AN ABSTRACT OF THE THESIS OF

Muhammed S Albahouh for the degree of Master of Science in Crop and Soil Sciences presented on April 15, 1992.

Title: Genetic Variability for Kernel Hardness in Two Soft White Winter Wheat (*Triticum aestivum* L.) Cultivars

Abstract approved: Redacted for Privacy

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To remain competitive in the international marketplace, soft white wheat cultivars grown in the Pacific Northwest must have consistent and predictable flour properties including kernel texture. As a consequence, there is a need to develop wheat cultivars for specific end uses. Wheat cultivars with very soft kernels are used largely for making cookies and cakes. Harder soft white wheats are more suitable for noodles and flat breads. Numerous studies have been made to determine the inheritance of kernel texture between hard and soft wheat; however, very little information is available concerning the amount of genetic variability within soft white wheat.

Reciprocal crosses were made between a very soft (TJB/MON"S") and a soft (Yamhill) white winter wheat genotype. Data were collected on an individual plant basis for kernel texture, protein content, and eight selected agronomic traits. Kernel hardness and protein content were

determined using the near-infrared reflectance spectroscopy (NIR).

Genetic differences for kernel texture and the other nine traits were found between the two parents and the resulting F1 progenies. It would appear that kernel texture is qualitatively inherited with one or more genes reflecting additive and nonadditive gene action. However, a large component of non-genetic variation was also detected.

Of particular interest was the apparent reciprocal differences found between F1 populations for most of the traits measured and particularly kernel texture. However, for kernel texture, such differences were not due to a dosage effect of the 3n endosperm.

Kernel texture was not found to be associated with protein content. A negative association of kernel texture with heading date would suggest a compromise may be necessary when selecting these traits. Positive associations were found between kernel hardness with number of tillers, total biological yield, grain yield, and number of kernels per spike.

Genetic Variability for Kernel Hardness in Two Soft White Winter Wheat (Triticum aestivum L.) Cultivars

by

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A THESIS

submitted to

Oregon State University

In partial fulfillment of
the requirements for the
degree of

Master of Science

Completed April 15, 1992
Commencement June 1992

APPROVED:

Redacted for Privacy

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Date thesis is presented April 15, 1992

Typed by researcher for Muhammed S Albahouh

DEDICATED TO:

my mother

Hissa

my wife,

Nadia

my son,

Fawaz

and

my aunt,

Shiekha

ACKNOWLEDGEMENT

I wish to express my sincere appreciation to Dr W. E. Kronstad, my major professor, for his constructive criticism, guidance and encouragement throughout this program.

I would like to take this opportunity to thank Dr Russ Karow and Dr David Thomas for serving in my graduate committee and providing their time and expertise. I would also like to extend my thank to Dr Kenneth Beals for serving as a graduate council representative.

I am very grateful to my family for their patience and understanding.

Sincere thanks to Kuwait Institute for Scientific Research (KISR), my employer, for their financial support to make this study possible.

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GENETIC VARIABILITY FOR KERNEL HARDNESS IN TWO SOFT WHITE WINTER WHEAT (*Triticum aestivum* L.) CULTIVARS

INTRODUCTION

Texture of a wheat kernel is a mechanical property related to endosperm. It has been defined as the degree of adhesion between the major endosperm components, starch granules and proteins (Norris et al. 1989). As such, it should not be confused with vitreousness as vitreous kernels usually result from high temperatures and high nitrogen availability during grain maturation. Differences in kernel texture may adversely influence dough mixing, water absorption and other milling and baking properties. Wheats with soft kernels are used for pastry products while hard wheats are used for breadmaking or semolina products.

Investigators have employed several methods for measuring texture of wheat grain. To date, near-infrared reflectance (NIR) analysis appears to be a reliable and rapid method. Williams and Sobering (1986b) demonstrated the ease with which NIR reflectance can be standardized and that calibration was transferable to other instruments, including the Technicon InfraAlyzer 400.

Although kernel texture of wheat cultivars can be classified as either hard or soft, a great range of NIR and particle size index (PSI) values can be found within each class.

Most published reports on the inheritance of kernel hardness have dealt with crosses between hard and soft textured wheat cultivars. Little attention has been given to variation in hardness among cultivars with the same texture or to possible maternal effects influencing this trait.

With increased interest in developing soft, semihard and hard kernel white wheat cultivars for different end product uses, an understanding of the amount and nature of genetic variability associated with kernel hardness is imperative for any plant improvement effort.

The objectives of this study were to 1) determine the nature of inheritance of grain texture in a cross between a very soft white wheat selection and a commercial soft white cultivar using the NIR technique, 2) determine if maternal effects play a role in kernel hardness, and 3) evaluate possible associations between the degree of kernel hardness and selected agronomic traits.

LITERATURE REVIEW

Measurement of hardness

Kernel hardness can be measured by several techniques. Pearling index (Beard and Poehlman, 1954), particle size index (PSI) (Symes, 1965), starch damage (Doekes and Belderok, 1976), grinding time (Baker, 1977), work (in joules) required to grind 50 g of wheat, and near-infrared reflectance (NIR) of ground wheat (Miller et al. 1982), have been the most common methods. Of these, NIR is the most rapid and efficient.

Other researchers have measured kernel hardness by NIR spectroscopy using wavelengths of 1680 and 2230 nm, and obtained excellent discrimination among wheat classes of different grain hardnesses (Fuller et al. 1975; ; Williams 1975 and 1979; Obuchowski and Bushuk, 1980a; Osborne et al. 1981; Hook, 1982; Sampson et al. 1983; Pomeranz, 1985c; Williams and Sobering, 1986b, and Norris et al. 1989).

Two types of NIR reflectance instruments both using tungsten light source (Law and Tkachuk, 1977 and Watson, 1977) are in use. One type utilizes narrow band filters (up to 20 different filters) and the other tilting filters (using only 3 filters). The wavelengths of light emitted by each type are directed at the sample. Some wavelengths are reflected and others absorbed (Rotolo, 1979). Photodetectors which sense very low light levels throughout the NIR region are placed above the sample at different positions. Signals are converted into quantitative results by a computer.

Using several spring wheat lines, Sampson et al. (1983) compared two methods for measuring kernel hardness; grinding time and NIR spectroscopy. They concluded that grinding time was more accurate. It gave lower coefficients of variation and higher correlations between years, but it requires five times more grain than NIR spectroscopy. Also, from a practical standpoint, NIR can provide both protein and moisture contents determinations simultaneously using the same flour sample. Williams and Sobering (1986b) reviewed the findings of an international collaborative study to verify the integrity of NIR spectroscopy as a rapid method for measuring kernel hardness. They proposed a near-infrared reflectance index (NIRI) with a scale extending from 0 to 100. A score of 50 is considered the cutoff point between the hard and soft wheats.

Mattern (1988) described a microscopic test for the identification of wheat hardness of a single kernel. This test was highly correlated with both PSI and NIR.

Inheritance of wheat hardness

Symes (1965) demonstrated a simple inheritance pattern for grain hardness in Australian wheat cultivars as measured by PSI. He used eight crosses involving hard and soft wheat parents and detected two major genes and many modifier genes which influenced the degree of kernel hardness. Different major genes were detected in various crosses. In two other crosses he found no indication of any discrete classes and suggested the presence of minor genes. Symes also emphasized the importance of the donor parent. Falcon, a cultivar with a hard kernel, produce a very different result from that obtained with another hard kernel parent Spica. Gaba, also a hard kernel type, gave similar results as with Falcon.

According to Baker (1977), the soft grain cultivar Pictic 62 and a hard grain cultivar Neepawa differed by two major genes. A single major gene accounted for the difference in hardness between Neepawa and the very hard Glenlee. In both crosses, one or more minor gene(s) were also present.

Lukow et al. (1989) investigated the nature of hardness in three wheat cultivars with medium kernel hardness and in seed mixtures consisting of soft, medium, and hard wheats. Their results indicated that there was no single major gene conferring medium hardness in spring wheat. They suggested that medium hardness is a result of an accumulation of one or more modifier genes.

The work of Baker and Sutherland (1991) on the inheritance of kernel hardness in five spring wheat crosses showed significant genetic variation between the very hard Glenlee and the hard Columbus cultivars. They noted significant genetic variation between the very soft 'Fielder' and the soft 'Potam' cultivars. The same authors found two gene differences between the very hard and soft cultivars, while hard and soft cultivars differed by only one gene.

Williams (1986) studied the influence of polyploidy level on wheat kernel hardness. He noted that diploid types (DD) were soft, tetraploid wheats (AABB) were hard, and combinations of AABB genomes with the DD genome in hexaploid wheats resulted in a complete spectrum of kernel hardness.

The studies of Morris et al. (1966, 1968) using substitution lines of the donor cultivar Cheyenne into the recipient Chinese Spring, indicated that chromosomes 1B, 4B, 7B and possibly 1A, with lessor effects from 4D, 5D, and 7D, contributed for kernel hardness, loaf volume, and crust appearance. A similar experiment was performed by Doeks and Belderok (1976) to identify the chromosomal location of genetic traits controlling wheat quality. They used chromosome substitution lines of Cappelle Desprez, Hope, and Timstein in addition to Cheyenne into the recipient Chinese Spring. In their study, the presence of one of the chromosomes either 3B, 5D, or 7D in the hard kernel line Timstein was sufficient to make the wheat kernel hard.

Maternal effect

Maternal contributions to seed related traits arise from such sources as seed coat (testa), endosperm, and cytoplasm, where other Mendelian components can be transmitted only with the maternal cytoplasm. Quantitative contributions of a maternal effect are not predictable from parental performance and are usually non-persistent over generations (Jinks et al. 1972, and Fooland and Jones, 1992). The seed coat (2n) in white wheat is unpigmented and it is a maternal tissue derived from the integument of the ovule. The aleurone layer is the outer cell layer that comprises the periphery of the triploid (3n) endosperm of which two-thirds of the genetic make up comes from the female parent. It contains no gluten nor starch. Soft and hard wheats are different in terms of the subaleurone layer. In hard wheats, the subaleurone layer forms a complete shell around the inner endosperm, while the shell in soft wheats is discontinuous and endosperm cell extends out into the aleuorone layer (Kent, 1969). The embryo (2n) is produced following fertilization of the egg nucleus. It reaches final size before the development of the endosperm is complete.

Bhat and Dhawan (1970) noted that cytoplasmic effects on quantitative traits are expressed when genes from one parent remain below a certain threshold level in the hybrid nucleus. The cytoplasmic effect disappears if the threshold level is exceeded. Bhat and McMaster (1976) observed a dosage effect for bread wheat flour color in F2's of three reciprocal crosses.

Factors affecting wheat hardness and their association with other traits

Environmental factors

Baker and Kosmola (1977) found genotype and environment interactions to be less important in kernel hardness than in strength parameters, such as mixograph development time. The variance due to genotype was found to be more than 100 times greater than that of location or season.

Kernel hardness scores of 1900 wheat samples representing more than 125 cultivars grown in 10 states (scanned by the NIR procedure) were presented by Slaughter (1989). He found that kernel hardness varies with cultivars and location. He noted that the NIR hardness scores may not be representative of a cultivar when grown at different locations. Trupp (1976) observed small genotypic and environmental correlations between kernel hardness and protein using a modified PSI method. In studying the effects of selected wheat cultivars when grown on light, sandy and heavy, clay loam soils over two years, Williams and Sobering (1984) found that differences in kernel hardness were higher in both years in the heavy clay loam soil with the interactions between cultivars and soil type being significant in both years.

Differences in precipitation during the crop year and in temperature during grain maturation may also influence kernel hardness. Milner and Shellenberger (1953) showed that natural wetting and drying of wheat caused softening of the kernel, as evaluated by ease of penetrability of water. A decrease in grain hardness (8%) and 1000-kernel weight (1.4%) with delayed harvest was reported by Czarnecki and Evans (1986). They evaluated five wheat cultivars for the effect of weathering by subjecting windrowed grain to different periods of exposure.

Influence of temperature on the accuracy of some instruments for measuring hardness has been reported in the literature. Miller et al. (1981b) found that increased temperature reduced grinding time, particularly in soft wheats. Canadian Hard Red Winter wheat showed a

considerable increase in softness at approximately 38C; however, there was no effect on NIR spectroscopy and PSI (Pomeranz and Williams, 1990).
Their reason for this was that heat generated during operation remains constant after certain warming period.

Moisture content is important in any measurement of wheat kernel hardness, especially those tests that involve a penetrometer or depend on measurement of energy such as grinding time, but less so in the case of PSI and NIR (Pomeranz and Williams, 1990). Obuchowski and Bushuk (1980a) tested 12 methods for measurement of hardness and found a moisture range of 9.5 to 15.5% affected all the methods. Soft wheats had a tendency to be softer at higher moisture (Kosmolak, 1978).

Protein content

Protein content has not been found to be a reliable index of kernel hardness. Studies regarding the relation between these two traits have yielded conflicting results. Pomeranz and Miller (1982), and Miller et al. (1982) noted that protein contents of Hard Red Winter Wheats had no significant effect on kernel hardness measured by any of the methods previously mentioned. Using the grinding time technique, Sampson (1982) found no correlation between kernel texture and protein content. Inconsistent correlation values between kernel hardness and protein content have also been reported by Miller et al. (1984) using three methods of measuring different kernel hardness, and by Pomeranz et al. (1985c) using four methods. However, Obuchowski and Bushuk (1980b) reported a negative correlation of -0.75 between protein content and kernel hardness. Similar findings for spring wheat cultivars have been reported by Baker et al. (1971). Among authors who reported a positive association between hardness and protein of the wheat grain included, Anderson et al. (1966), and Fowler and De La Roche (1975).

Pomeranz and Williams (1990) attributed this confusion to the strong cultivar, seasonal, and location interactions. It seems like different methods give different results in describing the association between these two parameters.

Milling Properties and other Factors

Gaines (1985) evaluated 83 soft wheat lines for kernel hardness, protein content, and other milling quality characteristics. He found that cake volume and cookie diameter were positively associated with soft textured and low protein content.

Baker and Dyck (1975) studied the effects of kernel hardness on several measures of wheat quality in random lines from two crosses of spring wheat. They found that lines with hard kernels had significantly more flour nitrogen, higher mixograph peaks, higher flour yield, higher farinograph absorption, shorter grinding time and greater loaf volume than soft lines. The same investigators reported no significant relationship between kernel hardness and sedimentation value or between kernel hardness and mixograph development time.

The fact that bran of hard wheats is generally thinner and easier to mill than soft wheats is frequently mentioned in the literature. Pomeranz and Williams (1990) reasoned that by "bran layers of hard wheats are more readily separated from the endosperm in the mill" and "the endosperm of soft wheats is less regular in terms of the cellular structure of the mature kernel than that of hard wheats, which retain their structure throughout maturation."

Near-infrared reflectance (NIR) was found to be directly related to kernel size especially with shrunken kernels (Pomeranz and Afework, 1984). However, as determined by reduction in revolution per minute (rpm), kernel size has no effect on hardness (Williams et al. 1987).

Chesterfield and Lind (1971), and Fowler and De La Roche (1975) observed no relationship between test weight and kernel hardness as measured by grinding time.

Pomeranz and Afework (1984) reported decreased NIR values as a-amylase increased in wheats with hard kernels. An opposite trend was observed in the case of soft wheats.

MATERIALS AND METHODS

Experimental procedures

To study the possible genetic variation of kernel hardness within soft white wheat cultivars and its associations with other traits, two parental lines were selected. Yamhill (Heines VII/Redmond (Alba)), a soft white common winter wheat cultivar was released by Oregon State University in 1971. It is commercially adapted to growing conditions prevailing in the Pacific Northwest. Yamhill is late maturing, low tillering, medium height, high yielding, and awnless. It possesses large fertile spikes with medium to large kernels.

The second parent, Selection 3870552 (TJB406.892/ MON"S") was developed from a cross made in Mexico between TJB (Trumpington John Bingham), a line developed at the Plant Breeding Institute - Cambridge, United Kingdom, and Moncho "S", a line developed by The International Maize and Wheat Improvement Center (CIMMYT). Subsequent selection within segregating populations was conducted in Oregon until a fix line identified as Selection 3870552 was established. This line is awned with very soft white grain. This parent will be referred to as TJB/MON"S" throughout this manuscript.

Reciprocal crosses were made between individual plants of the two parental cultivars. These populations are identified as Yamhill//TJB/MON"S" where Yamhill was used as a female parent, and TJB/MON"S"//Yamhill where it is used as a male parent. Randomly selected spikes not used for crossing were bagged to ensure self-pollination. Seed obtained from the two reciprocal F1's and parents was used as the experimental material in this investigation.

The parents and F1's were sown on September 4, 1990 in vermiculite flats and allowed to germinate for 14 days in the greenhouse. Seedlings were then moved outside the greenhouse for 7 days to acclimatize the material before transplanting into the field.

The field study was conducted during the 1990-1991 growing season at Hyslop Crop Science Laboratory. This experimental site is located 11 Km northwest of Corvallis, Oregon. The soil type at this location is Woodburn silty clay loam which is a fine, silty mixed mesic Aquultic Agrixeroll (Soil Survey-USDA,1969).

Seedlings were transplanted into the field on September 28, 1990. The experiment design was a randomized complete block with four replications. The entries included two parents and two reciprocal F1 crosses. Plots consisted of three rows of 10 plants each, plant spacing was 25 cm between rows and 25 cm within rows. There were 480 plants in total [(4 replicates x (3 rows x 10 plants) x 4 genotypes)] with each replication containing 120 plants.

Jackmar a club type cultivar, was planted around plots to lessen any potential border effect. The trial was sprayed with a combination of "Finesse" (Chlorosulfuron) and "diuron" herbicides at rates of 9 and 16 grams per hectare, respectively. The application was made on December 11, 1990 to minimize any competition due to weeds. Weeds were removed by hand throughout the growing season. The fungicide "Tilt" was applied at a rate of 250 grams per hectare on May 15, 1991, just after flowering, to control the foliar pathogen *Septoria tritici*.

Fifty kilograms per hectare of nitrogen was applied twice to experimental area. The first application was made prior to transplanting, and the second on February 25, 1991, toward the end of the tillering stage. A summary of climatic data recorded at the Hyslop site during the period of the experiment is presented in Appendix Table 1.

The following traits were measured on individual plants;

1) Kernel hardness: A Udy Cyclone grinder fitted with a 0.5 mm screen was used to grind wheat kernels. Ten wheat samples from five hard and five soft cultivars were used as standards for the calibration of the InfraAlyzer 400. The cultivar names and their scores are provided in Appendix Table 2. All experimental material (standards along with experimental genotypes) was left at room temperature for 48 hours prior to measurement of hardness.

Calibration of the NIR instrument followed the standard method of the American Association of Cereal Chemists (AACC Method 39-70A). The samples were scanned using wavelengths of 1680 and 2230 um. The moisture content of all experimental material was equilibrated at 10.2% level.

The near-infrared reflectance (NIR) values for the F2 seed on the reciprocal F1 plants were divided into two classes. A NIR score of 25 was set as the separation between very soft and soft textures. This point was selected as the mid-point of the conventional soft wheat class that extends from 0 to 50 using the NIR and a value that falls between the mean values of the two parental lines.

2) **Protein content**: measured by the NIR spectroscopy. The instrument was calibrated and adjusted for bias using protein data from wheat samples sent for Kjeldahl total nitrogen analysis to the Plant Testing Laboratory of Oregon State University. The total N Kjeldahl was multiplied by 5.7 to obtain protein percentage.

3) **Kernel weight**: randomly selected 500 kernels, weighed in grams and multiplied by two to obtain an estimate of thousand kernel weight.

4) **Tillers number**: number of fertile tillers (spikes) per plant at harvest time.

5) **Kernel per spike**: measured as the average number of kernels on the first three primary tillers.

6) **Total grain yield**: measured in grams from all spikes from individual plants.

7) **Biological yield**: dry weight in grams of above ground plant tissues.

8) **Harvest index**: grain yield divided by biological yield, and multiplied by 100.

9) **Plant height**: measured one week prior to harvest as the distance in cm between the soil surface (base of culm) and the tip of the highest spike, excluding the awns if present.

10) **Heading date**: number of days from the first of January to the date when more than half of the spikes had emerged from the flag leaf sheath.

Statistical procedures

Analyses of variance were performed to determine if there were differences between genotypes for kernel hardness, protein contents, 1000-kernel weight, number of tillers (spikes) per plant, number of kernels per spike, total grain yield per plant, total biological yield per plant, harvest index, plant height, and heading dates.

Fisher's protected least significant difference (LSD) test was used to separate mean values for each trait for the two parents and their reciprocal F1's.

A chi-squared test was used to test the goodness-offit for a 1:3 ratio expected if a one-gene difference existed between parents for kernel texture.

Narrow sense heritability estimates were obtained using the parent-offspring regression method (Vogel et al.1980).

Heterosis was estimated for the reciprocal F1's generation in terms of percent deviation from the mid-parent value, using the general formula;
Heterosis = [(F1-MP)/MP]*100, where, F1= mean performance of the first generation, and MP= mid-parent value.

Heterobeltiosis was calculated by the formula
Heterobeltiosis = [(F1-HP)/HP]*100, where, F1= mean performance of the first generation, and HP= highest parental value.

Associations between the selected agronomic traits and kernel hardness for the different genotypes were estimated through coefficient of determination (R^2).

RESULTS

Analysis of variance

Analysis of variance was conducted to test for differences between parents and their reciprocal F1's for each of the 10 measured trait. As can be noted in Table 1, differences were found among genotypes for all traits.

Coefficient of variations (C.V.) were high for kernel hardness (18.58%), total grain yield (17.17%), total biological yield (16.87%), and number of tillers (13.90%). Traits that showed coefficient of variations below 10% were number of kernels per spikes (8.99%), protein content (6.84%), harvest index (5.62%), plant height (5.76%), and heading dates (0.61%).

Separation of means

Mean comparison for all traits for the genotypes are presented in Table 2. Differences between parents and their reciprocal F1's and between reciprocal F1's for specific traits can be observed.

When the mean values for kernel hardness per plant are considered, the progenies TJB/MON"S"// Yamhill and Yamhill// TJB/MON"S" had the highest near-infrared reflectance (NIR) score, followed by the

Table 1. Observed mean squares and coefficients of variation for 10 traits involving two parents and their reciprocal F1's grown on Hyslop Crop Science Laboratory in 1990/1991.

Source of variations	df	Kernel hardness (NIR)	Protein content (%)	1000-Kernel wt. (g)	Number of tillers	No. of kernels/ spike
Total	479	-	-	-	-	-
Replications	3	21376.15	3.28	149.84	13005.28	41583.17
Genotype	3	6373.95**[1]	3.38	2269.99**	122.05*	1255.59**
Experimental error	9	93.85	2.62	76.30	37.68	103.77
Sampling error	464	33.15	0.84	33.94	15.70	37.03
C.V. (%)	-	18.58[2]	6.84	12.55	13.90	8.99

[1] *,** significant at the 0.01 and 0.05 probability levels, respectively.
[2] Based on plants within plot variability.

Table 1. (Continued) Observed mean squares and coefficients of variation for 10 traits involving two parents and their reciprocal F1's grown on Hyslop Crop Science Laboratory in 1990/1991.

Source of variations	df	Grain yield (g)	Biological yield (g)	Harvest index (%)	Plant height (cm)	Heading date
Total	479	-	-	-	-	-
Replications	3	194630.31	143127.92	409.43	188.11	21.88
Genotype	3	13676.56**	92752.24**	436.14**	11016.16**	2141.88**
Experimental error	9	1831.73	7511.75	60.61	358.71	21.88
Sampling error	464	183.44	1492.07	3.62	42.18	0.65
C.V. (%)	-	17.17	16.87	5.62	5.76	0.61

[1] *,** significant at the 0.01 and 0.05 probability levels, respectively.
[2] Based on plants within plot variability.

Table 2. Comparison of the mean values of 10 traits for parents and their reciprocal F1's grown at Hyslop Crop Science Laboratory 1990-1991.

Genotype	Kernel hardness (NIR)	1000-Kernel wt.(g)	Number of tillers	Number Kernels/spike
Yamhill	35.00a[1]	43.05d	28.12ef	63.73i
TJB/MON"S"	20.00b	42.32d	28.82ef	68.73gh
Yam//TJB/MON"S"	33.00a	49.65c	27.36f	66.88h
TJB/MON"S"//Yam	36.00a	50.68c	29.73e	71.43g
LSD (0.05)	2.83	2.55	1.79	2.98

[1] rows with the same letter within each column are not significantly different based on Fisher's Protected least significant difference (LSD) test at the .05 probability level.

Table 2. (Continued) Comparison of the mean values of 10 traits for parents and their reciprocal F1's grown at the Hyslop Crop Science Laboratory 1990-1991.

Genotype	Grain yield (g)	Biological yield (g)	Harvest index (%)	Plant height (cm)	Heading date
Yamhill	66.05l	207.84n	31.15p[2]	115.29r	138.00s
TJB/MON"S"	74.38kl	202.74n	35.66o	98.79q	128.00u
Yam//TJB/MON"S"	85.64jk	247.13m	34.12o	116.58q	131.25t
TJB/MON"S"//Yam	89.43j	258.20m	34.36o	120.46q	131.00t
LSD (0.05)	12.50	25.31	2.27	5.53	1.37

[1] rows with the same letters within each column are not significantly different based on the Fisher's Protected least significant difference (LSD) at the 0.05 probability level.

[2] Calculated on an individaul plant basis.

Yamhill//TJB/MON"S" along with the parent Yamhill, meanwhile the parent TJB/MON"S" had the softest kernels.

No differences were found among genotypes for protein percentage.

Observation of the population means for thousand kernel weight shows a clear separation between parents and their reciprocal F1's, with the latter possessing higher kernel weight than their parents.

Examination of the number of tillers per plant reveals a large difference between the two F1 populations. The cross TJB/MON"S"//Yamhill gave the highest number of tillers per plant, while Yamhill//TJB/MON"S" gave the lowest. However, there was no difference between the parent TJB/MON"S" and TJB/MON"S"// Yamhill nor between Yamhill and Yamhill//TJB/MON"S".

With regards to the number of kernels per spike, TJB/MON"S"//Yamhill had the highest kernels per spike, followed by TJB/MON"S', Yamhill//TJB/MON"S" and Yamhill, respectively.

The progeny TJB/MON"S"//Yamhill had the highest grain yield per plant, followed by Yamhill//TJB/MON"S", TJB/MON"S" and Yamhill, respectively.

As to the total biological yield per plant, the reciprocal F1's performed superbly over their parent.

The parent TJB/MON"S" and the reciprocal F1's had higher harvest index than Yamhill.

There was a difference in plant height between TJB/MON"S" and the rest of the genotypes, where TJB/MON"S" had a shorter stand.

There was a ten-day difference in heading dates between the two parents with Yamhill being latest. Heading dates for the F1 populations were similar and slightly later than the earliest parent TJB/MON"S".

Nature of Inheritance

A phenotypic ratio of one very soft to three soft was obtained, with P-values of > 0.20 and < 0.10 for Yamhill//TJB/MON"S" and TJB/MON"S"//Yamhill, respectively (Table 3). The mean NIR values for TJB/MON"S"//Yamhill and Yamhill// TJB/MON"S" were closer to mean value of Yamhill. The frequency distribution for parents and the F2 segregating populations are illustrated in Appendix figures 1 through 4. If the reciprocal F2 population are combined, a X^2 of 0.098 was obtained, or probability of one major gene being involved being between P=0.95 and 0.50.

Results of the parent-offspring regression analysis for nine agronomic traits are provided in Table 4. Regression coefficients of 0.714, 0.681, 0.477, 0.371, 0.349, 0.344, 0.210, 0.161, and 0.017 were obtained for plant height, kernel hardness, number of kernel per spike, grain yield, total biological yield, number of tillers per

Table 3. Chi square values for fitting one-gene hypothesis to near-infrared reflectance (NIR) of progenies of two soft wheat genotypes grown at the Hyslop Crop Science Laboratory, 1990-1991.

Cross	Sample size	Number in class		Chi-Square	P-value
		v. soft	soft		
Yamhill//TJB/MON"S"	120	35	85	1.11	>0.20
TJB/MON"S"//Yamhill	120	22	98	2.84	<0.10
Combined	240	57	183	0.098	0.5-0.95

Table 4. Parent-offspring regression coefficients for estimating narrow sense heritability for nine traits for parents and their reciprocal F1's grown at Hyslop Crop Science Laboratory 1990-1991.

Trait[1]	Regression coefficient (b)	Standard error
Kernel hardness (NIR)	0.681	0.035
Protein contents (%)	0.017	0.082
Tillers number	0.344	0.083
Biological yield (g)	0.349	0.100
Grain yield (g)	0.371	0.098
Harvest index (%)	0.210	0.048
Kernel per spike	0.477	0.070
Plant height (cm)	0.714	0.056
1000-Kernel wt. (g)	0.161	0.075

[1] n=480.

plant, harvest index, 1000-kernel weight, and protein content, respectively.

Heterosis and heterobeltiosis

The reciprocal F1 populations were higher than the mid-parent value for most traits measured (Table 5). When these differences are classified as percentage they ranged from -3.90 (number of tillers) to 21.97 (grain yield) percent for Yamhill//TJB/MON"S", and from -1.77 (protein content) to 30.91 (kernel hardness) percent for TJB/MON"S"//Yamhill. The latter F1 progeny exceeded the mid-parent value for the following traits; kernel hardness, 1000-kernel weight, number of tillers per plant, kernels per spike, grain yield, total biological yield, harvest index and plant height. Yamhill//TJB/MON"S" exceeded the mid-parent value for the same traits except for number of tillers and number of kernels per spike.

Heterobeltiosis values were also calculated for the 10 traits and are summarized in Table 6. The different percentages range from -5.71 (number of tillers) to 18.90 (total biological yield) percent for the cross Yamhill//TJB/MON"S", and from -5.07 (heading date) to 24.23 (total biological yield) percent for the other F1 reciprocal. Whenever TJB/MON"S" was used as the female parent as in TJB/MON"S"//Yamhill, the F1 exceeded the

Table 5. Heterosis estimates for 10 traits for reciprocal F1's grown at the Hyslop Crop Science Laboratory, 1990-1991.

Cross	Kernel hardness (NIR)	Protein content (%)	Kernel weight (g)	No. of tillers	Kernels/ spike
Yamhill//TJB/MON"S"	33.00	13.23	49.65	27.36	66.88
TJB/MON"S"//Yamhill	36.00	13.30	50.68	29.73	71.43
Mid-parent value	27.5	13.54	42.69	28.47	66.23

Cross	Grain yield (g)	Biol. yield (g)	Harvest index (%)	Plant height (cm)	Heading date
Yamhill//TJB/MON"S"	85.64	247.13	34.12	116.58	131.25
TJB/MON"S"//Yamhill	89.43	258.20	34.36	120.46	131.00
Mid-Parent Value	70.22	205.29	33.41	107.04	133.00

Table 6. Heterobeltiosis estimates for 10 traits for reciprocal F1's grown at the Hyslop Crop Science Laboratory Station, 1990-1991.

Cross	Kernel hardness (NIR)	Protein content (%)	1000-kernel wt. (g)	Number of tillers	Number kernels/ spike
Yamhill//TJB/MON"S"	33.00	13.23	49.65	27.36	66.88
TJB/MON"S"//Yamhill	36.00	13.30	50.68	29.73	71.43
Higher parent value	35.00	13.59	43.05	28.82	68.73

Cross	Grain yield (g)	Biol. yield (g)	Harvest index (%)	Plant height (cm)	Heading date
Yamhill//TJB/MON"S"	85.64	247.13	34.12	116.58	131.25
TJB/MON"S"//Yamhill	89.43	258.20	34.36	120.46	131.00
Higher Parent Value	74.38	207.84	35.66	115.29	138.00

performance of the highest parent in five out of the 10 traits measured. These include 1000-kernel weight, number of kernel per spike, grain yield, biological yield, and plant height. It also outperformed the highest parent (TJB/MON"S") for the number of tillers per plant, however, the difference was small.

Association among traits

Coefficient of determination of 10 traits for parents and their reciprocal F1 progeny can be found in Table 7.

Associations were noted between kernel hardness with the number of tillers per plant, total biological yield per plant, grain yield per plant, number of kernels per spike, and plant height. A small relationship was observed between kernel hardness and harvest index.

No associations with either 1000-kernel weight, heading date or protein content were observed with kernel hardness.

Number of tillers (spikes) per plant was found to be positively associated with total biological yield, grain yield, harvest index, and number of kernels per spike. However, no association was observed between plant height, 1000-kernel weight, heading date, and protein content with the number of tillers.

Total biological yield per plant was positively

Table 7. Coefficients of determination of 10 traits measured for parents and their reciprocal F1's grown at Hyslop Crop Science Laboratory, 1990-1991.

Trait[1]	Number of tillers	Biological yield (g)	Grain yield (g)	Harvest index	
Kernel hardness	0.760	0.834	0.766	0.074	
No. of tillers		0.916	0.906	0.223	
Biological yld.			0.978	0.186	
Grain yield				0.284	
Trait	**Number kernels/ spike**	**Plant height (cm)**	**1000-kernel wt. (g)**	**Heading date**	**Protein content (%)**
Kernel hardness	0.701	0.176	0.010	0.065	0.001
No. of tillers	0.933	0.008	0.004	0.004	0.004
Biological yld.	0.903	0.046	0.003	0.005	0.130
Grain yield	0.920	0.026	0.002	0.025	0.002
Harvest index	0.332	0.015	0.003	0.265	0.015
Kernels/spike		0.013	0.001	0.020	0.005
Plant height			0.213	0.116	0.013
Kernel weight				0.016	0.176
Heading date					0.007

associated with grain yield, harvest index, number of kernels per spike, and to a lessor extent with plant height. Low R^2 values were observed between total biological yield and 1000-kernel weight, and heading date. An intermediate R^2 value was noted between this trait and protein content.

Grain yield per plant was associated with harvest index, and number of kernels per spike. There was no association between grain yield per plant and 1000-kernel weight.

Harvest index showed a positive relationship with number of kernels per spike. While plant height was associated with 1000-kernel weight, and heading date.

DISCUSSION

Among several milling and baking properties, different flour hardness values are required for different end product uses. In the past, a range in kernel hardness values within soft wheat cultivars was acceptable. However, in recent years, buyers for foreign markets have become much more demanding as to the level of hardness. Millers in these countries recognize that a consistent level of hardness is essential for milling and subsequent baking for specific end product uses. Very soft wheats are desired if they are used for making cookies or crackers. For noodles and flat breads, a harder soft white wheat kernel is preferred. Thus, it is becoming more important to obtain consistent and desired hardness levels in breeding soft white wheat cultivars. The amount of genetic variability within the soft wheat germplasm, and how such variability is influenced by the environment are critical questions for the wheat breeders.

In this study, parents were selected based on their extreme values for softness within the Soft White Wheat market class. To examine how much genetic variability exist within soft white wheat, reciprocal F1 populations were developed and the F2 seed evaluated. Since endosperm tissue is a 3n, a further objective was to determine if there is a maternal effect influencing kernel hardness.

Also if kernel hardness is associated with selected agronomic traits.

Based on the analysis of variance and differences between population means, genetic differences did exist for kernel hardness in the experimental material evaluated. However, the high coefficient of variation (C.V.) values and the wide dispersion of samples as noted in the frequency distributions for the hardness within the parental lines suggests that considerable non-genetic variation exists as well. This finding is in agreement with the work of Sampson et al. (1983), where similar C.V. values were reported using the NIR spectroscopy to determine hardness in spring wheat cultivars.

There are several possible sources contributing to non-genetic variation in the present study. Even though all the plant samples were handled in the same manner, the precision and repeatability of NIR spectroscopy may not have been adequate. However, as previously noted, samples of known hardness were used as checks throughout the evaluation to ensure the repeatability of the data. Another source of variation might have resulted when the samples were processed using the Udy Cyclone mill. The high C.V.'s observed for grain yield, total biological yield, and number of tillers per plant were expected as such traits are often subject to large environmental influences. Kernel hardness may also fall in this category as well since similar magnitudes of variation were noted for this trait in the present investigation.

Nature of Inheritance

Despite the non-genetic variation, evidence obtained from this study suggests that the two parents differed by one or a few genes for kernel hardness. Considering one gene difference between the parents, a ratio of 1:3 was obtained favoring kernel hardness. This ratio, plus the skewness of the frequency distribution, and the heterosis and heterobeltiosis values obtained indicate that the gene or genes were partially dominant for hardness. Again, based primarily on the wide dispersion of samples as noted in the frequency distribution of the parents, the question of penetrance and expressivity, or perhaps modifying genes, might also be involved in the expression of kernel hardness. Many authors have suggested similar explanations for the inheritance patterns observed for kernel texture (Symes, 1965; Baker, 1977; Sampson, 1983 and Lukow et al. 1989)

As noted by the relatively high narrow sense heritability value for kernel texture, it should be possible to select for various level of kernel hardness in early generations (F2 or F3), due to the large amount of additive genetic variance. Unfortunately, with the large non-genetic variation plus what appears to be some nonadditive genetic variance, it may be necessary to delay selection until later generations (F4 or F5). At which time it would be possible to use replicated trials across locations to more clearly identify the environment and genetic x environment interaction of new cultivars. It would also be advisable to compare other methods of determining kernel hardness and milling procedures to ensure repeatable results.

Maternal Effect

Reciprocal differences between F1 populations were evident in some of the traits measured. Such results might be expected for kernel hardness where the 3n endosperm is the result of 2n polar nuclei contributed by the female, and 1n contributed by the male. In this study, however, the F2 segregating population of TJB/MON"S"//Yamhill, where TJB/MON"S", the softer parent was used as the female, harder kernels resulted. Therefore, it would appear that in the experimental material used, a dosage effect was not present. Differences between reciprocal crosses have been reported for wheat flour pigment (Bhat and McMaster, 1976). However, no specific reports were found for kernel hardness in the literature. Reciprocal effects were noted for number of tillers per plant and number of kernels per spike. The superior performance of TJB/MON"S"//Yamhill F1 population suggest that in this cross it would be important as to which parental line was used as a female.

Association of kernel hardness with other traits

Results obtained indicated that kernel hardness and protein percentage are independently inherited. These findings are in agreement with Trupp (1976), who found a non-significant correlation between PSI and protein in 30 soft red and soft white winter wheat cultivars. Similar findings have been reported by Sampson (1982) in 99 winter wheat lines.

There are no reports in the literature describing an association between heading date and kernel hardness. However, the result obtained in this study would suggest that kernel hardness and earliness cannot be selected for simultaneously as negative association was observed. Making selections within a segregating population would require a compromise between these traits.

The positive associations between kernel hardness and number of tillers, total biological yield, grain yield, harvest index, and number of kernels per spike suggests that simultaneous selection for kernel hardness and these traits could be achieved successfully. However, since many of these traits are quantitatively inherited with large environmental influences, it would be necessary to delay selection until later generations, when the nonadditive genetic variability has been lost and estimates of the environmental influences evaluated.

Results obtained in this study provided evidence that there is genetic variations within soft white wheats. It also appears that for this experimental material, it would be important as to which parent should be used as the female.

Despite an apparent qualitative nature of the inheritance involved in the expression of kernel texture within the soft white wheats used in this investigation, the importance of the environmental influences and the partial dominance or nonadditive gene action noted cannot be ignored. Therefore, a further investigation based on F4 or later generations along with testing in multiple locations and over years to determine possible interactions would be necessary to determine the effect and magnitude of non-genetic factors on the change in kernel texture of new cultivar.

SUMMARY AND CONCLUSIONS

Parents having a very soft and soft kernel texture along with reciprocal F1 populations represented the experimental material. A randomized complete block design with four replications was used in an experiment conducted at the Crop Science Field Laboratory in 1990-1991 season.

Data were collected on an individual plant basis for kernel texture, protein content, 1000-kernel weight, number of tillers, number of kernels per spike, grain yield, total biological yield, harvest index, plant height, and heading date. Near-infrared reflectance (NIR) spectroscopy method was used to determine kernel hardness and protein content.

Analysis of variance was used to detect differences between parents and their reciprocal F1 progenies. Least significant test (LSD) was used to separate mean values for all traits which were found to be significant.

Chi-Squared test was performed to determine how many gene(s) involved in the expression of kernel hardness. Potential maternal or dosage effect for kernel texture, and the other traits were evaluated. Also possible associations between kernel texture and selected traits were investigated.

Based on the results from this study, the following conclusions were drawn:

1) Genetic variation does exist between the two wheat genotypes. Based on a value of 25 on the NIR scale, one or more genes are involved in the expression of kernel texture.

2) Narrow sense heritability estimate of kernel texture further suggest the existence of additive type gene action. However, partial dominance was also observed based on the F2 segregating ratio, the skewed frequency distribution and heterosis values favoring the harder kernel parent. Thus, selection for kernel texture should be delayed until later generations (F4 or later, if necessary).

3) Despite the fact that Kernel texture involves 3n endosperm, no dosage effect was detected.

4) No relationship between kernel texture and protein content was observed suggesting that they are inherited independently.

5) A compromise must be made when selecting for kernel texture and earliness due to a negative association.

6) The NIR spectroscopy proves to be capable technique for discriminating between different softness levels within soft wheats.

7) Due to the large non-genetic variation and possible non-additive gene action, selection for kernel texture can not be made in early generations. Advanced lines must be tested over different environments to determine the level

and possible genetic x environment interactions for kernel texture.

BIBLIOGRAPHY

American Association of Cereal Chemists - AACC Method 39-70A. 1989. Wheat hardness as determined by near-infrared reflectance.

Anderson, R.A., V.F. Pfeifer and A.J. Peplinski. 1966. Measuring wheat hardness by standardized grinding procedures. Cereal Sci. Today 11:204-206, 208-209.

Baker, R.J., K.H. Tipples, and A.B. Campbell. 1971. Heritability of and correlations among quality traits in wheat. Can. J. Plant Sci. 51:441-448.

Baker, R.J. 1977. Inheritance of kernel hardness in spring wheat. Crop Sci. vol. 170: 960-962.

Baker, R.J. and P.L. Dyck. 1975. Relation of several quality characteristics to hardness in two spring wheat crosses. Can. J. Plant Sci. 55: 625-627.

Baker, R.J. and K.A. Sutherland. 1991. Inheritance of kernel hardness in five spring wheat crosses. Can. J. Plant Sci. 71:179-181.

Baker, R.J. and F.G. Kosmolak. 1977. Effects of genotype-environment interaction on bread wheat quality in western Canada. Can. J. Plant Sci. 57: 185-191.

Beard, B.H. and Poehlman, J.M. 1954. A study of quality, as measured by pearling test, in crosses between hard and soft wheats. Agron. J. 46: 220-223.

Bhat, B.K., and N.L. Dhawan. 1970. Threshold concentration of plsmon-sensitive polygenes in the expression of quantitative characteristics of maize (Zea mays L.). Theor. Appl. Genet. 40:347-350.

Bhatt, G.M., and G.J. McMaster. 1976. Variation in pigment control of flour color in bread wheat (Triticum aestivum L.). Euphytica 25:685-691.

Chesterfield, R.S., and P. Lind. 1971. Factors affecting the pearling resistance of New South Wales wheats. Pages 245-256 in: Proc. Annu. Conf., 21st (Melbourne). R. Aust. Chem. Inst., Cereal Chem. Div., Melbourne.

Czarnecki, E., and L.E. Evans. 1986. Effect of weathering during delayed harvest on test weight, seed size and grain hardness of wheat. Can. J. Plant Sci. 66: 473-

482.

Doekes, G.J., and B. Belderok. 1976. Kernel hardness and baking quality of wheat: A genetic analysis using the chromosome substitution lines. Euphytica 25:565-576.

Fooland, M.R., and R.A. Jones. 1992. models to estimate maternally controlled genetic variation in quantitative seed characters. Theor. Appl. Genet. 83:360-366.

Fowler, D.B., and I.A. De La Roche. 1975. Wheat quality evaluation. II. Relationships among prediction tests. Can. J. Plant Sci. 55: 251-262.

Fuller, P., J.J.C. Hinton and J.B. Hutchinson. 1975. Development of small scale tests for the determination of the milling quality of wheats. Progress reports on research and development. Home Grown Cereal Authority, London, U.K.

Gaines, C.S. 1985. Associations among soft wheat flour particle size, protein content, chlorine response, kernel hardness, milling quality, white layer cake volume, and sugar-snap cookie spread. Cereal Chem. 62:290-292.

Hook, S.C.W. 1982. Determination of wheat hardness - An evaluation of this aspect of wheat specification. FMBRA, Chorlywood, U.K. Bull. (2): 12-23.

Jinks, J.L., J.M. Perkins, and S.R. Gregory. 1972. The analysis and interaction of differences between reciprocal crosses of Nicotiana rustica varieties. Heridity 28:363-377.

Kent, N.L. 1969. Structural and nutritional properties of cereal proteins. pp. 280-299. in: Proteins as human food. R.A. Lawrie ed. Butterworths, London.

Kosmolak, F.G. 1978. Grinding time - A screening test for kernel hardness in wheat. Can. J. Plant Sci. 58: 415-420.

Lukow, O.M., R.I.H. McKenzie and R.M. De Pauw. 1989. Genetic implications of kernel hardness variation in Canada prairie spring wheats. Can. J. Plant Sci. 69:667-74.

Mattern, P.J. 1988. Wheat hardness : A microscopic classification of individual grains. Cereal Chem. 65 (4) : 312-315

Law, D.P., and R. Tkachuk. 1977. Near-infrared diffuse reflectance spectra of wheat and wheat components. Cereal Chem. 54(2):256-265.

Miller, B.S., Y. Pomeranz, and S. Afework. 1984. Hardness (texture) of hard red winter wheat grown in a soft wheat area and of soft red winter wheat grown in a hard wheat area. Cereal Chem. 61:201-203.

Miller, B.S., S. Afework, Y. Pomeranz, B. Bruinsma and G.D. Booth. 1982. Measuring the hardness of wheat. Cereal Foods Word 27: 61-64.

Miller, B.S., S. Afework, J.W. Hughes, and Y. Pomeranz. 1981b. Wheat hardness Time required to grind wheat with the Brabender automatic micro-hardness tester. J. Food Sci. vol. 46: 1863-1869.

Milner, M., J.A. Shellenberger. 1953. Physical properties of weathered wheat in relation to internal fissuring detected radiographically. Cereal Chem. 30: 202-212.

Morris, R., J.W. Schmidt, P.J. Mattern, and V.A. Johnson. 1966. Chromosomal location of genes for flour quality in the wheat variety "Cheyenne" using substitution lines. Crop Sci. 6: 119-122.

Morris, R., J.W. Schmidt, P.O. Mattern, and V.A. Johnson. 1968. Quality tests on six substitution lines involving "Cheyenne" wheat chromosome. Crop Sci. 8: 121-123.

Norris, K. H., W.R. Hruschka, M.M. Bean and D.C. Slaughter. 1989. A definition of wheat hardness using near-infrared reflectance spectroscopy. Cereal Foods World. 34: 696, 698, 701, 703-705.

Obuchowski, W., and W. Bushuk. 1980a. Wheat hardness : Comparison of methods of its evaluation. Cereal Chem. 57: 421-425.

Pomeranz, Y., and B.S. Miller. 1982. Wheat hardness - Its significance and determination. Pages 399-404, In: Proc. World Cereal and Bread Congress, 7th Praque, Czechoslovakia. J. Holas and J. Kratochvil,(Eds.).

Elsevier, Amesterdam.

Pomeranz, Y., and P.C. Williams. 1990. Wheat hardness: its genetics, structural and biochemical background, measurement, and significance. In: Advances in Cereal Science and Technology. (Ed.) Y. Pomeranz. Americ. Assoc. of Cereal Chem. Inc. St Paul, Minnesota. Pages 471-557.

Pomeranz, Y., and S. Afework. 1984. The effects of kernel size in plump and shrunken kernels, and of sprouting, on kernel hardness in wheat. J. Cereal Sci. 2:119-126.

Pomeranz, Y., C.J. Peterson, and P.J. Mattern. 1985c. Hardness of winter wheats grown under widely different climatic conditions. Cereal Chem. vol. 62 (6): 463-467.

Rotolo, P. 1979. Near-infrared reflectance instrumentation. Cereal Foods World 24(3):94-98.

Sampson, D.R. 1982. Lack of correlation between kernel hardness and protein content in a winter wheat progeny. Can. J. Plant Sci. 62:797-799.

Sampson, D.R., D.W. Flynn, and P. Jui. 1983. Genetic studies on kernel hardness in wheat using grinding time and near-infrared reflectance spectroscopy. Can. J. Plant Sci. 63: 825-832.

Slaughter D. 1989. Guide to wheat hardness U.S.D.A., Ag. Res. Serv., ARS-79, 89pp.

Soil Survey of Benton County Area, Oregon. 1969. USDA-Soil Conservation Service, in cooperation with Oregon Agric. Exper. Station.

Symes, K.J. 1965. The inheritance of grain hardness in wheat as measured by the particle size index. Aust. J. Agric. Res. 16: 113-123.

Trupp, C.R. 1976. Particle Size Index - Breeding behavior and association with protein percentage in wheat. Crop Sci. 16: 618-620.

Vogel, K.P., F.A. Haskins and H.J. Gorz. 1980. Parent-offspring regression in Indiangrass: Inflation of heritability estimates by environmental covariances. Crop Sci. 20:580-582.

Watson, C.A. 1977. Near-infrared reflectance spectroscopic analysis of agricultural products. Analytical chemistry 49:835A.

Williams, P.C., and D.C. Sobering. 1986b. Attempts at standardization of hardness testing of wheat. II. The near-infrared reflectance method. Cereal Chem. 31: 417-420.

Williams, P.C. 1979. Screening wheat for protein and hardness by near-infrared reflectance spectroscopy. Cereal Chem. 56: 169-172.

Williams, P.C., R.H. Kilborn, P.W. Voisey, and M. Kloek. 1987. Measuring wheat hardness by revolutions per minute reduction. Cereal Chem. 64 (6): 422-427.

Williams, P.C. 1986. The influence of chromosome number and species on wheat hardness. Cereal Chem. 63 (1): 56-57.

APPENDIX

APPENDIX TABLE 1
Selected weather data collected at Hyslop Crop Science Laboratory, Corvallis, Oregon for the crop year 1990-1991.

Month	Temp. (C) Max.	Temp. (C) Min.	Precipitation (cm)	Relative humidity (%)	Evaporation (cm)	Solar Radiation (Langley)
September	26	11	2.1	74	12.8	357
October	17	5	11.6	87	4.6	200
November	12	4	12.4	100	-[1]	108
December	5	-3	14.6	100	-	82
January	8	-1	6.8	100	-	119
February	13	5	8.2	-	-	148
March	12	2	14.9	-	-	249.7
April	14	4	8.8	-	6.6	-
May	16	6	9.9	82.3	7.8	332.7
June	20	8	3.9	82.9	11.5	416.1
July	28	11	1.0	68.2	21.0	591.8
August	28	11	1.8	67.4	18.6	49

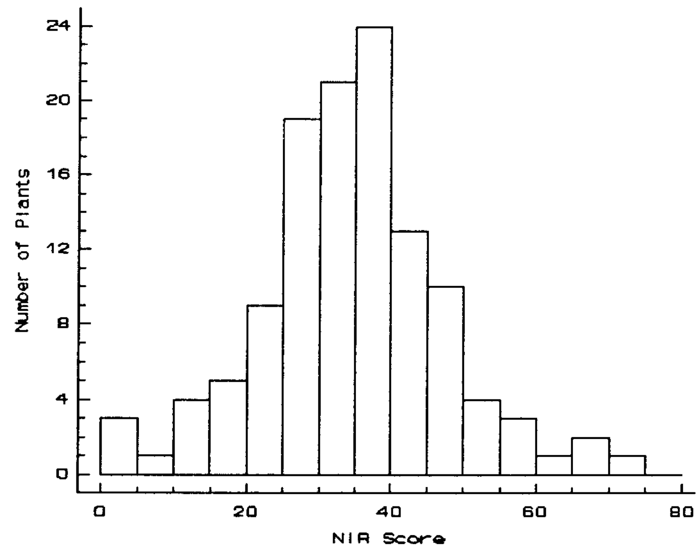
[1] - denotes missing data.

APPENDIX TABLE 2

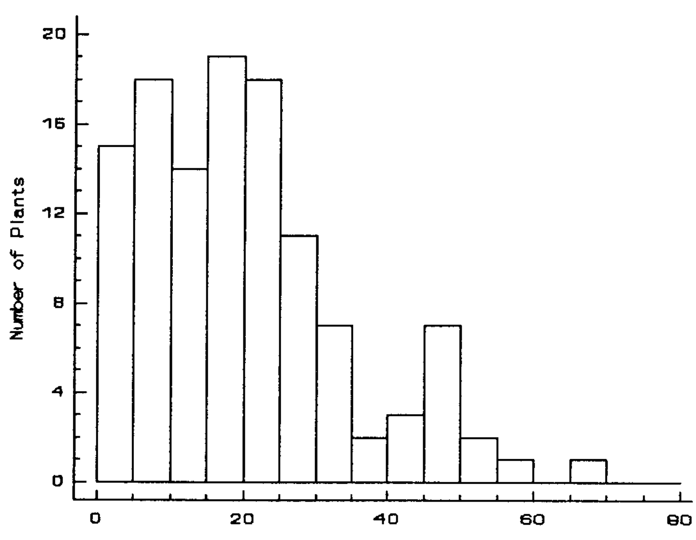
Wheat samples used for the calibration of the NIR spectroscopy and their NIR scores:

Soft Wheats	NIR score
SPN/QLP	15
TJB842-12919/SPN	31
SPN/CROW	42
YMH/HYS//VPM/MOS	22
AFG2//MAYA/MON	11

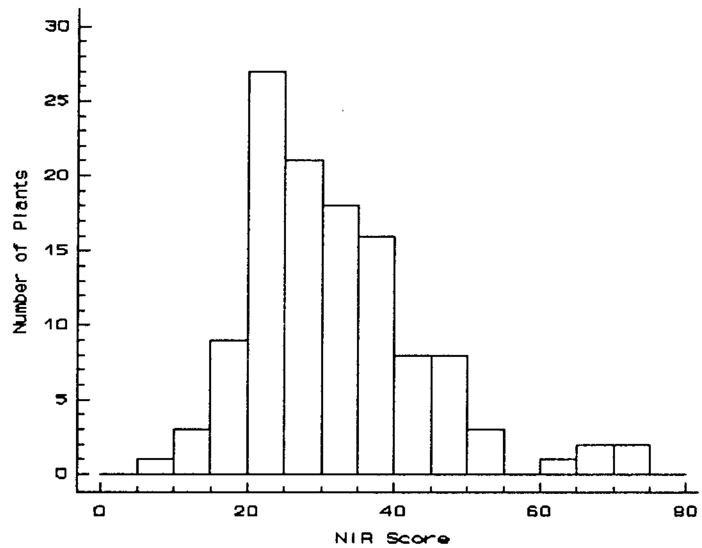
Hard Wheats	NIR score
D6301/HN7//ERA/3/BUC/4/1523/ DRCDW	65
F34-70/TRM//PAR*2	91
PJ/HN4//GLL/3/KVZ/CGN	84
AGRIC/BJYS//VEES	72
TEN/JUB*/2//BND/3/YR/4/FFN/7	58



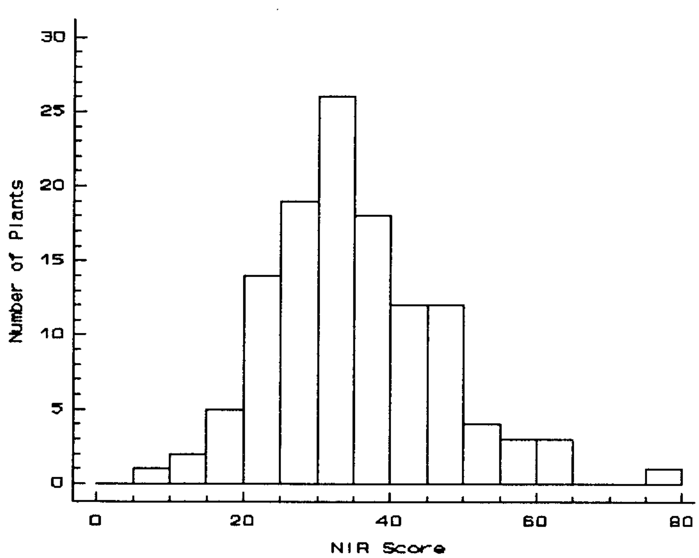
Appendix Figure 1. Frequency Distribution of Kernel Hardness for Yamhill



Appendix Figure 2. Frequency Distribution of Kernel Hardness for TJB/MON"S"



Appendix Figure 3. Frequency Distribution of Kernel Hardness for Yamhill//TJB/MON"S"



Appendix Figure 4. Frequency Distribution of Kernel Hardness for TJB/MON"S"//Yamhill