and Quality Factors of Wheat (*Triticum aestivum* L.). Major Professor; L. E. Evans.

This study which was conducted over a 2 year period at three harvest dates each year, was designed to evaluate the effects of delayed harvest on test weight and other physical factors of wheat (Triticum aestivum L.). Five cultivars, four hard red spring and one utility, were tested at one location each year.

Moderate rain (4 to 6 cm) on swathed grain caused a significant reduction in test weight (5% annually). Decreases in density and packing efficiency were about equally responsible for the reduction. Loss in test weight and susceptibility to bleaching was found to be a varietal characteristic. Neepawa bleached and lost test weight more rapidly than all other wheats.

Samples from 1976 were officially graded and primarily reflected cultivar differences in susceptibility to bleaching. The better grading utility wheat Glenlea and hard red spring lines RL 4137 and RL 4348 were more resistant to bleaching and test weight loss. The grades assessed to

RL 4137 and Neepawa did not accurately reflect differences in falling number among samples of the second and third harvests.

The 1000-kernel weight decreased significantly by 1% in 1976. Grain hardness decreased significantly for both years with delayed harvesting. Rates were similar for all cultivars. The hard-grained cultivar Glenlea, was highly resistant to test weight loss and bleaching. From the results of delayed harvesting studies, it was concluded that moderate rains on swathed grain can cause severe test weight loss and bleaching and subsequent degrading in wheat. Cultivars differed in resistance to both factors indicating improved selection is possible.

I. INTRODUCTION

The major areas of wheat production are located in the temperate regions (Loomis, 1976) and in the northern hemisphere in particular the fall harvest frequently coincides with inclement weather (Mckay, 1975). On the Canadian prairies the maturing grain is generally windrowed to promote uniform ripening and to avoid prolonged exposure which can result in a loss of quality and yield due to climate, green weeds or insects (Dodds, 1966). Adverse weather before harvesting may bleach the grain and cause damage ranging from physically non-evident enzyme activity (Olred, 1967) to fully sprouted kernels. Fluctuating moisture levels may also affect test weight (bulk density) and the percentage of vitreous kernels. Test weight, bleaching and percentage vitreous kernels are some of the major factors considered in Canadian wheat grading as these reflect the nature and degree of weathering. Grain may also be degraded because of diseased kernels, frost, foreign matter, immature kernels and insect damage.

Preliminary tests indicated that Neepawa, a cultivar grown on considerable acreage, bleached and rapidly lost test weight when exposed to a heavy shower or series of light rains. In contrast, an unlicenced line, RL 4137, grown under similar conditions appeared more tolerant to test weight and color loss (Table 1). A cultivar with more resistance to bleaching and test weight loss could conceivably receive a better grade ultimately benefiting the producer. Whether this type of cultivar would be superior for baking and milling characteristics would require further research. A significant test weight loss due to wet seasons would emphasize the importance of early harvesting in the wetter areas of production. Economics permitting, the acquisition of a grain drier may not only reduce degrading but hasten the entire harvest operation. Identification of

TABLE 1. Test weight loss and degree of bleaching.[1]

Cultivar	Test weight loss (kg/hl)		Bleaching resistance
	1974	1975	1975
Neepawa	3.9	4.5	Poor
Glenlea	-	2.4	Good
RL 4137	2.0	2.9	Good
RL 4347	-	4.2	Fair
RL 4348	-	3.0	Good

[1]Mean of two replicates.

superior genotypes would direct selection toward the development of better adapted cultivars.

This study was initiated to examine the effect of prolonged exposure on swathed wheat, particularly to observe any major physical changes in the grain which can have implications on the grading system. Five hard red spring wheat cultivars were to be investigated through three harvest dates.

II. LITERATURE REVIEW

1. Definition of Test Weight

Historically one of the oldest, simplest and most widely used criteria of physical quality in grain marketing is the weight per unit volume or test weight (Zeleny, 1971; Pushman and Bingham, 1975). Test weight, expressed in kilograms per hectoliter or pounds per bushel, is the weight of grain which fills a specified volume under standard packing conditions (Hlynka and Bushuk, 1959; Pushman and Bingham, 1975). The hectoliter or bushel weight is established as a basic standard in most wheat grading systems, however, depending on the type and class of grain, minimum specifications can vary widely among the major exporters (Bushuk, 1978; Table 2). Test weight determinations are made on dockage free grain according to regulatory procedures. Impurities such as weed seeds, chaff and other grains which would adversely affect packing (Thomas, 1917) are thus eliminated.

1.1 Test Weight as an Indicator of Flour Yield

A high test weight is usually associated with sound well-filled kernels (Thomas, 1917). Within a cultivar sound plump kernels contain a greater proportion of endosperm to bran compared to shrivelled or shrunken samples so that a

TABLE 2. Minimum test weight specifications for highest quality bread wheat grades[1] (kilograms/hectoliter).[2]

Country	Grade			Class
	No. 1	No. 2	No. 3	
Argentine	78.0	75.0	72.0	Hard Red
Australia	74.0	74.0	71.1	Hard White
Canada	75.0	72.0	69.0	Hard Red Spring
France	76.0	75.0	--	Strong White
United States	74.6	73.4	70.8	Hard Red Spring
	77.2	74.6	72.1	Hard Red Winter

[1]Abstracted from Bushuk (1978).

[2]Basis cleaned sample.

high test weight potentially indicates higher flour extraction (Bailey, 1916; Mangels and Sanderson, 1925; Scott, 1951; Shuey, 1960; Merkle et al, 1969). Although many studies have supported the test weight-flour yield relationship, the experimental evidence has not always been consistent. Thomas (1917) observed a definite relationship between test weight and flour yield among several classes of American wheat. In a study of over 1600 North Dakota hard red spring wheat samples (8 year sampling) Mangels and Sanderson (1925) obtained a correlation coefficient of 0.76 between test weight and flour yield. Bailey and Markley (1933) determined correlations ranging from 0.62 to 0.76 among 40 samples milled by a commercial mill and two laboratories. Shuey (1960) reported a correlation coefficient of 0.74 between test weight and milling yield for 287 wheat samples tested between 1949 and 1954. Non-significant or non-linear relationships have been reported by Swanson (1941), Ali Altaf et al. (1969), Ghaderi et al. (1971) and Pushman and Bingham (1975). Swanson (1943) concluded that field exposure reduced test weight of 5 hard winter wheats by over 2 kilograms per hectoliter with no reduction in flour yield. Similarly, Shuey (1960) found no significant difference in flour yield between wheats differing by over 4 kilograms in test weight. Ali Altaf et al. (1969) observed that out of 9 strains grown at one location and 13 strains at another, only one location gave a significant test weight-flour yield correlation. Kernel volume, density of endospern and moisture content were indicated as major factors in milling yield. Ghaderi et al. (1971) reported no significant correlation between test weight and milling yield from a study of 59 soft winter wheats grown in Michigan. Some classes of wheat have inherently low test weights which is not reflected in reduced flour yield (Barmore and Bequette, 1965; Pushman and Bingham, 1975). Pacific Northwest club wheats are discounted for their low test weight yet have flour yields 5% above other common white cultivars. Among the higher yielding cultivars in the United Kingdom, Maris Huntsman has a 70% flour yield but an unusually low test weight caused by a kinking in the crease that results in less efficient packing. These examples of non-significant correlation suggest that there are varietal and environmental factors which affect test weight without influencing flour yield. Zeleny (1971) concluded that at values above 73.4 kg/hl (57 lbs/bus) test weight was not a reliable index of flour yield. Watson et al. (1977) indicated that because of the increased number and types of American cultivars now grown commercially, the relation between test weight and flour yield was no longer as reliable.

1.2 Importance of Test Weight in Grain Grading

Murphy (1955) reported that test weight was the oldest criteria used in the marketing of grain while Mangels and Sanderson (1925) noted that in the United States, test weight was used as a grade factor even before federal standards were established. Zeleny (1971) stated that weight per unit volume was an important factor in all wheat grading systems. Grain grading systems have been designed and adapted by many countries to establish a market value for their grains and to provide uniformity and efficiency in handling and processing (Bushuk, 1978).

In Canada grain is visually assessed on physical characteristics related to quality and grades are assigned in accordance with specifications established under the Canada Grain Act. The main grading factors considered under standards of quality are, test weight, cultivar, percentage vitreous kernels and degree of soundness (Table 3). The degree of soundness is a guide to possible kernel damage which may be due to frost, immaturity, diseases, drought,

TABLE 3. Standard of quality for grades of hard red spring wheat.[1]

Grade name	Min. wt. per measured bus. in lbs.	Min. % by wt. of hard vitreous kernels	Degree of soundness
No. 1 Canada Western Red Spring[2]	59 (75)	65	Reasonably well matured, reasonably free from damaged kernels
No. 2 Canada Western Red Spring[2]	57 (72)	35	Fairly well matured, may be moderately bleached, or frost damaged, but reasonably free from severely weather damaged kernels
No. 3 Canada Western Red Spring[3]	54 (69)	--	Excluded from higher grades on account of frosted, immature or otherwise damaged kernels

( ) = kg/hl

[1]Abstracted from Grain Grading Handbook for Western Canada, Canadian Grain Commission, 1975.

[2]Marquis or any variety equal to Marquis.

[3]Any variety of fair milling quality.

weathering or other factors. A high test weight is usually associated with sound vitreous grain (Scott, 1951). Test weight specifications are also a basic factor in the grade schedules of the major wheat exporting countries (Table 2). Recently, there has been an attempt to reassess some of the grade standards in the United States (Philips and Niernberger, 1976; Watson et al., 1977). In a study of hard red winter wheats, Philips and Niernberger,(1976) observed that dark hard vitreous kernels and test weight were positively and highly correlated. Protein content was shown to be a much better indicator of loaf volume than percentage of dark hard vitreous kernels. Subsequently, subclasses of hard red winter wheat (based on percent dark hard vitreous kernels) have been eliminated from the American specifications (Watson et al., 1977). An extensive study relating grading, wheat quality factors and end use quality characteristics in commercial hard red spring wheats (harvested over a 5-year interval) was conducted by Watson et al. (1977). Test weight and protein were attributed to be the best indicators of quality for hard red spring wheat when used for pan bread. In correlations with quality factors, test weight consistently correlated better than the percentage of dark red vitreous kernels. Shellenberger (1979) questioned the importance of test weight as a factor in grading and advocated wider differences between grades. The accession of the United Kingdom to the European Economic Community established that commercially transacted wheats be subject to test weight criteria. Pushman and Bingham (1975) recommended that requirements in test weight not be fixed for all cultivars.

2. Components of Test Weight

Test weight is a complex character dependent on kernel density and the packing characteristics of the grain (Roberts, 1910; Thomas, 1917). A decrease in either or both components would cause reduced test weight. Test weight is generally determined on dockage free grain since any low density impurities would reduce bulk density. In contrast, dense impurities such as metal or stone may contribute to the overall test weight.

2.1 Kernel Density

Kernel density or specific gravity is calculated from weight-volume determinations and if the kernel dry weight remains constant any net change in volume would be reflected by a corresponding change in density.

2.1.1 Factors Affecting Density

(a) Cultivar and environment. Wide differences in density may be found within the same cultivar or between classes. Peters and Katz (1962) found that kernels from a homogeneous sample of hard red spring wheat ranged from 1.29 to 1.41 g/cc (moisture constant). Baker et al. (1965) reported that hard red spring wheats had higher average densities than the soft red winter class.

The addition of nitrogenous fertilizer to ten varieties of winter wheat grown in England increased the mean density by 1.8% (Pushman and Bingham, 1975). The grain density ranged from 1.331 to 1.398 g/cc. Addition of nitrogen tended to narrow the cultivar range by one-half.

The density of Kanred winter wheat was significantly different in a two year comparison (Bracken and Bailey, 1928). The higher density and increased vitreousness of the 1925 crop was attributed to a slightly higher spring soil nitrate content and reduced grain yield.

(b) Chemical Composition and Physical Characteristics of the Grain. The approximate composition and density of the various kernel components are compared in Table 4. The main kernel components are starch, protein and water and their relative contribution would be expected to reflect the overall density of the grain. The addition of moisture has been shown to linearly decrease kernel density (Sharp, 1927; Tkachuk and Kuzina, 1979). Endosperm density was also shown to be linearly related to moisture content (Jones and Campbell, 1953). Baker et al. (1965) and Tkachuk and Kuzina (1979) found that the rate of change in density (with added moisture) was greatest above 12% moisture content.

The addition of moisture and subsequent drying of grain has been shown to result in a net increase in kernel volume (Sharp, 1927; Bracken and Bailey, 1928; Scott, 1951; Campbell and Jones, 1955; Pushman, 1975). Bushuk and Hlynka (1960) reported that wheat subjected to a sorption-desorption cycle in the moisture range 0-26%, resulted in a net decrease in density of 0.014 g per ml.

TABLE 4. Kernel composition and density.[1]

Kernel component	Range %	Density g/cc
Water	8-18	1.000
Protein	7-18	1.297
Ash	1.5-2.0	2.5
Lipids	1.5-2.0	0.91-0.96
Starch	60-71	1.53
Sugar	2.3-3.5	1.61
Cellulose	2-3	1.53
Air	N/A	0.001293
Pericarp	5.8-9.5	1.24
Embryo	2-4	1.34
Endosperm	75-86	1.39-1.46

[1]Abstracted from Sharp, 1927; Scott, 1951; Jones and Campbell, 1953; MacMasters et al., 1971.

The relationship between starch and protein and their effect on density is not clear. Tkachuk and Kuzina (1979) found a highly significant negative correlation between protein content and density among 6 varieties of hard red spring wheat. This was in contrast to previous reports where higher protein content correlated with increased density (Sharp, 1927; Bracken and Bailey, 1928; Pushman and Bingham, 1975). The densities of wheat starch and protein have been determined as 1.53 and 1.30 respectively (Table 4). A high starch-low protein combination could presumably be reflected in higher density. This paradox is explained by the packing of protein into the interstitial spaces between the starch granules (Scott, 1951; Ghaderi et al., 1971).

Hard vitreous kernels of wheat which are flinty and translucent, are normally associated with higher protein and density (Roberts, 1919; Sharp, 1927; Philips and Niernberger, 1976). Vitreous kernels generally command a premium over piebald or yellowberry wheats because of their superior protein content and flour extraction (Table 5).

TABLE 5. Comparison of vitreous and piebald wheats.[1]

	Spring Wheat		Winter Wheat	
	Vitreous	Piebald	Vitreous	Piebald
Specific gravity g/cc	1.4207	1.4063	1.4227	1.4034
Flour Yield %	71.0	69.3	71.0	67.6
Nitrogen %	2.48	1.93	2.27	1.60

[1]Abstracted from Scott (1951).

Shollenberger and Coleman (1926) separated three classes of wheat (hard red spring, hard red winter and durum) into dark, mottled and starchy categories. In comparison to the starchy wheats, the dark hard vitreous group had a higher protein content, higher flour yield, greater test weight and higher specific gravity (Table 6). The mottled category had a relatively high test weight, specific gravity and flour yield with a decreased level of protein content. Presumably, the starch content (density of 1.53 g/cc) was similar in both the dark and mottled group. Scott (1951) reported similar results among spring and winter wheats (Table 5).

TABLE 6. Comparison of dark, mottled and starchy wheats.[1]

	Class		
	Dark	Mottled	Starchy
Test weight kg/hl	77.6	78.2	76.6
Specific gravity g/cc	1.3996	1.3845	1.3425
Flour yield %	73.0	72.7	71.8
Protein %	12.0	9.6	8.8

[1]From Shollenberger and Coleman (1926).

Piebald or yellowberry kernels contain air vacuoles in the endosperm (Bracken and Bailey, 1928) and are degraded in the marketplace because of the lower protein content (Philips and Niernberger, 1976). Sound hard wheat which has been subjected to prolonged wetting and drying, not only undergoes a net increase in kernel volume, but also becomes mealy or chalky-opaque in appearance (Sharp, 1927; Bracken and Bailey, 1928; Swanson, 1943b; Campbell and Jones, 1955). The main distinction between piebald and weathered kernels is the reduced density, bleached bran and chalky endosperm appearance of weathered kernels (Table 7).

TABLE 7. Comparison of vitreous, piebald and weathered grain.[1]

	Vitreous	Piebald	Weathered
Density g/cc	1.4207	1.4063	1.3749
Nitrogen %	2.48	1.93	2.48
Flour Yield %	71.0	69.3	71.0
Endosperm	Flinty, hard, translucent	Flinty, scattered vacuoles	Mealy, chalky, opaque, starchy
Bran	Non-bleached	Non-bleached	Bleached
Air spaces	Few	Scattered pockets	Extensive throughout

[1]Compiled from Sharp, 1927; Bracken and Bailey, 1928; Swanson, 1946; Scott, 1951; Milner and Shellenberger, 1953.

2.2 Packing Efficiency

Packing efficiency (or packing quality by Roberts, 1910) refers to the percent of bulk volume occupied by the grain (Yamazaki and Briggle, 1969). The complement would be air space or porosity (Tkachuk and Kuzina, 1979). Packing efficiency has been reported to range from 48 to 60% (Pushman and Bingham, 1975; Tkachuk and Kuzina, 1979).

2.2.1 Factors Affecting Packing Efficiency. Kernel packing efficiency is affected by kernel shape and seed coat characteristics (Scott, 1951; Ghaderhi et al., 1971).

(a) Kernel Shape and Uniformity of Size. Roberts (1910) showed that provided all other factors remain equal, a smaller length to width ratio could increase test weight by 1.7 kg/hl. Ghaderi et al. (1971) found that the kernel length-width ratio was responsible for 39% of the variability in test weight. Bhattacharya et al. (1972) stated that spherically-shaped kernels in comparison to long slender ones, pack more efficiently resulting in less void space in bulk grain. A wide or folded crease (the latter found in Maris Huntsman) or surface concavities also add to the void ratio (Pushman and Bingham, 1975). Merkle et al. (1969) concluded that seed thickness (depth) contributed the major variation in test weight, however, Ali Altaf et al. (1969) found no significant correlations between kernel length, width, thickness and test weight. According to Scott (1951), Yamazuki and Briggle (1969) and Gotoh and Finney (1974) the theoretical packing efficiency of equal spheres should be about 67.8%, 60.5%, or 64% respectively. Monosized regular ellipsoides show similar packing efficiency as spheres (Yamazuki and Briggle, 1969) and although the wheat kernel is not an exact ellipsoid, it resembles that form in addition to retaining a fair uniformity of shape for kernels of different sizes. Humpbacked kernels increase distances between centres of kernels. Club wheats, which have typically humpbacked kernels have reduced packing efficiency and are generally downgraded because of low test weight (Barmore and Bequette, 1965), even though flour yields are 5% greater than for other local common wheats.

Under standard packing conditions, a heterogeneous mixture of kernels would be expected to pack more effectively than a uniformly sized sample (Hlynka and Bushuk, 1959).

(b) Seed Coat Characteristics. The surface of the kernel may be rough or smooth depending on the variety and weathering history (Thomas, 1917; Swanson, 1946). The durum variety, Golden Ball, is often wrinkled on the dorsal side in comparison to Mindum which has a smooth bran (Dollery and Owen, 1950). Wetting and drying, drought and frost can also cause bran wrinkling (Swanson, 1943; Shebeski et al., 1950). Some durum wheats in contrast to hexaploids have no brush and pack better (Dollery and Owen, 1950).

The surface coefficient of friction of a particular wheat may affect its packing and consequently, test weight (Scott, 1951). Handled grain, achieves a more polished surface and packs more tightly (Swanson, 1943). An increase in grain temperature tends to raise the coefficient of surface friction and also increases kernel volume both of which tend to lower test weight (Scott, 1951).

(c) Kernel Size. Most reports indicate that kernel size does not appreciably influence air space and hence test weight, however, evidence is contradictory (Scott, 1951; Yamazuki and Briggle, 1969).

Hlynka and Bushuk (1959) indicated that the components of 1000-grain weight were kernel volume and density and although the volume of the kernel would not be expected to be related to test weight the density would be directly related. Pushman and Bingham (1975) found that varietal differences in test weight were positively correlated with grain density and protein but were not related to 1000-grain weight. Ghaderi et al. (1971) separated commercial cultivars into different sized kernels and found that smaller-sized kernels, due to their shrivelled poor packing condition, gave lower test weights. Tkachuk and Kuzina (1979) obtained a highly significant positive correlation between test weight and 1000-grain weight but unlike the results of Pushman and Bingham (1975), only density (and not protein) was correlated with hectoliter weight. The 1000-grain weight in the Tkachuk and Kuzina (1979) study had a smaller range (11 vs 15g), mean (34 vs 57g) and standard deviation (2.8 vs 4.33) as compared to Pushman and Bingham (1975). No data were provided on uniformity of kernel size in either study although packing efficiency means and range were similar.

3. Effect of Weathering on Test Weight

In some years a substantial amount of wheat grown in western Canada is degraded (Table 8). Three major factors, bleaching, loss of vitreousness and test weight reduction of unharvested ripe grain resulting from adverse weather conditions are the usual cause of much degrading.

The effects of weathering (exposure to bleaching and alternate wetting and drying) are well documented (Bracken and Bailey, 1928; Whitcomb and Johnson, 1928; Larmour et al., 1933; Swanson, 1946). Bleaching occurs to the bran pigments of ripened grain and is caused by the combined effects of a light rain or heavy mist and sunlight, but has no apparent adverse effect on quality (Larmour et al., 1933; Swanson, 1936, 1943). The loss of vitreousness caused by kernel expansion enhances the weathered effect. Bleached grain is regarded as evidence of weathering and tolerances establishing severity are outlined in the statutory wheat grade standards for quality (Table 3).

TABLE 8. Annual distribution of grades[1] 1968-1978.

Crop year	Percent production			
	1 CW[2]	2 CW	3 CW	3 CU[3]
1968	14	20	--	66
1969	66	16	--	18
1970	57	23	12	8
1971	68	25	7	--
1972	39	36	25	--
1973	45	34	14	4
1974	17	25	29	26
1975	20	45	28	7
1976	70	21	5	4
1977	21	22	37	16
1978	30	32	27	8

[1]Abstracted from Canadian grains industry statistical handbook 1976, Canada Grains Council and Canadian Red Spring Wheat Crop Bull. 1968-1978, Canadian Grain Commission.

[2]Grades. Canada Western Red Spring, Canada Utility.

[3]Includes degraded hard red spring wheat also. Glenlea licensed in 1972.

Test weight loss due to delayed harvest is commonly encountered in Western Canada and the midwestern states (Whitcomb and Johnson, 1928; Pool et al., 1958, Johnson, 1959). Test weight losses of 8% on spring wheats (Whitcomb and Johnson, 1930) and 9% on soft red winter (Pool et al., 1958) have been observed. Loss of test weight can be due to roughening of the bran coat which counteracts grain packing (Swanson, 1941; Milner and Shellenberger, 1953; Johnson, 1959), a net decrease in kernel density (Bracken and Bailey, 1928; Whitcomb and Johnson, 1930) or decrease in kernel dry weight (Whitcomb and Johnson, 1928; Pool et al., 1958).

3.1 Effect of Weathering on Kernel Packing

Swanson (1946) indicated that small amounts of wetting and drying may produce a significant reduction in test weight primarily due to decreased packing efficiency. Whitcomb and Johnson (1930) observed packing efficiency decreases of 41 and 63% on overwintered shocks of Marquis and Kanred wheats respectively.

3.2 Effect of Weathering on Kernel Density

A net decrease in kernel density has been commonly associated with loss in test weight. Density reductions of 5% were determined by Bracken and Bailey (1928) and Whitcomb and Johnson (1930). Sharp (1927) found that sound wheat which was moistened and redried, did not regain its former density but gained volume according to the degree of moistening (wetting was limited to approximately 20%). A hard wheat, Kubanka durum, had the least density change, Marquis was intermediate while Pacific Bluestem, a white wheat had the largest increase. This was an early indication that there may be varietal differences under field conditions. Bracken and Bailey (1928) observed that low density and low protein wheat showed a greater net increase in volume after exposure, than wheat of a higher density and protein content. The reduction in density of moistened endosperm particles was found to be fully reversible on drying (Campbell and Jones, 1955) but full reversibility disappeared if the moisture content was raised to over 20%. In contrast, even slight moistening of whole grains caused a density reduction that was not fully reversible on subsequent drying. The difference in behaviour between whole grain and endosperm was attributed to permanent changes in bran structure. Bushuk and Hlynka (1960) predicted a 1% net decrease in test weight (due to density loss) following a 10% wetting and drying range.

3.3 Effect of Weathering on Kernel Weight

In a study of the effects of delayed harvests on soft winter wheat, it was estimated that loss in kernel weight accounted for 31% and 18% of the test weight reduction over 2 consecutive years (Pool et al., 1958). Dry matter losses have also been reported by Johnson (1959) (1.4%) and Whitcomb and Johnson (1928).

3.4 Degree and Frequency of Wetting

Swanson (1943b) demonstrated that one severe wetting had a much more drastic effect on the reduction of test weight than several light wettings. Wheat moistened to 26% and redried reached near maximum test weight loss and was little affected by similar subsequent treatments. Samples wetted (to 14% moisture content) and redried up to six times, did not attain the equivalent reduction of one severe wetting.

4. Effect of Moisture Fluctuation on the Kernel

The moisture content of ripening wheat continues to fall until the equilibrium moisture level is reached or until the saturation deficit is relatively low (Robertson, 1957). Grain maximum dry weight is attained at approximately 35% moisture content (wet basis; Hyde, 1971) or the stage at which swathing is recommended (Dodds, 1957). Moisture content continues to fall as the drying process is maintained, drying depending on the ambient air saturation or vapour pressure deficit; the latter being influenced by a combination of temperature, sunshine and wind (Robertson, 1956). Drying may be interrupted by nights of cool temperatures, condensation or rainfall. During periods of low vapour pressure deficit, high relative humidity, condensation or mist may maintain or slightly increase kernel moisture but major gains can only be attributed to rainfall (Robertson, 1956; Blight, 1962; Dodds and Pelton, 1968). Following heavy dew, moisture contents of wheats averaged 18% (Pool and Patterson, 1958) while after 0.25 cm of rain the same wheats averaged 24%. Drying can be rapid as in one day the moisture content decreased from 26 to 14%.

As reviewed earlier condensation, dew or rainfall may cause bleaching and a net increase in kernel volume. Sufficient wetting of the ripened grain may also cause vitreous kernels to become chalky in appearance and mealy internally (Sharp, 1927; Bracken and Bailey, 1928; Whitcomb and Johnson, 1930; Larmour et al., 1933). Sharp (1927) found that when vitreous kernels were moistened to between 18 and 25% and then dried the resulting kernels were always opaque and when cut were starchy in appearance. Swanson (1946) obtained similar chalkiness at 25% moisture on winter wheats while Milner and Shellenberger (1953) suggested that moistening to 20% or more resulted in mealiness.

The decrease in density and development of mealiness of weathered grain is also associated with the development of internal fractures radiating in towards the centre of the kernel causing a difference in the refraction of light and allowing the entrance of air (Bracken and Bailey, 1928). Internal fissuring first proposed by Sharp (1927) was detected radiographically by Milner et al. (1952) as radial and transverse cracks. Rapid drying of high moisture content immature wheat (38 to 50%) did not produce fissuring (Milner and Shellenberger, 1953), however, the same grain when rewetted and dried, fissured readily indicating a fundamental change in the structure of the endosperm with maturation.

Grosh and Milner (1959) found that fissuring occurred in hard vitreous endosperm in advance of water movement through the kernel. Cracks were most discernible at moisture levels employed in commercial tempering (17%). The cracking phenomena was not detectable in soft or mealy hard wheats. Under laboratory tests, Milner and Shellenberger (1953) determined that fissuring was promoted when moisture-swollen grain was subjected to stress under high temperatures causing very rapid drying.

The mechanism of fissure formation is not fully understood. It is postulated that a residual stress is set up within the wheat endosperm during kernel maturation (Grosh and Milner, 1959). A gradient of swelling forces is also produced when moisture is absorbed. At some point the combined stresses cause the kernel to fracture. Apparently, for most kernels, the internal stresses are not released until a moisture gradient is established.

Weathered grain has been found to absorb water more rapidly and this is thought to be due to the capillary effect of the fissures (Milner and Shellenberger, 1953). Grain hardness and energy requirement for grinding are also reduced with weathering (Bracken and Bailey, 1928; Swanson, 1941; Johnson, 1959). Weathered grain would thus be more susceptible to fracture during harvest, introducing another degrading factor although some of this may be removed as dockage.

Pool and Patterson (1958) noted that cultivars of soft red winter wheat differed significantly in the rates at which they absorbed and lost moisture. The rate of change of absorption properties also differed among cultivars in the delayed harvest period. The most rapidly drying cultivars also absorbed more water. Sharp and Gortner (1923) reported that glutens from different varieties varied in their imbibitional properties even though the protein contents were similar. Fraser and Haley (1932) indicated that soft wheats absorb less water than hard wheats but that protein content differences had no effect on absorption.

According to Swanson (1943), Bracken and Bailey (1928) and Pool et al. (1958) weathered wheats may be unfairly degraded. No significant variation was found in protein content, flour yield or baking performance in comparisons between weathered and non-weathered wheats (Whitcomb and Johnson, 1928 and 1930; Swanson, 1943c). Baking absorption was also unaffected (Bracken and Bailey, 1928; Swanson, 1941). Flour ash increased in one study (Whitcomb and Johnson, 1928) but Swanson (1941, 1946) found no differences.

One of the most serious problems associated with adverse weather is the development of alpha-amylase activity (Bingham and Whitmore, 1966). Enzyme activity may develop depending on the cultivar grown and the amount of exposure. Unless sprouting is evident, amylase activity can only be detected by laboratory tests. The alpha-amylase activity affects the starch and gluten components of flour and has a detrimental effect on breadmaking properties.

5. Inheritance of Test Weight and Breeding for Resistance to Weathering

Roberts (1910) indicated that test weight may be increased dramatically by selection for an optimum packing type kernel. Varietal differences in net decrease of density after wetting and drying was demonstrated by Sharp (1927). In studies conducted on the components of test weight in winter wheats grown in Michigan and Ohio, no relationship was found between varietal density and test weight (Yamazuki and Briggle, 1969; Ghaderhi et al., 1971). A highly significant positive correlation was obtained between packing efficiency and test weight indicating that packing tendency was a strong varietal characteristic. Pushman and Bingham (1975) reported similar results among United Kingdom winter grown wheats. Kernel density was not associated with cultivars but reflected the effect of location and environment. These studies concluded that any breeding program directed towards improvement of test weight should ignore density and concentrate on packing criteria such as kernel shape and surface characteristics.

Pool et al. (1958) observed the effect of several harvest dates on three cultivars of soft red winter wheat and determined that the test weight decrease during the delayed harvest period was highly significant, however, the interaction between cultivar and harvest date was not significant in any of the 3 years.

A study of genotype-environmental interaction of test weight and its components in Eastern soft winter wheat by

Ghaderi and Everson (1971) identified lines that were relatively resistant to environmental variation and always had good test weight performance. These lines would apparently have a high test weight to begin with and in relation to other genotypes, would not lose test weight as rapidly. As density was an environmental characteristic, the superior lines would be more resistant to loss in packing efficiency or dry matter.

III. MATERIALS AND METHODS

Five cultivars of spring wheat, Triticum aestivum L. em Thell., were selected for this experiment. The cultivars and pedigrees are indicated in Table 9. Neepawa is a commercial hard red spring wheat widely grown in western Canada. Glenlea, a recently licensed utility wheat was developed by the University of Manitoba. RL 4137, a cultivar developed by the Winnipeg Agriculture Canada Research Station, is noted for its sprouting resistance. RL 4347 and RL 4348 are two backcross lines (developed in Winnipeg) which were known to differ in test weight loss and degree of bleaching. The five cultivars are very similar in time to maturity.

A split-plot design was used with the five cultivars being the main plots and harvest dates as subplots all comprising a block which was replicated six times. Each subplot consisted of four 5 m rows sown at a rate of approximately 350 seeds per row at a spacing between rows of 15 cm. Three adjacent sub-plots 46 cm apart made up the main plot of each cultivar (Figure 1). Three harvest dates were used following a common date of swathing. A guard row of Glenlea divided each cultivar providing separation prior to and protection after swathing. Additional plots of Neepawa and RL 4137 were sown for observing test weight changes

Figure 1. Experimental main and subplots at the University of Manitoba, Winnipeg, Manitoba.

TABLE 9. Cultivars and their pedigree.

Key	Cultivar or station no.	Pedigree
1	Neepawa	RL 4125/RL 4008
2	RL 4137[1]	RL 2520//Canthatch
3	Glenlea	Pembina *2/Bage//CB 100
4	RL 4347[1]	Neepawa *6/RL 4137
5	RL 4348[1]	Neepawa *6/RL 4137

[1]Agriculture Canada, Winnipeg Research Station accession numbers.

Accession numbers parentage:

RL 2520 - Frontana//McMurachy/Exchange/2 *Redman
RL 4008 - Thatcher *2//Frontana/Thatcher
RL 4125 - Thatcher *7/Frontana//Thatcher *6/Kenya Farmer
CB 100 - Sonora 64//Tezanos Pintos Precoz/Nainari 60

throughout the trials. The experiment was conducted for two years, in 1976 at the University of Manitoba campus site and in 1977 at the Agriculture Canada Research Station experimental farm located 12 miles south of Winnipeg. Precipitation and humidity data were obtained from local records. The swathing and harvest dates together with the precipitation and grain moisture content are illustrated for both years (Figure 2, 3). The accumulated precipitation between harvest dates and daily humidity values are also recorded (Appendix Table 1 and 2 respectively). In 1976 the crop was windrowed at approximately 35% moisture content, whereas swathing of the 1977 crop was delayed due to saturated field conditions and averaged 16% moisture when cut.

Figure 2. Swathing, harvest dates, grain moisture and precipitation, 1976.

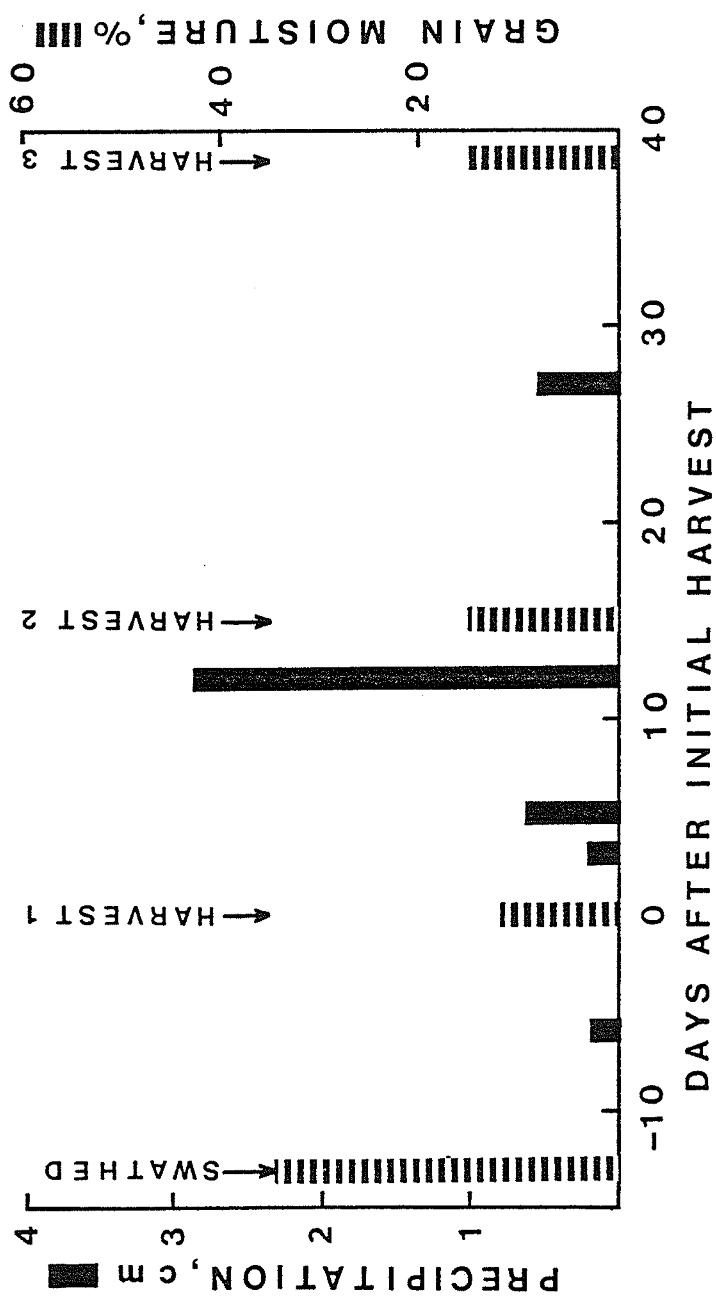
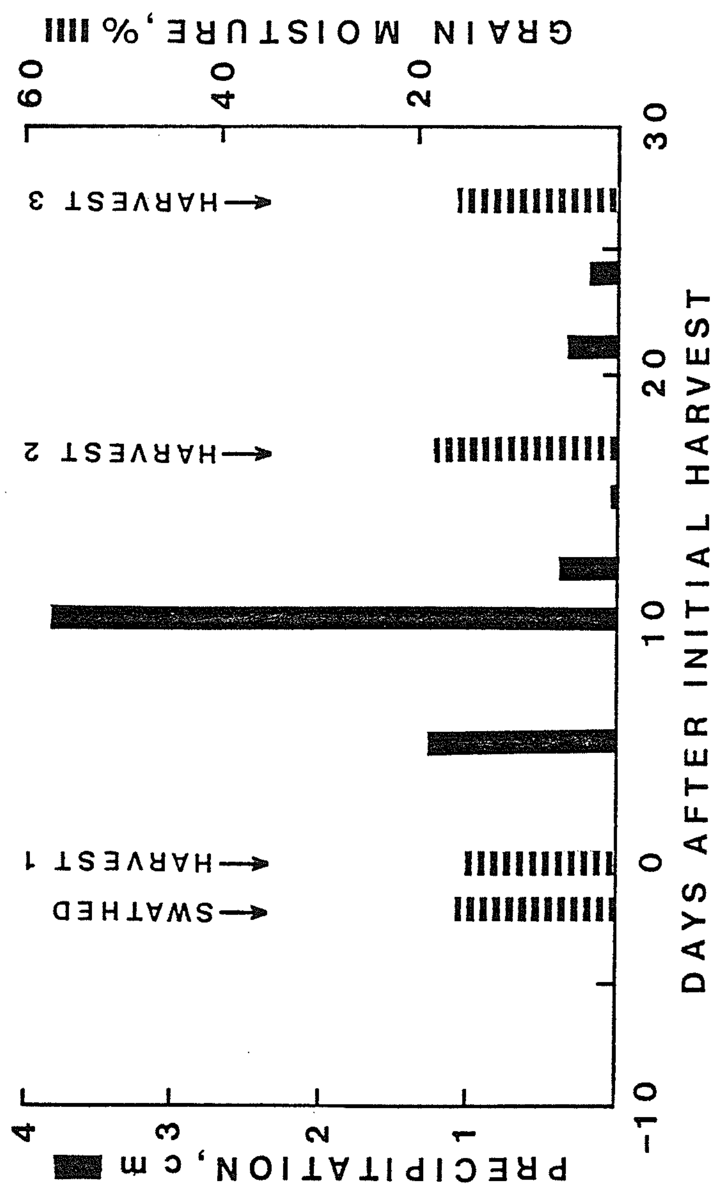

PRECIPITATION, cm
GRAIN MOISTURE, %
DAYS AFTER INITIAL HARVEST
SWATHED
HARVEST 1
HARVEST 2
HARVEST 3
-10
0
10
20
30
40
1
2
3
4
20
40
60

Figure 3. Swathing, harvest dates, grain moisture and precipitation, 1977.



GRAIN MOISTURE, %
60
40
20
PRECIPITATION, cm
4
3
2
1
-10
0
10
20
30
DAYS AFTER INITIAL HARVEST
SWATHED
HARVEST 1
HARVEST 2
HARVEST 3

Swathing was done with a modified Italian binder and threshing with a Hege model 125 small plot combine. Grain samples were stored indoors in cloth bags until the moisture content reached equilibrium.

Characteristics studied included test weight, density, packing efficiency, grinding time, moisture content, grade, falling number (1976 only) and 1000 kernel weight. All determinations were obtained on dockage free grain.

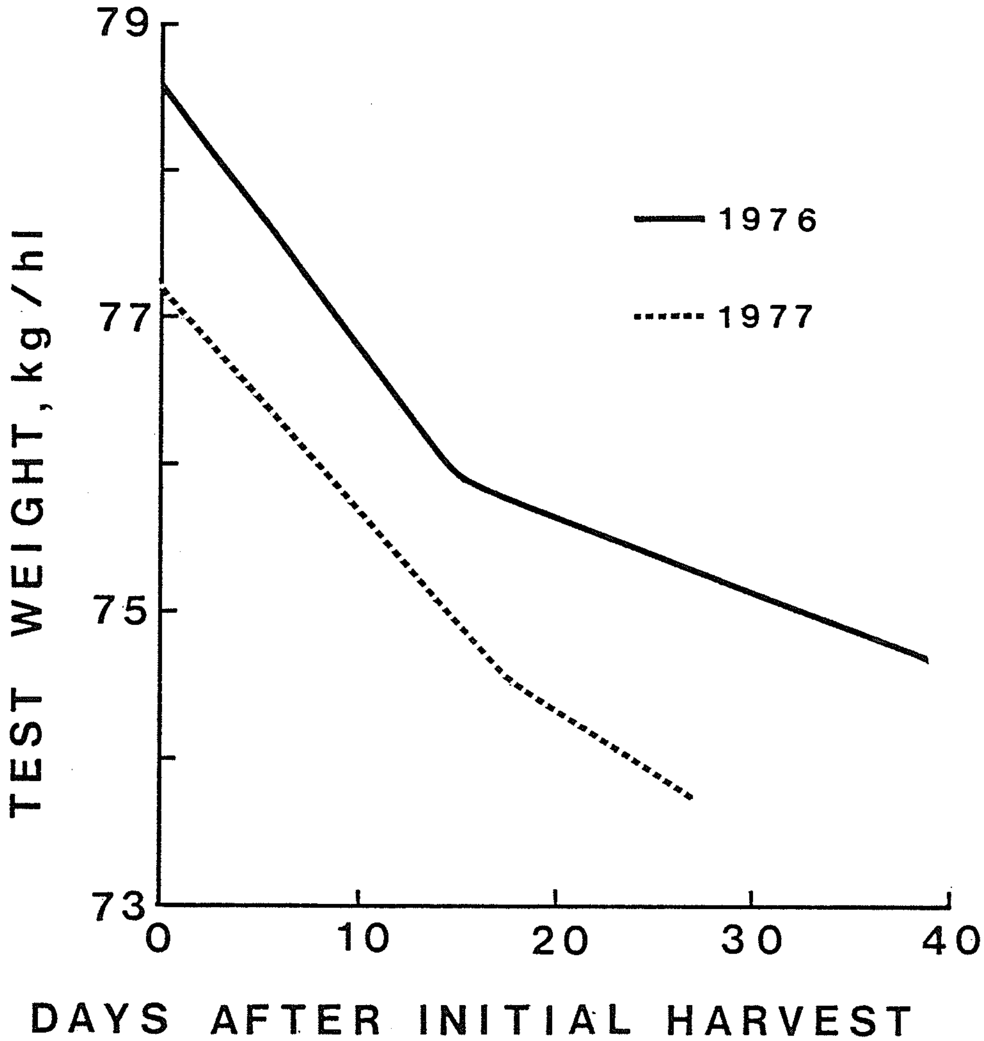
Test weight was determined by the Canadian method employing the Imperial pint measure and Cox funnel; the resulting weight of a pint of wheat was multiplied by 64 to provide bushel weight. Hectoliter weights were calculated by multiplying bushel weight by a factor of 1.247. Percent moisture content was determined in two ways; (i) Model 919 Moisture Meter and accompanying tables (winter wheat factors used for Glenlea), (ii) Air-oven method (American Association of Cereal Chemists, 1972). Weight per 1000 kernels was determined with an electronic seed counter using 50 g of wheat (from which broken kernels and foreign material had been removed) and adjusted to 13.5% moisture basis. Density was calculated from weight-volume data, the volume being determined by a Beckman air comparison pycnometer. The volume of the test weight container (Imperial Pint 568 cc) actually occupied by the grain, is referred to as packing efficiency expressed as a percentage, was calculated by dividing the values for test weight by those for density (Pushman and Bingham, 1975). Grinding time, a measure of kernel hardness (Baker and Dyck, 1975), was determined by pouring approximately 6 g of whole grain into a Brabender SMI grinder, at a setting of 17.6 and recording the time (minutes) required to obtain 5 g of meal. The 1976 samples were submitted to the Canadian Grain Commission for official grading. Glenlea was graded according to the standards for utility wheats. The grades were based on the Imperial pint measure as originally determined before conversion. Falling number is a measure of grain soundness which can indicate the development of alpha-amylase activity. The falling number apparatus was used to measure the starch-paste viscosity of a heated wheat and water mixture. Gelatinization time (in seconds) was determined on whole meal samples (of the cultivars Neepawa and RL 4137 only) according to AACC method 56-81B (1972). Data were analyzed individually for each year and overall significance of results were examined by analysis of variance as presented in Cochran and Cox (1950).

IV. RESULTS AND DISCUSSION

1. Test Weight Loss

The mean test weight of the five cultivars decreased with each delay in harvest in both 1976 and 1977 (Figure 4). The overall and between harvest decreases in test weight were highly significant (Table 10), and although the timing of harvests and accumulated rainfall were very different for the two years (Table 11), the net reduction was similar amounting to 3.9 and 3.5 kg/hl for 1976 and 1977 respectively. In 1976, the test weight of the initial harvest was considerably higher (78.6 kg/hl) than in 1977 (77.2 kg/hl) and was probably due to the precipitation that occurred after maturity but before the 1977 crop could be swathed. The series of showers on September 1, 6, 9 and 12 amounting to 5.9 cm, inundated the plots and delayed swathing until September 14 (Appendix Table 3). The 1976 crop was swathed at about 35% moisture content in contrast to 16% in 1977. It is likely that cultivars which were mature could have lost some test weight due to the physical processes of wetting and drying preceding the initial harvest. Glenlea was the only cultivar with a mean test weight that was greater in 1977 (Table 12) and being the last to mature, may have been cut prematurily in 1976 thus reducing overall test weight (Dodds, 1957). For both years the largest

Figure 4. Effect of delayed harvest on test weight, 1976 and 1977 (mean of 5 cultivars).


79
77
75
73
TEST WEIGHT, kg /hl
0
10
20
30
40
DAYS AFTER INITIAL HARVEST
1976
1977

reduction in test weight (69 to 74%) occurred between the first and second harvests, the periods of major precipitation (Table 11) . Such a rapid decline in test weight following one or two heavy showers could have serious consequences on the resulting grades which are based on close test weight tolerances.

TABLE 10. Effect of delayed harvest on mean test weight (kg/hl).

Harvest no.	Year	
	1976	1977
1	78.6	77.2
2	75.9	74.6
3	74.7	73.7
Decrease %	5.1	4.6
SE	.12	.13
LSD (.05)	.24	.27

TABLE 11. Time, precipitation and test weight loss between harvests in 1976 and 1977.

Harvest no.	Rain cm	Time days	Test weight loss kg/hl	Test weight loss %
1976				
0-1	.20	13		
1-2	3.20	15	2.7	69
2-3	.56	24	1.2	31
TOTAL	3.96	52	3.9	
1977				
0-1	0	2		
1-2	5.54	17	2.6	74
2-3	.51	10	0.9	26
TOTAL	6.05	29	3.5	

TABLE 12. Cultivar mean test weight (kg/hl).

1976 Cultivar	1976 Test weight	1977 Cultivar	1977 Test weight
RL 4348	78.1	RL 4348	76.1
RL 4137	77.1	RL 4137	76.0
RL 4347	77.1	RL 4347	75.7
Neepawa	75.7	Glenlea	74.9
Glenlea	73.9	Neepawa	73.2
SE	.22		.33
LSD	.47		.69

1.1 Effect of Delayed Harvest

Many studies have documented the effect of delayed harvest on test weight of wheat (Bracken and Bailey, 1928; Whitcomb and Johnson, 1930; Larmour, et al., 1933; Swanson, 1943c, 1946; Pool, et al., 1958 and Johnson, 1959). Swanson (1941) determined test weights after laboratory wetting and drying from one to six times at moisture contents ranging from 12 to 28%. The degree of wetting in contrast to frequency, had much more effect on reducing test weight. A single moistening to 20% moisture content and drying to the original moisture resulted in a decrease of approximately 5 kg/hl. Five further cycles of wetting and drying reduced test weight by only an additional 2 kg/hl.

Decreases in test weight following different amounts of exposure as described in the literature are summarized into categories of nil, light and heavier precipitation amounts in Table 13. Large test weight losses (5-6 kg/hl) can occur with overwintering (Whitcomb and Johnson, 1930) or long periods of exposure (Pool, et al., 1958). Swanson (1941) reported reductions of 5.6 kg/hl on Kanred winter wheat following 2 months of accumulated rainfall totalling 13 cm. In contrast, protected shocks covered with waterproof canvas were not affected. Even several lighter rains can have a moderate effect. Bracken and Bailey (1928) reported a reduction of almost 5 kg/hl after 2 showers totalling 2.08 cm (Table 13). Johnson (1959) indicated a test weight reduction of .29 kg/hl per day for soft red winter wheat.

TABLE 13. Decreases in test weight after precipitation as indicated in the literature.

Wheat	Post harvest exposure days	Precipitation cm	Decrease kg/hl	Reference
Medium to Heavy Precipitation				
Kanred winter	10	2.54	2.7	(1)
Turkey winter	17	4.17	3.0	(3)
Kanred winter	16	2.08	4.9	(1)
Kanred winter	wintered	n/a	5.5	(2)
Soft red winter	39	n/a	5.6	(4)
Marquis spring	wintered	n/a	6.5	(2)
Light Precipitation				
Kanred winter	18	.46	.1	(1)
Kanred winter	10	.51	.3	(1)
Turkey winter	28	.74	1.5	(3)
No Precipitation				
Kanred winter	7	Nil	Nil	(1)
Kanred winter	10	Nil	Nil	(1)
Turkey winter	60 +	Nil	Nil	(3)

(1) Bracken and Bailey, 1928.
(2) Whitcomb and Johnson, 1930.
(3) Swanson, 1941.
(4) Pool, Patterson and Bode, 1958.
n/a not available.

Lighter amounts of precipitation appear to have only a minor effect on test weight (Table 13).

In the 1976 study, there were 3 showers, 2 light and one heavier, preceding the second harvest and a lighter shower during the 24 days before the final harvest (Figure 2). The threshed grain was relatively dry for all harvests. In considering the effect of rainfall on the second harvest, presumably the heavier shower of 2.3 cm on August 27 (Figure 2) would have likely had the largest effect on reducing test weight (2.7 kg/hl). The decline of 1.2 kg/hl for the final harvesting appears excessive considering only .56 cm of rain fell during this long period, however, local weather records indicated over a week of high relative humidities which would have some effect on raising moisture content (Appendix Table 2).

The 1977 swathed crop received a combination of two heavier showers (1.27 cm and 3.84 cm) and two light rains between the first and second harvest. The test weight decrease was almost identical to the previous years (2.6 versus 2.7 kg/hl respectively). The elapsed time differed by two days, while the accumulated precipitation was 5.5 cm for 1977 compared to 3.2 cm for 1976. The time before the final harvest in 1977 was much shorter (10 compared to 24 days), however, the light rainfall and test weight decreases were similar (Table 11). Apparently, even light rains may reduce test weight of ripened wheat by several kg/hl, but heavier precipitation causes larger decreases. After losses of 6-7 kg/hl, further cycles of wetting and drying produces only minor decline (Swanson, 1946).

1.2 Grain Moisture Content During Harvest

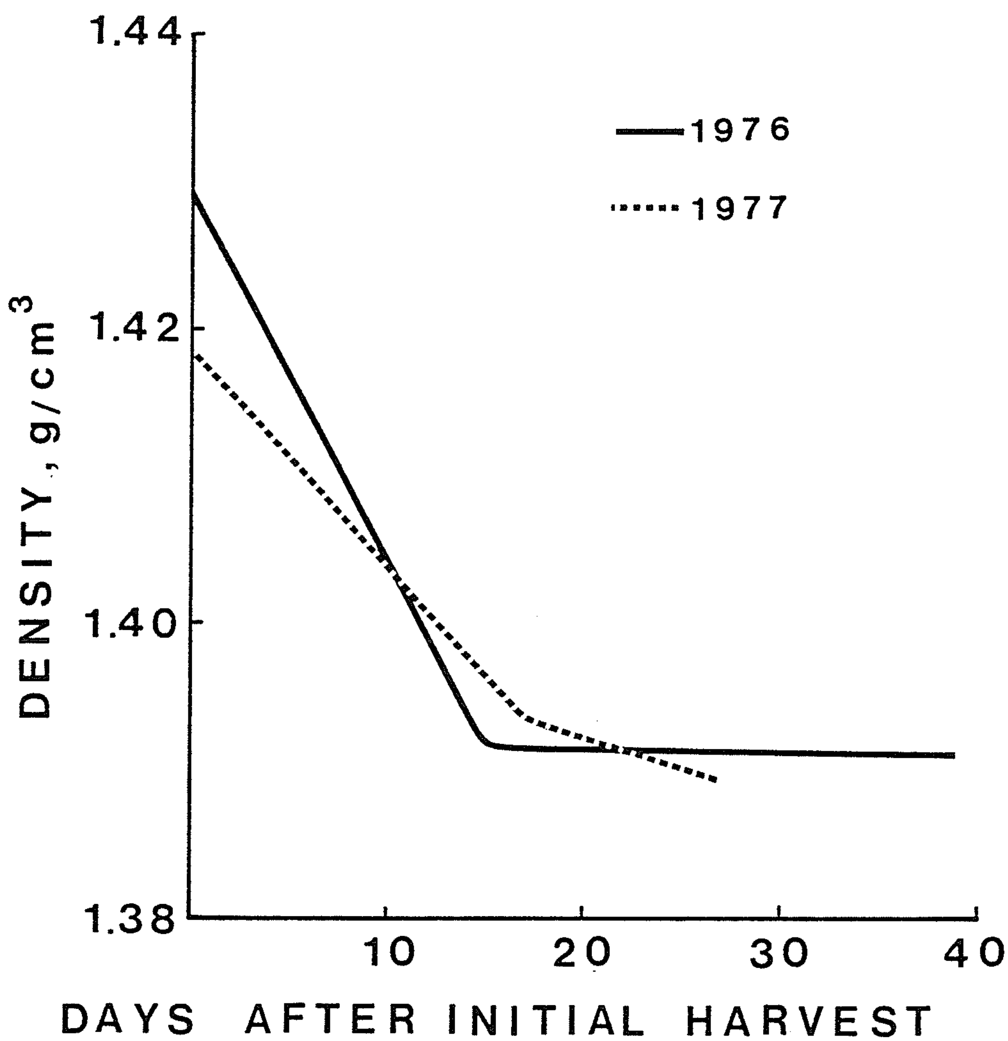
Several studies have examined the moisture content of harvest ripe grain following precipitation or high relative humidity (Robertson, 1956; Pool and Patterson, 1958). Grain moisture content fluctuates according to the saturation deficit (amount by which the saturation vapour pressure exceeds the observed value) of the atmosphere (Robertson, 1956). Under saturated conditions the uptake of moisture by grain is relatively slow (approximately 1-2% per day) depending on the temperature and the prior moisture content of the grain (Dillman, 1930; Pixton and Warburton, 1968). Rain is considered to be the major contributor to an increase in kernel moisture (Dodds and Pelton, 1967; Pool and Patterson, 1958). Several studies (Robertson, 1956, 1957; Blight, 1962) indicated that condensation and mist arrested moisture reduction, however, van Kampen (1971) stated that dew increased kernel moisture content. Dillman (1930) determined the rate of absorption of free water by wheat seeds to be a 12% and 17% gain in one hour at temperatures of 10C and 25C respectively. van Kampen (1971) reported that the rise in kernel moisture resulting from precipitation, depended on initial moisture content and the amount and duration of the precipitation. Ripe grain moisture content rose to 26% following 2.3 cm of rain on soft red winter wheats grown in Indiana (Pool and Patterson, 1958). Five hours of dew at another time brought the moisture content up to 18%. A light rain (.25 cm) 3 weeks later increased the moisture to 24%, however, in both post-rain instances the wheat had dried to 14% by late afternoon. A large fluctuation in moisture content could conceivably decrease test weight by several kilograms per hectoliter. Dodds (1967) indicated that kernel moisture in excess of 35%, wet weight basis, may be considered as free water.

The mean moisture content of the second harvest in 1977 for the check varieties (Neepawa and RL 4137) was 18.5%. Five days previously the moisture content of the 5 varieties averaged 45.8% shortly following the heavy shower on the 26th of September.

1.3 Effect of Delayed Harvest on Density and Packing Efficiency

The mean density of 5 varieties for 1976 and 1977 is illustrated (Figure 5). There was a highly significant decrease in density for the last two harvests in 1977 but only between the first and second harvest in 1976 (Table 14). The overall decrease in 1976 amounted to 2.7% compared to 2.1% the following year. Indeed, not only was the initial density higher in 1976, but the overall decrease was larger. Bracken and Bailey (1928) attributed annual differences in initial densities to dissimilar levels of protein content (lower protein would equate with lower densities) however, the 1977 wheat protein content (lower densities) was over

Figure 5. Effect of delayed harvest on density, 1976 and 1977 (mean of 5 cultivars).


1.44
1.42
1.40
1.38
DENSITY, g/cm³
1976
1977
10
20
30
40
DAYS AFTER INITIAL HARVEST

one percent higher than that of 1976 (Table 15). The lower densities in 1977 may have been partially due to weathering before swathing. A negative correlation between protein content and density was reported by Tkachuk and Kuzina (1979).

TABLE 14. Effect of delayed harvest on density (g/cc).

	Year	
Harvest no.	1976	1977
1	1.4291	1.4186
2	1.3916	1.3937
3	1.3911	1.3887
Decrease %	2.7	2.1
SE	.001	.001
LSD (.05)	.002	.002

TABLE 15. Annual density and protein content.

Year	Mean density	Net loss	Cultivar % Protein[1]	
	(g/cc)	%	Neepawa	RL 4137
1976	1.4039	2.7	14.6	14.3
1977	1.4003	2.1	16.3	15.2

[1]Protein basis 14% moisture. Mean of two replicates.

Several investigators determined densities after field exposure with and without precipitation. Bracken and Bailey (1928) found no apparent density change in wheat between rains. However, during the 1925 and 1926 seasons weathered

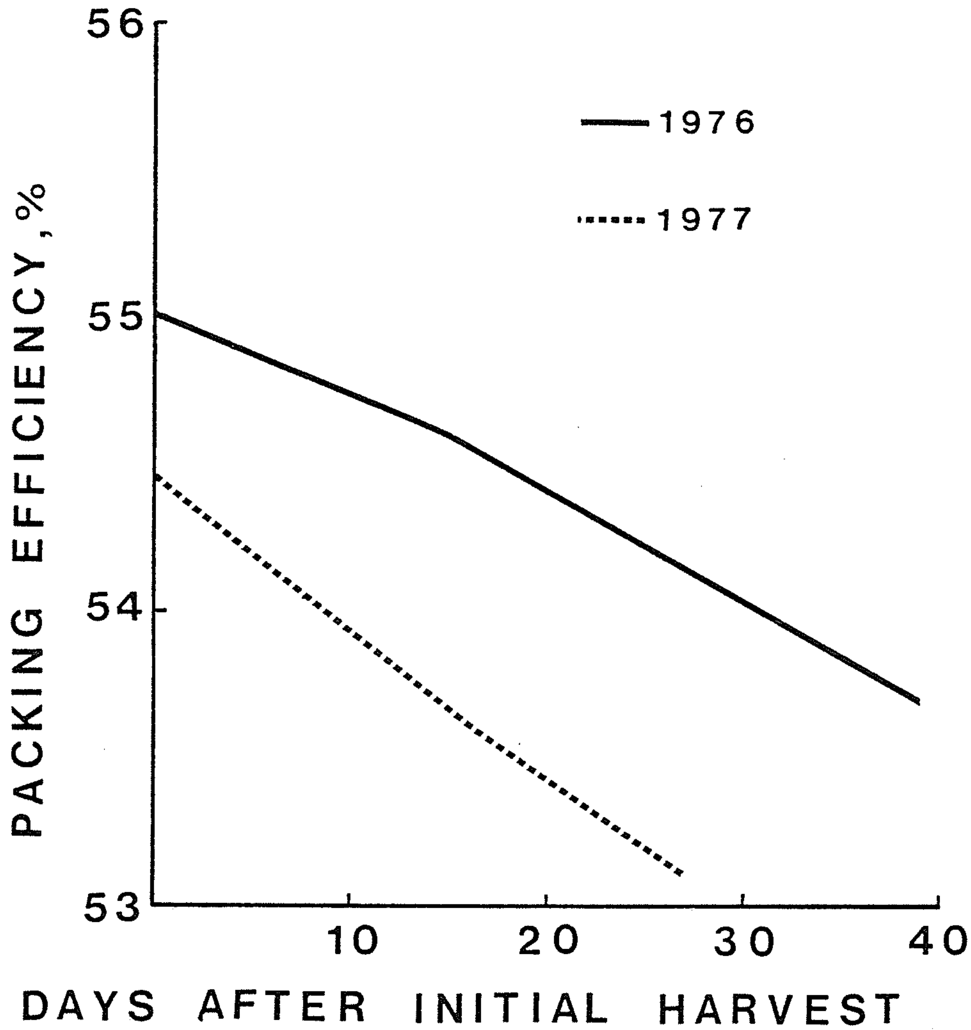
(2-3 cm rain) stands of Kanred winter wheat decreased in density 5.4% and 4.2% respectively. Whitcomb and Johnson (1930) reported similar results on overwintered shocks of Marquis spring and Kanred winter wheats.

Lower protein content, lower density wheats were found to undergo a larger net loss in density after weathering (Bracken and Bailey, 1928). The lower protein content samples of 1976 did exhibit a correspondingly greater density loss (2.7%), however, density and protein content were negatively correlated (Table 15).

The packing efficiency means (5 cultivars) for the three harvests of 1976 and 1977, decreased with each successive harvesting(Figure 6). The decrease was highly significant for all dates and years (Table 16), and amounted to approximately 2.5% overall. Packing efficiency accounted for 48% and 55% of the test weight reduction for 1976 and 1977 respectively. This compared with 42% and 63% found on overwintered Marquis and Kanred wheats (Whitcomb and Johnson, 1930).

After the second harvest in 1976 the decrease in density was considerably reduced, however, the void space continued to increase (Figures 5 and 6). This would indicate that the surface wrinkling of the kernel was increasing (roughening of the bran, increased friction) causing it to occupy more space (Figure 7). Scott (1951) stated that changes in surface friction play a greater role in altering test weight than did changes in grain size, i.e., density.

Figure 6. Effect of delayed harvest on packing efficiency, 1976 and 1977 (mean of 5 cultivars).


56
55
54
53
1976
1977
PACKING EFFICIENCY, %
10
20
30
40
DAYS AFTER INITIAL HARVEST

The foregoing results indicate that both factors (density and packing efficiency) were about equally responsible although this ratio may be quite different for soft or harder wheats (Sharp, 1927).

TABLE 16. Effect of delayed harvest on packing efficiency (%).

Harvest no.	Year	
	1976	1977
1	55.1	54.5
2	54.6	53.6
3	53.7	53.1
Decrease %	2.5	2.6
SE	.07	.09
LSD (.05)	.15	.18

1.4 Cultivar-Harvest Date Interaction

There were significant interactions between cultivars and harvest dates for test weight loss in both 1976 and 1977 indicating that the decrease in test weight varied among cultivars (Appendix Tables 4 and 5). Selection in a breeding program for a high test weight during a delayed harvest period (provided there is sufficient wetting and drying), should be effective in identifying superior genotypes.

In 1976, it appeared that the cultivars Neepawa and RL 4347 lost test weight more rapidly between the first and second harvest (Figure 8). This probability was examined by analysis of variance for interaction between dates

Figure 7. Comparison of sound (left) and weathered kernels of Neepawa wheat.

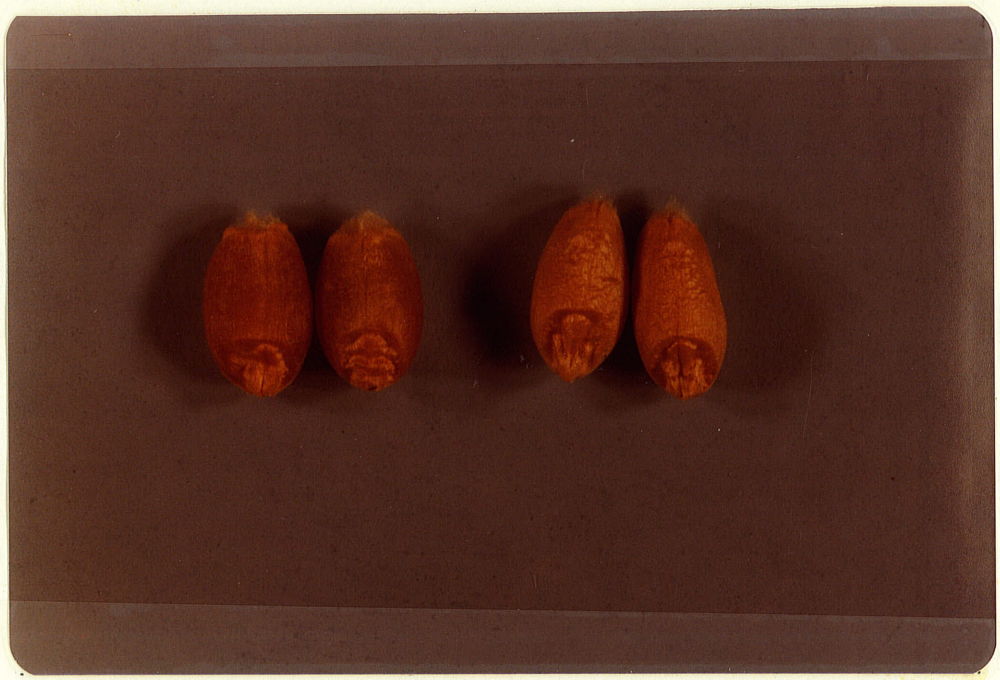


Figure 8. Effect of delayed harvest on cultivar-harvest date interaction, 1976.

Cultivar difference between harvest 1, 2 ▬
Cultivar difference between harvest 2, 3 ||||||

A - Neepawa
B - RL 4347
C - RL 4348
D - Glenlea
E - RL 4137
* significant at the 5% level
** significant at the 1% level


DECREASE IN PACKING, %
DECREASE IN DENSITY, g/cm3x10-2
DECREASE IN TEST WT, kg/hl
A
B
C
D
E

1, 2 and also 2, 3 (Dr. R. J. Baker, personal communication). There was a highly significant cultivar-date interaction between harvests one and two but no interaction in the residual comparison. Hence, the source of variation was among cultivars between the first two harvests. When Neepawa and RL 4347 means were contrasted against the residual effect (Glenlea, RL 4348 and RL 4137) there was no interaction among the latter. The source of variation was, therefore, due to Neepawa and RL 4347 decreasing in test weight more rapidly between the first and second harvest (Figure 8).

In 1977 Neepawa had the largest decrease in test weight (Figure 9). In the analysis of cultivar-harvest dates, the only significant interaction was between harvest dates one and three. The sums of squares for Neepawa was then compared to the remaining cultivars and no interaction was determined in the residual. Neepawa was again the source of interaction, however, in 1977 it was the only cultivar to lose test weight more rapidly.

The components of test weight were further examined for interaction. There was a highly significant interaction between cultivars and harvest dates for loss in density in both years (Appendix Tables 6 and 7) but only a significant interaction for decrease in packing efficiency for 1976 (Appendix Tables 8 and 9).

The density and packing efficiency cultivar-date interaction for 1976 was significant only between the first and second harvest dates (Figure 8) similar to the test

Figure 9. Effect of delayed harvest on cultivar-harvest date interaction, 1977.

Cultivar difference between harvest 1, 2 ▓
Cultivar difference between harvest 2, 3 ||||

A - Neepawa
B - RL 4347
C - RL 4348
D - Glenlea
E - RL 4137
* significant at the 5% level


DECREASE IN TEST WT, kg/hl
0
1
2
3
4
5
A
B
C
D
E
*
DECREASE IN DENSITY, g/cm3x10-2
0
1
2
3
4
5
A
B
C
D
E
*
*
*
DECREASE IN PACKING, %
0
.5
1.0
1.5
2.0
A
B
C
D
E

weight interaction. In the comparison of cultivars for decrease in density, Neepawa had the largest loss. When Neepawa was compared (harvest dates 1, 2) to the residual sums of squares, there was no significant interaction in the latter indicating that Neepawa was decreasing in density more rapidly. In the comparison of cultivars for decrease in packing efficiency, RL 4137 appeared to weather very little between the first two harvests (Figure 8), and was found to be responsible for the cultivar-date interaction. The small decrease in packing characteristics combined with the reduced density loss of RL 4137 gave it the lowest net decrease in test weight. Although Neepawa and RL 4347 were responsible for the cultivar-date interaction for test weight loss, only Neepawa was significantly different for density loss. However, when the large decrease in density and packing characteristics of RL 4347 were combined the net result was the second poorest performance.

As indicated earlier, in 1977 only the variety Neepawa lost test weight more rapidly. There was a highly significant cultivar-date interaction for decrease in density but no interaction for packing efficiency (Figure 9). Three varieties (Neepawa, RL 4347 and RL 4348) seemed to have similar rates of density loss, while Glenlea and RL 4137 were uniformly less. A comparison of the three varieties to the Glenlea and RL 4137 residual sums of squares indicated the latter interaction was not significant.

Although density loss was apparently much more rapid for Neepawa, RL 4347 and RL 4348 compared to the remaining varieties, only Neepawa showed up as being significantly different for test weight loss. This may have been due to the higher loss in packing ability of Neepawa combined with the density loss, thus resulting in a greater net decline (Figure 9).

Although the harvest dates and rainfall for the two years were not identical, the leading prairie acreage cultivar Neepawa consistently lost test weight more quickly (compared to 4 other cultivars), because of a rapid decrease in density and packing ability. Glenlea, a licensed utility wheat and RL 4137, had the lowest test weight decrease for both years.

Sharp (1927) reported cultivar differences for decrease in density among three types of wheat after laboratory wetting and drying. Whitcomb and Johnson (1930) determined a 7% and 8.4% test weight loss on overwintered Kanred and Marquis wheat respectively. Swanson (1943c) compared the test weight and loss of vitreousness among cultivars of hard red winter wheat after exposure to light rains following binder harvest in 1941. Two cultivars, Kanred and Chieftan showed improved resistance to exposure for both traits. Although soft red winter wheats decreased significantly in test weight in each of three years, no significant interaction was found between cultivars and harvest dates (Pool, Patterson and Bode, 1958). Ghaderi and Everson (1971) observed the genotype-environmental interaction of test weight and its components in Eastern soft winter wheats at several locations over two years. Density was reported to be primarily an environmental characteristic and a minor component of test weight. In contrast, packing efficiency was described as a varietal characteristic that should be selected for gain in genetic improvement. Lines were identified that had a favourable genotype-environment interaction and consistently performed well under favourable and unfavourable environments.

2. Grinding Time

Grinding time comparisons can indicate the degree of kernel hardness existing among cultivars (Kosmolak, 1958). Differences in kernel hardness have been associated with differences in mixing characteristics, flour yield and loaf volume (Symes, 1969; Baker and Dyck, 1975).

The mean grinding time of all cultivars showed a highly significant increase with consecutive harvests in both years (Table 17) and although the grain was somewhat harder in 1976 the net change was similar (Figure 10). The interaction between cultivars and harvest dates was not significant in either year (Appendix Tables 10 and 11) indicating that all cultivars become softer at a similar rate. The cultivars showing more resistance to test weight loss in 1976 (Glenlea, RL 4137 and RL 4348) were also harder grained (Table 18). As in the previous year Glenlea had the hardest kernel in 1977 (and lowest test weight loss), however, RL 4137 and Neepawa were of intermediate hardness. RL 4137 and Neepawa were at extremes in their amount of test weight decline, Neepawa being significantly more than any of the other varieties. With the exception of the hard-grained cultivar Glenlea, kernel hardness seemed to be an environmental characteristic.

TABLE 17. Effect of delayed harvest on grinding time (minutes).[1]

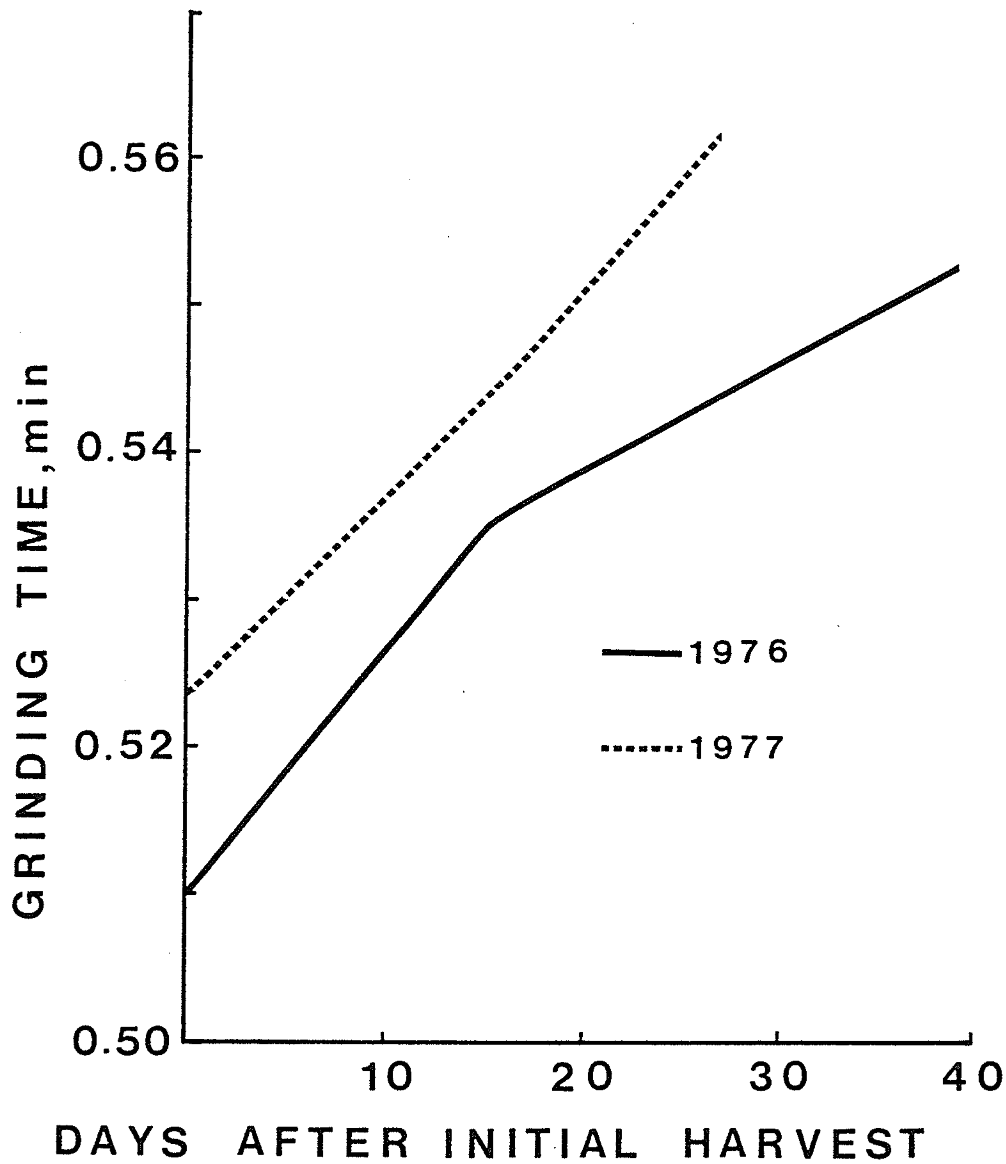
Harvest No.	Year	
	1976	1977
1	.509	.523
2	.535	.547
3	.553	.562
Increase %	8.6	7.5
SE	.003	.006
LSD (.05)	.005	.013

[1]Mean of 5 cultivars.

TABLE 18. Cultivar mean grinding time (minutes).

Cultivar	Year 1976	Cultivar	Year 1977
Glenlea	.502	Glenlea	.486
RL 4137	.514	Neepawa	.540
RL 4348	.515	RL 4137	.541
Neepawa	.564	RL 4347	.576
RL 4347	.567	RL 4348	.577
SE	.008		.020
LSD (.05)	.016		.042

Figure 10. Effect of delayed harvest on grinding time, 1976 and 1977 (mean of 5 cultivars).



0.56
0.54
0.52
0.50
GRINDING TIME, min
10
20
30
40
DAYS AFTER INITIAL HARVEST
1976
1977

The decline in kernel hardness caused the grain to become more brittle and prone to fracture during harvest, a process similar to tempering before milling (Scott, 1951). Broken kernels are an important degrading factor in the schedule of tolerances with amounts limited to 6%, 10%, and 15% for grades No. 1, 2 and 3, Canada Western respectively.

An important consideration in determining kernel hardness would be the comparison of results from different stations or samples harvested at various stages after exposure. Such comparisons could lead to inaccurate conclusions regarding the relative ranking of a cultivar.

The effect of reduced kernel hardness due to delayed harvesting has been documented (Bracken and Bailey, 1928; Whitcomb and Johnson, 1930; Johnson, 1959). Pool, Patterson and Bode (1958) reported a significant increase in kernel softness in late harvested soft red winter wheat. Milner and Shellenberger (1953) indicated that wheat hardness and energy requirement for grinding were both reduced when grain became weathered and internally fissured. The rate of water absorption also increased.

Weathering may be beneficial where the grain is to be used for inclusion into a cattle ration, i.e. hammer milled.

3. Kernel Moisture Content

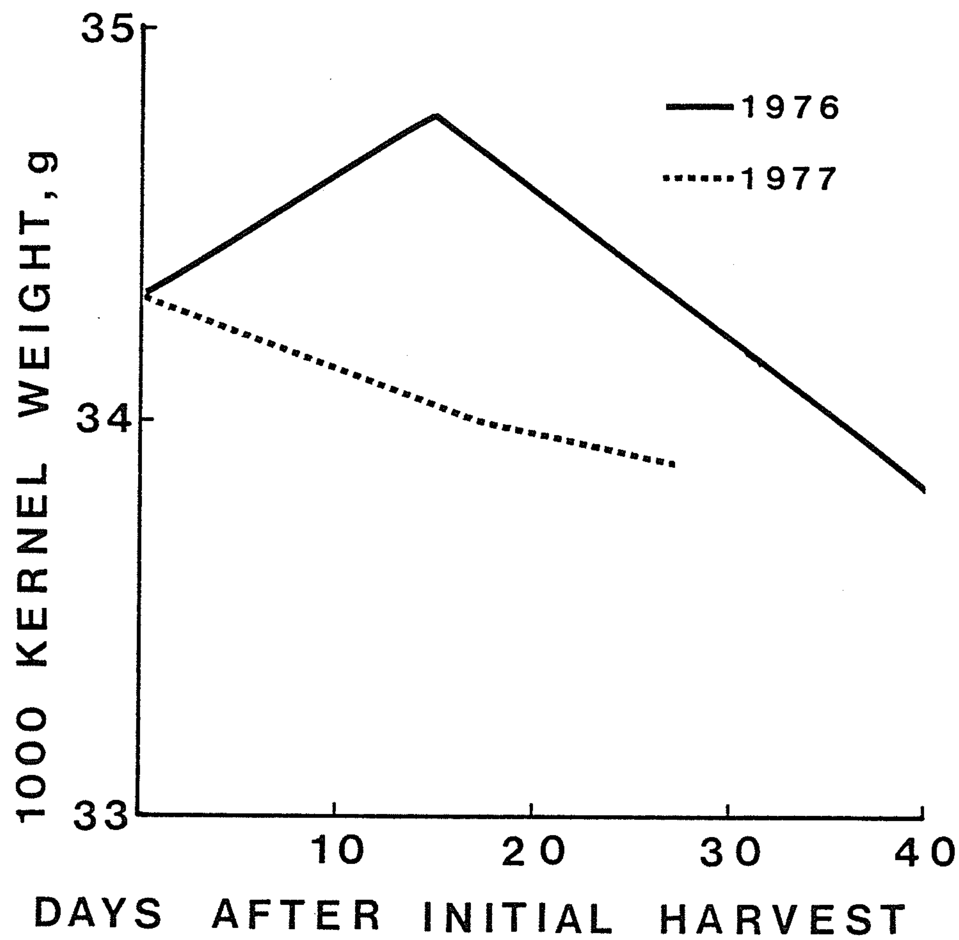
The moisture content of the grain during physical determinations averaged 10.7 and 8.6% for 1976 and 1977 respectively. Neither the difference among cultivars and harvest dates nor the interaction between cultivars and harvest dates was significant in either year (Appendix Tables 12 and 13).

4. Kernel Weight

The 1000-kernel weight (adjusted to 13.5% moisture content) harvest date means were significantly different for the 3 dates in 1976 but were uniform in 1977 (Figure 11). There was no significant cultivar by harvest date interaction (Appendix Tables 14 and 15). The 1976 kernel weight mean increased 1.3% for the second harvest then decreased to 1.4% less than the initial value. The increase in kernel weight may have been due to continued translocation following early swathing at 35% moisture content. Since there was no significant difference among the cultivars and no harvest-date cultivar interaction in moisture content, test weight was determined on an as is basis. Provided volume and packing characteristics did not change, an increase in kernel weight would elevate test weight, however, both density and packing efficiency decreased and the test weight significantly declined (Figure 8). A 1.4% decrease in kernel weight would not reduce yield appreciably (35 kg per hectare or 0.4 bus/acre).

Johnson (1959) observed a 1.4% decrease in 1000-kernel weight over a 20 day period and concluded that since the reduction in test weight for the same period was 6.5%, dry matter loss was not responsible. Dry matter decrease was attributed to possibly leaching or oxidation,

Figure 11. Effect of delayed harvest on kernel weight, 1976 and 1977 (mean of 5 cultivars).


35
34
33
1000 KERNEL WEIGHT, g
1976
1977
10
20
30
40
DAYS AFTER INITIAL HARVEST

A significant decrease in kernel weight after severe weathering was reported by Whitcomb and Johnson (1928, 1930) for one out of two years. Pool, Patterson and Bode (1958) found significant differences among cultivars, among harvest periods and for the interaction of cultivars and harvest periods for weight per 1000 kernels in only one of a three year study. It was concluded that only a very small part of yield loss was due to kernel weight reduction. In European studies, wheat ranked between oats and barley for dry matter loss (van Kampen, 1971).

5. Comparison of Grades and Falling Number in 1976

5.1 Utility Wheat

All Glenlea samples from the first and second harvest graded No. 1 Canada Utility while the samples from the final harvest were evenly distributed between No. 1 and 2 Canada Utility (Table 19).

TABLE 19. Effect of delayed harvest on grades of Glenlea wheat, 1976.

Harvest no.	CU[1] grade in designated replicate					
	1	2	3	4	5	6
1	1	1	1	1	1	1
2	1	1	1	1	1	1
3	1	1	1	2	2	2

[1]Canada Utility

The several samples that graded No. 2 Canada Utility had below minimum requirement test weights (below 74 kg/hl or 58 lbs per bushel). Some of the samples from the two latter harvests were also described as lightly bleached (Table 20), however, this was not responsible for the degrading.

TABLE 20. Effect of delayed harvest on bleaching, 1976.

	Second Harvest Sample Total			
Cultivar	No remarks	Lightly bleached	Heavily bleached	Severely bleached
Neepawa	0	1	5	0
RL 4137	2	4	0	0
RL 4347	0	3	3	0
RL 4348	1	3	2	0
Glenlea	3	3	0	0
	Third Harvest Sample Total			
Cultivar	No remarks	Lightly bleached	Heavily bleached	Severely bleached
Neepawa	0	0	3	3
RL 4137	1	2	3	0
RL 4347	0	1	4	1
RL 4348	0	3	3	0
Glenlea	2	4	0	0

5.2 Hard Red Spring Wheats

Most of the hard red spring cultivars had adequate minimum test weight requirements for the top grade throughout the 1976 test (Appendix Table 16), however, not all graded alike. For the first harvest all cultivars were graded No. 1 Canada Western Red Apring (CWRS) but only the cultivar RL 4137 remained completely No. 1 for the second harvest (Table 21).

TABLE 21. Effect of delayed harvest on grades of hard red spring wheats, 1976.[1]

Cultivar	Second Harvest			Third Harvest		
	No. of Samples in Grade			No. of Samples in Grade		
	1 CW[2]	2 CW	3 CW	1 CW	2 CW	3 CW
Neepawa	1	5	0	0	3	3
RL 4137	6	0	0	3	3	0
RL 4347	3	3	0	1	4	1
RL 4348	4	2	0	3	3	0

[1]All first harvest samples graded No. 1 Canada Western Red Spring.
[2]Canada Western Red Spring.

Samples showing different degrees of bleaching were down-graded accordingly. Heavily bleached samples were graded No. 2 CW while samples classed as severely bleached graded No. 3 CW (Tables 20 and 21). Because of heavy bleaching, Neepawa predominantly graded No. 2 CWRS for the second harvest. Cultivars RL 4347 and RL 4348 were almost equally divided between grades No. 1 and No. 2 CW, although the latter was somewhat better in having only two heavily bleached samples (Table 20). The remarkable contrast was the second harvest grade difference between the bleaching susceptible cultivar, Neepawa (planted on over 5 million hectares in 1979) and the unlicenced cultivar RL 4137, a line known to resist sprouting and bleaching.

In the third harvest, samples of Neepawa graded equally between No. 2 and 3 CWRS . The cultivar RL 4137 had three samples classed as 2 CWRS while the remainder maintained the top grade (Figure 12). For the second and third harvests, the cultivar RL 4137 averaged approximately one grade better than Neepawa throughout the tests. It would be of benefit to determine whether the bleaching difference reflects an advantage in some quality factor or whether it only reflects cultivar differences in resistance to bleaching.

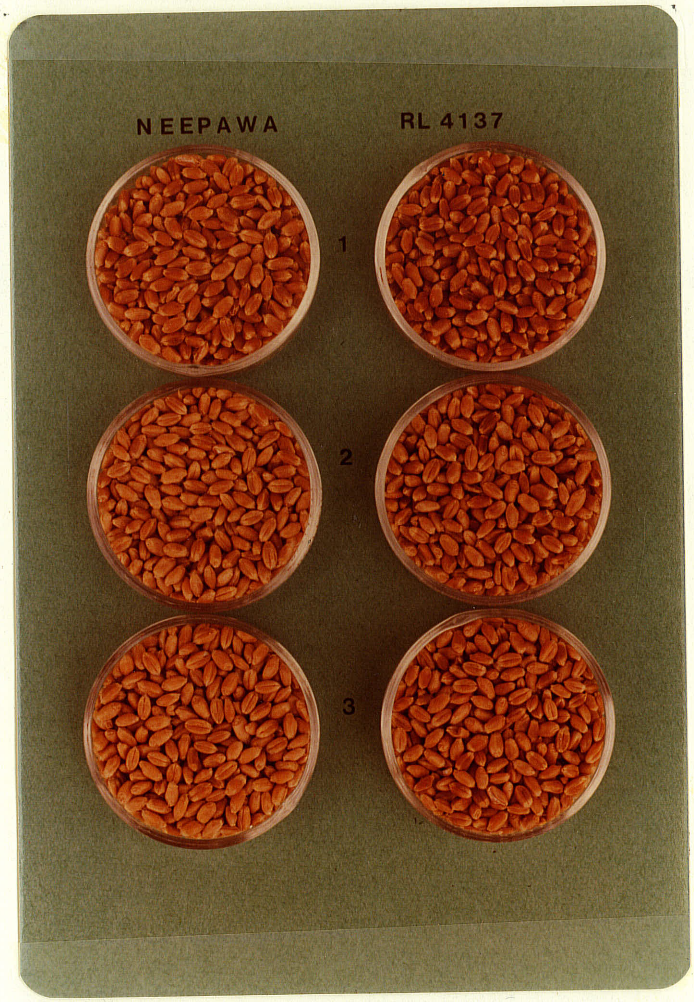
By the third harvest RL 4347 showed evidence of being more susceptible to bleaching and graded mainly No. 2 CW while RL 4348 samples were divided between grades 1 and 2 CW. RL 4348 and RL 4137 were the top two cultivars in grade performance and both had shown previous evidence of their bleaching resistance (Table 1).

The main degrading factor among samples was the degree of bleaching, a cultivar characteristic which showed a wide range in tolerance.

Although the 1977 samples were not submitted for grading, most second (5 out of 6) and all third harvest test weights of Neepawa were below the minimum requirement for the top grade (Appendix Table 17). All other hard red spring cultivars had satisfactory minimum weights. The Utility cultivar Glenlea had adequate test weigh+ requirements for the primary grade in 17 out of 18 samples.

Figure 12. Comparison of sound and weathered graded samples of Neepawa and RL 4137, 1976.

Harvest no.	Grade	
	Neepawa	RL 4137
1	1	1
2	2	1
3	3	1



NEEPAWA
RL 4137
1
2
3

5.3 Falling Number and Delayed Harvesting

Falling number is a qualitative test which examines wheat for evidence of alpha-amylase activity (Moss, Derera and Balaam, 1972) and may indicate the initiation of sprouting.

The cultivar and harvest-date falling number means and main grades for Neepawa and RL 4137 are presented in Table 22. Analysis of variance indicated a significant difference between cultivars and among harvest dates but no significant interaction for cultivar-harvest date performance (Appendix Table 18). Overall Neepawa had a significantly lower falling number mean than RL 4137 and the grading pattern was consistent in this respect, although both cultivars had similar rates of decline through the harvests (Table 22). Cultivar falling number was not affected by the second harvest (595 seconds) thus from that aspect, Neepawa was unfairly degraded to 2 CW. The significantly lower third harvest-date mean was in limited agreement with the cultivar grades. RL 4137 graded between 1 and 2 CW compared to 2 and 3 CW for Neepawa, not unwarranted however, if based on the six replicate falling number mean of 562 vs. 444 seconds respectively. Surprisingly, the higher grading third harvest samples had a lower falling number mean as compared to the remainder.

The grades and falling numbers were based on one year and location and this should be considered in analyzing the results.

TABLE 22. Comparison of cultivar and harvest-date falling numbers and corresponding grades (1976).

Harvest no.	Falling no. (seconds)			Grade (CWRS)[1]	
	Neepawa	RL 4137	Mean	Neepawa	RL 4137
1	567	578	572	1	1
2	576	614	595	2	1
3	444	562	503*	2,3	1,2
Mean	529	585*			
SE			22		
LSD (.05)			45		

[1]Canada Western Red Spring.

*Significant at the 5% level.

V. SUMMARY AND CONCLUSION

The results of a 2 year delayed harvest study involving 4 hard red spring and one utility wheat, indicated that with exposure to moderate rainfall, the grain rapidly lost test weight and became bleached. Susceptibility to test weight loss and bleaching was found to be a varietal characteristic therefore, a breeder could select for improved resistance in both traits under a favourable environment. Neepawa, a prairie wheat grown on over 5 million hectares in 1979, became bleached and lost test weight more quickly then all other cultivars in both years of the study.

The main criteria for standard of quality in the Canadian Statutory grades for hard red spring wheat specify minimum tolerances of test weight, percent vitreous kernels and degree of soundness. In western Canada, the fall harvest is frequently subjected to adverse weather conditions resulting in substantial amounts of wheat being degraded (Table 8). An earlier harvested crop or better grading cultivar could mean a considerable increase in income per hectare. The ten year mean price differential (1965-75) has been reported as $2.44 and $4.52 per tonne between the top three grades (Canada Grains Council, 1976).

Moderate amounts of rain (4 to 6 cm) on swathed grain resulted in a significant reduction in test weight amounting to about 5% annually. The decrease was almost equally divided between density and packing efficiency, the components of test weight.

The majority of samples from 1976 which were submitted for official grading had adequate test weight requirements. There were cultivar differences in bleaching resistance which was reflected in the grades assigned. The results confirmed that Neepawa was highly susceptible to bleaching and was severely down graded. Glenlea, a utility wheat, RL 4137 and RL 4348 were least affected by delayed harvesting and received better grades.

The 1000-kernel weight increased then decreased significantly in 1976 amounting to a net reduction of 1.4%, a minimal effect on yield.

Grain hardness decreased with delayed harvesting at similar rates for all cultivars causing the grain to become more brittle and to increase the number of broken kernels. Glenlea characteristically had the hardest kernel and ranked among the most resistant for test weight loss.

Some of the better graded samples of Neepawa had lower falling numbers (two-cultivar comparison) an indication of the difficulty of subjective grading based on visual characteristics.

In retrospect, test weight reduction and bleaching are an indication of the history of grain weathering, however, based on this study not all cultivars reacted alike. Past studies have indicated that packing efficiency was a varietal and density an environmental characteristic. Based on this study of 5 cultivars density loss due to weathering appears to reflect the cultivar in hard red spring wheats.

Cultivars resistant to weathering would be advantageous in areas of heavier precipitation. In some locations grain drying could hasten harvesting and insure better grades. Selection for improved resistance for test weight loss and bleaching should be possible provided cultivars resistant for both traits are included in the breeding program. Initial emphasis should be placed on high test weight, high density and acceptable kernel shape. One method of selection might be to grow replicated tests in higher rainfall areas and the cutting of sequential harvests. Segregating bulk populations with narrow maturities could be screened for higher density (following weathering) by utilizing a gravimetric separator. Selection for improved color could be attempted electronically.

Further research could be concentrated at improving the techniques of grading (other than visual) that would conform to the quality characteristics of the grain. Test weight, protein content and physical or chemical indication of grain soundness may be more accurate grading factors but the two latter are not practical at this time.

Methods of improving a similar delayed harvest study could include conducting harvests at regular intervals, determining moisture content following precipitation in addition to harvested samples and the inclusion of a range of soft to hard kernel types of wheat. Cultivars could also be examined for pigment differences. Further investigations might also compare grades (during delayed harvest) with extensive cultivar milling and baking data.

Presumably the short term objective of a breeder would be the development of a hard-grained cultivar resistant to test weight loss, bleaching and sprouting, thus not only easing the task of the grain inspector but in the long run benefitting the producer and ultimate consumer and agricultural industry as a whole.

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VII. APPENDIX

APPENDIX TABLE 1

Precipitation Between Harvests

Harvest no.	Accumulated Rainfall cm	
	1976	1977
1	.20	0
2	3.20	5.54
3	.56	.51
TOTAL	3.96	6.05

APPENDIX TABLE 2

Relative Humidity During Harvests (%)[1]

1976				1977			
Date	Relative Humidity	Date	Relative Humidity	Date	Relative Humidity	Date	Relative Humidity
Aug. 16	72	Sept. 5	69	Sept. 16	83	Sept. 30	100
17	80	6	77	17	89	Oct. 1	84
18	92	7	98	18	86	2	89
19	92	8	94	19	94	3	97
20	94	9	89	20	90	4	98
21	95	10	80	21	100	5	100
22	84	11	57	22	98	6	97
23	64	12	74	23	100	7	97
24	67	13	92	24	98	8	60
25	95	14	98	25	100	9	89
26	100	15	95	26	96	10	80
27	80	16	75	27	98	11	94
28	96	17	71	28	97	12	94
29	94	18	83	29	89	13	82
30	87	19	79				
31	93	20	69				
Sept. 1	76	21	97				
2	87	22	84				
3	88	23	85				
4	89	24	82				

[1]Morning observations (7 a.m.) taken at the Glenlea Research Station, University of Manitoba.

APPENDIX TABLE 3

Precipitation During the Harvest Period (cm)

1976			1977		
Date		Rainfall	Date		Rainfall
Aug.	9	.20	Sept.	1	1.27
	16	harvest		6	2.08
	19	.25		9	2.46
	20	.66		12	.08
	27	2.87		16	harvest
	31	harvest		21	1.27
				26	3.84
Sept.	12	.56		28	.38
	24	harvest			
			Oct.	1	.05
				3	harvest
				7	.28
				10	.18
				12	.05
				13	harvest

APPENDIX TABLE 4

Analysis of Variance for Test Weight of Wheat, 1976

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F = Value
Replicates	5	1.92	0.38	0.86NS
Cultivars	4	192.13	48.03	107.67**
Error	20	8.92	0.45	
Dates	2	247.76	123.88	586.56**
Interaction	8	8.58	1.07	5.08**
Error	50	10.56		
TOTAL	89	469.87		

** significant at the 1% level

NS not significant

APPENDIX TABLE 5

Analysis of Variance for Test Weight of Wheat, 1977

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F = Value
Replicates	5	16.76	3.35	3.42*
Cultivars	4	103.69	25.92	26.41**
Error	20	19.63	.98	
Dates	2	198.76	99.38	377.73**
Interaction	8	4.86	.61	2.31*
Error	50	13.16	.26	
TOTAL	89	356.86		

* significant at the 5% level

** significant at the 1% level

APPENDIX TABLE 6

Analysis of Variance for Density of Wheat, 1976

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F = Value
Replicates	5	.00094460	.00018892	9.14**
Cultivars	4	.00466407	.00116602	56.44**
Error	20	.00041327	.00002066	
Dates	2	.02845469	.01422734	676.20**
Interaction	8	.00059187	.00007398	3.52**
Error	50	.00105211	.00002104	
TOTAL	89	.03612046		

** significant at the 1% level

APPENDIX TABLE 7

Analysis of Variance for Density of Wheat, 1977

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F = Value
Replicates	5	.00132508	.00026502	13.00**
Cultivars	4	.00472165	.00118041	57.92**
Error	20	.00040767	.00002038	
Dates	2	.01542310	.00771155	539.64**
Interaction	8	.00048108	.00006013	4.20**
Error	50	.00071428	.00001429	
TOTAL	89	.02307286		

** significant at the 1% level

APPENDIX TABLE 8

Analysis of Variance for Packing Efficiency of Wheat, 1976

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F= Value
Replicates	5	.420	.084	0.28[NS]
Cultivars	4	114.944	28.736	96.55**
Error	20	5.952	.298	
Dates	2	28.476	14.238	171.75**
Interaction	8	1.785	.223	2.69*
Error	50	4.146	.083	
TOTAL	89	155.723		

* significant at the 5% level
** significant at the 1% level
NS not significant

APPENDIX TABLE 9

Analysis of Variance for Packing Efficiency of Wheat, 1977

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F = Value
Replicates	5	9.418	1.884	3.90*
Cultivars	4	49.341	12.335	25.51**
Error	20	9.671	.484	
Dates	2	28.263	14.131	122.67**
Interaction	8	1.562	.195	1.69[NS]
Error	50	5.762	.115	
TOTAL	89	104.017		

* Significant at the 5% level
** Significant at the 1% level
NS Not significant

APPENDIX TABLE 10

Analysis of Variance for Grinding Time of Wheat, 1976

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F = Value
Replicates	5	.01222	.002444	4.46**
Cultivars	4	.06877	.017193	31.37**
Error	20	.01096	.005483	
Dates	2	.029101	.014551	140.32**
Interaction	8	.001209	.000151	1.45[NS]
Error	50	.005188	.000104	
TOTAL	89	.127463		

** significant at the 1% level
NS not significant

APPENDIX TABLE 11

Analysis of Variance for Grinding Time of Wheat, 1977

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F = Value
Replicates	5	.007812	.001568	0.43^NS
Cultivars	4	.099773	.024943	6.85**
Error	20	.072859	.003643	
Dates	2	.023052	.011526	19.60**
Interaction	8	.005047	.000631	1.07^NS
Error	50	.029404	.000588	
TOTAL	89	.237978		

** significant at the 1% level
NS not significant

APPENDIX TABLE 12

Analysis of Variance for Moisture Content of Wheat, 1976

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F = Value
Replicates	5	2.9142	.5828	0.95^{NS}
Cultivars	4	.9922	.2481	0.40^{NS}
Error	20	12.2958	.6148	
Dates	2	.5429	.2714	2.41^{NS}
Interaction	8	1.0138	.1267	1.13^{NS}
Error	50	5.6300	.1126	
TOTAL	89	23.3889		

NS not significant

APPENDIX TABLE 13

Analysis of Variance for Moisture Content of Wheat, 1977

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F = Value
Replicates	5	2.3503	.4701	8.50**
Cultivars	4	.1929	.0482	.87^{NS}
Error	20	1.1058	.0553	
Dates	2	.3407	.1703	2.64^{NS}
Interaction	8	.4338	.0542	0.84^{NS}
Error	50	3.2256	.0645	
TOTAL	89	7.6490		

** significant at the 1% level
NS not significant

APPENDIX TABLE 14

Analysis of Variance for 1000 Grain Weight, 1976

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F = Value
Replicates	5	26.8334	5.3667	2.79*
Cultivars	4	299.4500	74.8616	38.88**
Error	20	38.5069	1.9253	
Dates	2	12.8542	6.4271	13.72**
Interaction	8	5.8263	.7283	1.55^{NS}
Error	50	23.4202	.4684	
TOTAL	89	406.8910		

* significant at the 5% level
** significant at the 1% level
NS not significant

APPENDIX TABLE 15

Analysis of Variance for 1000 Grain Weight, 1977

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F = Value
Replicates	5	73.3305	14.6661	4.04*
Cultivars	4	2020.5003	505.1251	139.29**
Errors	20	72.5359	3.6268	
Dates	2	3.0465	1.5233	1.91 NS
Interaction	8	8.4674	1.0584	1.33 NS
Error	50	39.8586	.7972	
TOTAL	89	2217.7393		

* significant at the 5% level
** significant at the 1% level
NS not significant

APPENDIX TABLE 16

Imperial Test Weight, 1976 (lbs per bus)

Cultivar	Harvest no.	Replicate 1	2	3	4	5	6
Neepawa	1	63.1	63.5	62.6	63.2	63.2	62.4
	2	60.7	60.1	59.3	59.8	60.5	60.1
	3	59.7	59.1	58.8	58.8	59.3	59.0
Glenlea	1	61.0	61.0	61.0	60.5	60.5	60.8
	2	60.0	59.0	59.1	58.8	58.6	58.3
	3	58.7	58.0	58.1	57.7	57.9	57.9
RL 4137	1	62.9	64.1	63.5	63.5	62.6	62.6
	2	61.8	62.5	61.2	61.8	61.0	61.8
	3	60.1	61.0	60.7	60.4	61.4	60.5
RL 4347	1	63.5	63.6	63.9	63.8	64.5	64.2
	2	61.7	61.7	60.7	60.8	61.0	61.4
	3	60.0	60.2	60.5	60.1	60.5	60.7
RL 4348	1	64.1	64.6	64.9	64.1	64.1	64.3
	2	62.5	62.4	62.5	61.8	62.9	62.5
	3	61.0	61.0	62.1	61.5	61.0	60.7

APPENDIX TABLE 17

Imperial Test Weight, 1977 (lbs per bus)

Cultivar	Harvest no.	Replicate 1	2	3	4	5	6
Neepawa	1	61.1	61.1	60.1	61.0	60.8	59.7
	2	59.0	58.7	57.6	58.7	58.3	57.0
	3	57.1	58.1	56.7	57.4	57.4	55.9
Glenlea	1	59.8	61.9	61.8	62.1	62.4	60.7
	2	58.7	60.1	60.1	60.4	60.2	58.1
	3	59.1	59.5	59.5	60.0	59.7	57.6
RL 4137	1	62.6	63.2	62.1	62.4	62.1	61.9
	2	61.4	61.4	59.3	60.7	60.7	60.1
	3	59.3	59.8	60.0	60.1	60.4	59.3
RL 4347	1	62.2	62.2	62.4	62.9	62.6	62.9
	2	60.5	60.5	59.5	60.5	60.1	59.4
	3	59.7	59.5	59.1	59.5	59.7	59.5
RL 4348	1	61.8	62.8	62.6	63.1	62.4	62.4
	2	61.2	61.2	60.1	60.7	59.8	61.2
	3	59.8	59.8	59.8	60.2	59.3	59.3

APPENDIX TABLE 18

Analysis of Variance for Falling Number, 1976

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F = Value
Replicates	5	49027.81	9805.56	4.73^{NS}
Cultivars	1	28056.25	28056.25	13.54*
Error	5	10360.25	2072.05	
Dates	2	55354.89	27677.44	9.91*
Interaction	2	18364.67	9182.33	3.29^{NS}
Error	20	55844.44	2792.22	
TOTAL	35	217008.31		

* significant at the 5% level
NS not significant