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Title: Prediction of kernel hardness and grain protein based on the performance of F_3 and F_4 populations derived from ten wheat crosses (Triticum aestivum L. em Thell)

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Ten wheat crosses (four winter x spring and six winter x winter) involving F_3 and F_4 generations and their respective winter parents were used to determine whether the early generation selection would be effective for kernel hardness and grain protein content. In 1980, twenty individual F_2 plants were selected with good phenotypic appearance from each cross. The F_3 progeny rows along with their respective winter parents were grown in a replicated yield trial in 1981.

Significant differences were found among the crosses for kernel hardness, percent protein, grain yield, 1000 kernel weight, and heading date.

Superior progeny with values above the winter parent were observed for both kernel hardness and percent grain protein in both

F_3 and F_4 generations in winter x spring corsses. Transgressive segregation was also observed beyond both parents in five of the six winter x winter crosses for both traits.

Correlations between F_3 and F_4 generations were found for kernel hardness. A high correlation coefficient between generations for kernel hardness indicated that early generation selection would be effective for this trait in these populations.

Small correlations were found in most of the crosses between the F_3 and F_4 generations for percent grain protein. Similarly small correlation between years for the winter parents indicated that percent grain protein was largely influenced by the environment and early generation selection may not be effective for this trait.

Little association was observed between kernel hardness and percent grain protein when all crosses are considered. However, significant negative correlations were observed in three of the four winter x spring crosses in the F_4 generation. The correlation between grain yield and hardness was low while the correlation between grain yield and protein content was significant and negative.

Prediction of Kernel Hardness and Grain Protein Based on the Performance of F_3 and F_4 Populations Derived from Ten Wheat Crosses (*Triticum aestivum L. em Thell*)

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Typed by Donna Lee Norvell-Race for Necati Hazar

IN DEDICATION TO:

My parents, my wife, and

My children, A. Serdar and Semih

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I. INTRODUCTION

Wheat is the primary source of food providing 20% of the total food calories and is the main staple food for 35% of the world population. It is also the major source of protein for these people.

Percent grain protein is one of the most important quality traits for both human nutritional requirements and end product use found in wheat. Kernel hardness is also important in order to obtain the desired end products. So, kernel hardness and percent grain protein in wheat play a major role in determining the quality of end products.

For these reasons, wheat breeders must be concerned with increasing yield levels and improving the quality of wheat. To provide high yield and desired end products, breeders must have usable genetic diversity. It would also be more efficient if traits such as kernel hardness and percent grain protein could be evaluated in the early generations. With the near infrared reflectance analyzer, it is now possible to analyze many samples in a short period of time.

This study was conducted to determine whether early generation selection for kernel hardness and percent grain protein could be used as an effective tool in identifying desired progeny based on the associations between F_3 and F_4 generations in ten different wheat crosses when both winter and spring parents are involved.

II. LITERATURE REVIEW

Protein Content

Protein is the primary and fundamental material of most living organisms. It is essential to the growth, restoration of body tissue, and is particularly important in the diets of young children. Protein deficiency in the childhood can impede brain development and learning ability. Statistics show that plants provide most of the protein for human nutrition in many developing countries. Among the crop species, wheat has long been one of the most important source of nutrients for people.

The percent protein in the grain is important for both human nutritional requirements and the quality of the end products from wheat. According to Hehn and Barmore (1965), a positive correlation between percent protein and bread making quality was reported by E. Millon as early as 1854. Thus the importance of the quality of wheat has long been recognized.

Studies on the inheritance of protein began after the rediscovery of Mendelian principles on segregation and independent assortment in 1900. The first report on the inheritance of grain protein came from Biffen (1905) who stated that grain protein content of F_2 plants derived from a cross between the cultivars Rivet and Polish showed a continuous distribution suggesting that this trait was quantitatively inherited. However, a comprehensive study of the inheritance of grain protein in wheat was not made until 1926. Clark (1926) reported that wheat protein was governed by multiple factors. Percent protein values in the grain of F_2 plants derived from a cross between Marquis and Hard Federation were normally distributed with a mean approximately equal to the mid-parent value. The correlation between F_2 plants and their respective F_3 progeny rows with regard to percent protein was not significant. He suggested that the inheritance of grain protein is complex. Whereas, Clark and Quisenberry (1929) found a significant correlation in the percent protein between F_2 plants and their F_3 progeny rows in a cross between the cultivars Marquis and Kota. Similar results were found by Aamodt and Torrie (1935) working with three hard red spring wheat crosses. They concluded that the protein content of wheat grain was a heritable trait and was governed by multiple factors.

Heritability estimates of grain protein were determined for three wheat crosses in which Atlas 66 was a common parent by Davis et al (1961). They determined the heritability estimates using the components of variance method and found values varied from 0.65 to 0.69. Haunold et al (1962) found that there was a significant positive correlation between percent protein values of F_2 plants and their F_3 progeny rows in a cross between Atlas 66 and Wichita. They also reported a close agreement between observed and predicted percent protein values. Whereas Stuber et al (1962) used the same cross "Atlas 66 x Wichita" to determine the heritability estimates for grain protein. They calculated heritability estimates using three different methods and obtained heritability values ranging between 0.678 and 0.827. The following years, Lebsock et al (1964) studied the inheritance of grain protein in a cross between Conley, a high protein cultivar, and PI 56121-12, a low protein line. The mean of F_1 plants was slightly below the mid-parent value, indicating low protein is partially dominant to high protein. They also found heritability estimates from the regression of F_5 to F_3 lines and of F_6 to F_3 lines which were 0.37 and 0.70 respectively. Sunderman et al (1965) found low heritability estimates (h^2=0.15-0.26) by using three different methods in a cross of Atlas 66 and Itana. On the other hand, Kaul and Sosulski (1965) found heritability estimates in a cross between two hard spring cultivars (Selkirk and Gabo) varying from 0.66 to 1.026 according to which method was used. The correlation between percent protein of F_3 plant rows and F_4 bulk rows was highly significant (r=0.925). They suggested that early generation selection for high protein content would be effective.

Two soft red cultivars (Atlas 66 and Atlas 50) were used in crosses with two hard red cultivars (Kaw and Triumph) by Logfren et al (1968). They evaluated the progeny of the F_2 plants for several quality characters in the F_3, F_4, and F_5 generations. Heritability estimates were found varying from 0.249 to 0.70 by using the regression of one generation's percent protein values on the previous generation's values. They concluded that the quality characteristics studied including protein percentage of hard red wheats were highly heritable.

Heritability estimates were found ranging from 0.422 to 0.802 in a diallel crossing system with four spring wheat cultivars by Hsu and Sosulski (1969). Transgressive segregation was also observed in most of the F_2 populations. In the same year, McNeal et al (1969) obtained an increase in protein content in the selected over unselected populations working with a cross between Lemhi and Thatcher. This suggests that selection for quality traits in early generations would be effective if the populations are the progeny of diverse parents.

The following year, the means of the F_1 and F_2 were found below the low protein parent by Chapman and McNeal (1970) working with a cross of two spring wheats. The results indicate dominance for low protein. However, Brock and Langridge (1973) reported that percent protein in cereals was under multigenic control and found a heritability estimate of 0.70 for protein content in the F_2 populations of intervarietal crosses. More recently, Ram and Srivastava (1975) found a narrow sense heritability estimate of 0.549 for protein in a diallel study with eight bread wheat cultivars.

Recurrent selection was used to improve grain protein content in wheat by McNeal et al(1978). Nine high protein genotypes from the world collection were crossed with each other and/or three U.S. commercial cultivars. The two highest protein selections from F_3

rows of each cross were then crossed in all possible combinations for use in the second cycle. Percent protein values were higher in the second cycle than the first cycle. Twenty-seven high protein lines from the second cycle had an average increase of 2.5% protein over the original parents.

Four common wheat populations were used to study early generation selection for grain protein by Ward (1978). He found significant intergeneration relationships for this trait and concluded that both F_2 individual and F_3 plant row values could be used as predictors of grain protein performance in later generations. Arora and Chandra (1980) concluded that gene action for protein content was non-additive by observing that Hira, Lerma Rojo, and PV 18 contributed non-additive components of variance in a 10 x 10 diallel cross of wheat cultivars. Schumaker (1980) found an F_1 mean which was lower than the low protein parent with the F_2 mean being intermediate between the parents in a cross between a low protein winter wheat (Yamhill) and a high protein spring wheat (Inia 66). Transgressive segregation was observed in the F_2 generation for both low and high protein content which suggests that early generation selection for grain protein may be effective.

Protein content in wheat is also influenced by the environment. All the scientists who worked on grain protein found large environmental effects to this trait. Johnson et al.(1969) reported that a single wheat genotype could produce grain protein varying from

8 to 18 % depending on the environment in which it was grown. It has also been shown that nitrogenous fertilizer application and timing the application increased the protein content in wheat. Hunter and Stanford (1973) examined the effects of N fertilization on percent protein in soft winter wheat. Average protein contents increased from 10.9 to 14.3 % with N fertilization with the spring application giving a higher response than the fall application. Knott (1974) used five diverse wheat cultivars to measure protein and yield response to nitrogenous fertilizer. Among the five cultivars, Pitic 62 and Era showed little yield response to N treatments but had the largest increase in grain protein. Inia 66 and W.S. 1809 had the largest increase in yield but showed little response in protein content. Neepawa had intermediate responses to both yield and protein content. These results indicate that cultivars vary in their yield and protein responses to nitrogenous fertilizer application.

Using the variance components, Fowler and De La Roche (1975) reported that the environmental effects on grain protein in wheat ranged between 0.57 and 0.96 with a mean of 0.81. Diehl et al (1978) found significant genotype x environment interactions for both grain protein and lysine working with three wheat crosses. Terman (1979) reported that grain protein increased with the amount of nitrogen applied in six wheat cultivars. Abdel Bary et al.(1980) stated that high nitrogen application led to higher heritability estimates for protein content.

The relationship between grain protein and yield has been discussed among plant breeders for a long time. Although the majority of the studies report a negative association between grain protein and yield, the problem still remains unclear. Clark (1926) worked with a cross of Marquis and Hard Federation and found a negative correlation between yield and protein content in the F_2 generation, and a positive correlation in the F_3 generation. Similar negative associations between grain protein and yield were reported by Clark and Quisenberry(1929). They concluded that these negative associations were small and would not be important to the plant breeder. Whereas Davis et al (1961) found negative correlation between yield and grain protein in three of four wheat crosses studied.

Contrasting results were reported by Johnson et al (1969). They found an increase in protein content ranging from 15 to 25 % without any reduction in yield using Atlas 66 as a parent. Whereas, Terman et al.(1969) found a high negative correlation between yield and percent protein for several cultivars under different nitrogen and moisture situations. A positive correlation between these two traits came from Briggs and Shebeski(1971). In evaluating the effect of selection in three different F_3 populations for yield and bread making properties they found a highly significant correlation between the performance in the F_3 and the F_5 two out of three years for protein content and one out of three years for yield. In the other two years the correlation between F_3 and F_5 yields were either non-significant or low.

Working with two spring wheat populations, Dyck and Baker(1975) observed no significant correlation between yield and grain nitrogen content. Whereas, Fowler and De La Roche (1975) reported a negative genotypic correlation (r=-0.52) and a negative environmental correlation (r=-0.60) between yield and grain protein in wheat. They concluded that the environment has more effect on the relationship between two traits than genotype.

Johnson et al (1978) reported on the development of high protein and high yielding cultivars where Atlas 66 was used in the crosses. They reported that Lancota is both high yielding and has a high protein content when compared to Centurk which is a commercially grown hard red winter wheat cultivar of the U.S. Bhatia et al (1978) studied mutation in wheat in a cross between Kalyan Sona and a high protein induced mutant from the same variety. Selections were made on the basis of yield components and grain protein in the F_2 through F_4 generations. Most of the selections in the F_4 generation were between the two parents for both yield and grain protein content.

In recent studies, Sukhorukov (1980) found either non-significant or negative correlations between yield and grain protein content in sixteen wheat cultivars. Whereas, Koycu and Yilmaz (1980) reported a significant positive correlation between crude protein and grain yield in wheat. On the other hand, Rousset et al (1980) improved the grain protein content and grain yield by jointly selecting for these characteristics. These results indicate that both the protein content and yield in wheat can be improved to a certain level depending on the parental lines used; even though in some cases there is a negative association between them.

Some work has been done on selection in early generation only for yield in wheat. Sneep (1977) stated that selection for yield in a self-fertilizing crop should begin in the F_3 generation to maximize the chances of finding productive genotypes. O'Brien et al (1978) observed a significant relationship between the yields of F_3 and F_5 lines in two of the four crosses where Glenlea was used as a common female parent in the crosses. They concluded that the early generation yield testing was influenced by the amount of environmental variation among the generation means and the amount of genotypic variance as well as genotype x environment interaction.

Kernel Hardness

Kernel hardness or softness is often used for grading purposes in wheat. Kent (1975) reported that hard wheats produce coarse, grity flour which is easily sifted whereas soft wheats yield fine flour in which the particles tend to adhere together and are difficult to sift. Kent (1975) also stated that endosperm cells in hard wheats seperate cleanly from the bran, therefore the endosperm remains intact, whereas in soft wheats, part of the endosperm attached to the bran. Davis et al (1961) reported that extremes hardness and softness can cause reduction in the flour yield. Very hard wheat requires more power for milling and longer milling time while, the endosperm particles in very soft wheat tend to adhere together and need more sifting time.

Kernel hardness also affects the end products of wheat. Hard wheats generally have strong gluten, therefore they are used for bread making, where soft wheats have weak gluten and short mixing times which are preferable for pastry flours. Stenvert (1974) reported higher starch damage in hard wheats during milling which resulted in higher water absorption of the dough, and subsequently higher bread yield. Fowler and De La Roche (1975) reported that kernel hardness in wheat plays an important role in determining most of the quality measurements for end products such as bread loaf volume, cookie width, farinograph tolerance index, mixograph peak area, etc.

For research purposes, kernel hardness is usually measured by a Pearling Index, which is the percentage of the material pearled off from a sample of wheat of prescribed weight in a laboratory barley pearler for a prescribed period of time (Taylor et al. (1939)). Yamazaki (1972) determined kernel hardness by using particle size index which is primarily related to the percent flour which passes through various mesh-sized sieves.

More recently, Bruinsma et al (1979) stated that kernel hardness can be measured by a near infrared reflectance analyzer. They found a high correlation (r=0.952) between this method and particle size index. Obuchowski and Bushuk (1980) compared the methods which are used to determine kernel hardness. They obtained different results from the particle size index and Pearling index. These differences were attributed to differences in bran properties rather than endosperm hardness.

Studies on the inheritance of kernel hardness are not as extensive as with protein content. However, Biffen(1908) first reported that common wheat shows differences in kernel hardness between cultivars. Worzella(1942) studied the inheritance of kernel hardness in wheat, as measured by particle size index, and found that the granularity was inherited as a quantitative trait. Similar findings were reported by Beard and Poehlman(1954), whereas Millington and Remilton (1954) found that one gene controlled vitreous or starchy appearance in the one cross. Symes (1965) found that the difference in particle size index between a hard wheat (Falcon) and a soft wheat (Heron) was due to a single major gene. He also reported the existence of minor genes which modify the action of the major gene in determining kernel hardness of wheat. Baker et al (1968) studied the variance components for seven traits in wheat. They found that starch damage was influenced more by environmental factors than by genotype. They also found a significant negative association between nitrogen content and starch damage, and a significant positive correlation between starch damage and yield. Symes (1969) worked with near isogenic lines of Falcon and Heron and found that milling extraction, loaf texture, and dough handling characteristics were strongly associated with kernel hardness. He failed to find any association between kernel hardness and grain protein. Whereas, Baker and Dyck (1975) found a significant positive correlation between flour nitrogen and particle size index.

Grinding time was used as the measurement of kernel hardness in two spring wheat crosses by Baker (1977). He found that kernel hardness was governed by two major genes and one or more minor genes in the cross between cultivars Pitic 62 and Neepawa. While, a single major gene and one or more minor genes caused difference in grinding time for a cross involving Glenlea and Neepawa. This indicates that the inheritance of kernel hardness depends on the genetic material used.

Schumaker (1980) found that kernel hardness was controlled by multiple genes which behave in an additive manner in a cross between the cultivars Yamhill, a soft wheat, and Inia 66, a hard wheat. She also observed transgressive segregation in the F_2 generation for kernel hardness.

Recently, Obuchowski and Bushuk (1980) found a negative association between protein content and wheat hardness index. They used several methods for measuring hardness of whole and de-branned grain. Protein content did not influence hardness in de branned grain. In whole samples, they found that the influence of protein content on kernel hardness seemed to vary according to the method used to measure kernel hardness in wheat.

III. MATERIALS AND METHODS

Parents, F_2 and F_3 generations from ten wheat crosses, were used to study kernel hardness and grain protein. The populations were derived from four winter x spring and six winter x winter crosses. Hybrid combinations are given in Table 1. Parental cultivars or lines listed in Table 2 and the descriptions of winter parents used in this study can be found in Appendix Table 1. Spring parents were not included into this study, because they do not do well in winter growing conditions. The crosses were made in 1978. The subsequent F_2 populations were grown on a grower's farm near Corvallis where the soil is a Coburg silty clay loam with a pH of 6.0. At the time of planting 30 kg N/ha was applied as 16-20-0. Urea (46% N) was applied as a top dressing at the jointing stage at the rate of 110 kg N/ha. For weed control Karmex was applied at the rate of 1.79 kg a.i./ha. The total precipitation for the 1979-80 crop year was 1,051 milimeters. Distribution of rainfall for the crop year is given in Appendix Table 2.

In 1979-80, 20 individual plants with good phenotypic appearance were selected from each F_2 population. Kernel hardness and percent protein were measured for each F_2 individual plant and their respective winter parents. A Kjheldal calibrated near infrared analyzer (Technicon Infraalyzer 400^{TM}) was used to make these determinations.

TABLE 1. The list of crosses involved in this study.

	Cross Numbers	Cross[1]
1	SWM 788849	Bezostaja-1/Nacozari 76
2	SWM 788858	Kavkaz//Kalyan/Bluebird
3	SWM 789117	Hyslop 706/Nacozari 76
4	SWM 789293	Stephens/Nacozari 76
5	OWW 780036	Riebesel 47-51/ F 60213-76
6	OWW 780040	Bezostaja-1/Ble Tendre//PI 178383/WA4765/3/WWP7147
7	OWW 780093	Bezostaja-1/Ble Tendre//PI 178383/WA4765/3/Stephens
8	OWW 780121	WWP7147/ Aspen
9	OWW 780167	Hill/ F 60212-76
10	OWW 780217	Stephens/ Nugaines

[1] 1-4 Winter x Spring and 5-10 Winter x Winter crosses

TABLE 2. The list of parents involved in ten crosses[1]

1	Bezostaja-1
2	Kavkaz
3	Hyslop 706
4	Stephens
5	Riebesel 47-51
6	Hill
7	Aspen
8	Nugaines
9	Bezostaja-1/Ble Tendre//PI 178383/WA4765
10	WWP 7147
11	F 60212-76
12	F 60213-76
13	Nacozari 76
14	Kalyan/Bluebird

[1]The first twelve parents are winter parents.

A randomized complete block experiment with three replications was conducted during the 1980-81 crop year using seed from the 20 individual plants from each F_2 population selected the previous year. This experiment was planted at Hyslop Agronomy Farm where the soil type is a woodburn silt loam with a pH of about 6.0. The respective winter parents were also grown in the same replicated yield trial. The two-row plots were three meters long with a spacing of 0.3 meter between rows. One hundred and ten seeds were sown in each row. Each replication was surrounded by a two-row border to eliminate the border effects. At the time of planting, urea (46% N) was applied at the rate of 30 kg N/ha. Urea was also applied as a top dressing at the jointing stage at the rate of 170 kg N/ha. Weed control was done both chemical, using Karmex at the rate of 1.3 kg a.i./ha, and by mechanical means. The total rainfall for the 1980-81 crop year was 972 milimeters. The distribution of rainfall within the crop year was given in Appendix Table 2.

The following traits were measured in 1981: Yield, 1000 kernel weight, heading date, kernel hardness, and percent protein. Yield was measured as grams of grain per 0.9 m^2. One thousand kernels were counted using an electronic seed counter and their weight in grams was recorded. Heading date was defined as the number of days from January first to the date when 50% of the plot was headed. Samples from each plot were ground in a UDY Cyclone grinder with a sieve size of 0.5 mesh. These whole grain samples were analyzed for kernel hardness with a near infrared analyzer

(Technicon Infraalyzer 400™). Whole grain flour samples were score on a scale from 0 to 100 for kernel hardness. Samples scoring between 0 and 50 were regarded as being soft wheat and any above 50 were designated as hard wheat. A hardness value known wheat sample was analyzed in every twentieth sample to insure accuracy. Precent protein was analyzed in a Kjeldahl calibrated near infrared analyzer. Kjeldahl protein analysis was conducted for every twentieth sample to insure the reliability of the results.

Two years of data for kernel hardness and percent protein were obtained for each F_2 individual plant (1979-80) and their F_3 progeny rows(1980-81). The means of F_3 plant rows were regressed on F_2 individual plant values for each population to determine whether F_2 individual plant values could be used to predict the performance of F_3 plant rows for both kernel hardness and percent protein. The correlations were calculated between F_2 and F_3 generations for both traits for each cross. Then the correlations were also calculated between predicted and observed values in the F_3 generation for both traits for each cross. Progeny were compared to their winter parents for both traits in each generation. The correlations between kernel hardness and percent protein were also determined for each generation for each cross.

The mean values of F_3 plant rows were used to determine the correlations of five traits (kernel hardness, percent protein, yield, 1000 kernel weight, and heading date) between each other for each cross. An analysis of variance was also computed for each of these traits.

IV. EXPERIMENTAL RESULTS

In 1980, twenty individual F_2 plants were selected based on their phenotypic appearance from four winter x spring (WxS) and six winter x winter (WxW) crosses. Kernel hardness and percent protein were analyzed on an individual plant basis of F_3 seeds along with the respective winter parents for each cross. Seeds from each individual F_2 plant and the respective winter parents were grown in a replicated yield trial in 1980-81 crop year. Kernel hardness and percent protein were determined for the following F_4 seed along with respective parents again on an individual plant row basis.

The analysis of variance presented in Table 3 indicates that significant differences were found among winter parents for kernel hardness, percent protein, 1000 kernel weight, and heading date but not for yield. The highest coefficient of variation (C.V.) value was found for grain yield (16.21%). The C.V. values for kernel hardness, percent protein, 1000 kernel weight, and heading date were 11.35, 5.89, 4.80, and 0.72, respectively, for the winter parents.

Tukey's test was applied at the significance level of 0.05 for ranking of winter parents for the traits measured based on mean values (Table 4). Among winter parents, F60212-76 had the highest percent protein with 11.30% followed closely by Kavkaz with 11.16%. Hill had the lowest protein content of 8.23 with Stephens and Nugaines being similar at 8.83 and 8.89, respectively. BEZ/BT// PI178383/WA4765 had the highest hardness score of 77.9 with the

TABLE 3. Observed mean squares from analysis of variance for percent protein, hardness, yield, 1000 kernel weight, and heading date for twelve winter parents grown in 1981

		Observed mean squares				
Source of variation	df	Protein	Hardness	Yield	1000 K.W.	Heading date
Cultivars	11	2.62**	918.28**	25457.97	115.54**	465.67**
Replications	2	0.94	481.85**	5299.20	6.44	1.08
Error	22	0.33	26.76	12462.32	4.38	1.05
Coefficient of variation(%)		5.89	11.35	16.21	4.80	0.72
Mean		9.79	45.56	688.53	45.64	143.17
Standard deviation		0.576	5.173	111.635	2.094	1.026

** Significant at 0.01 level.

TABLE 4. Mean values for protein, hardness, yield, 1000 kernel weight, and heading date for twelve winter parents grown in 1981

Cultivars	Protein(%)	Hardness	Yield(g/p)	1000 K.W.(g)	Heading date(Days)
Bezostaja-1	9.47^{cd}[1]	62.7^{bc}	710.7	49.2^{ab}	135.0^{f}
Kavkaz	11.16^{ab}	26.7^{d}	795.7	54.5^{a}	138.0^{f}
Hyslop-706	9.89^{abcd}	35.6^{d}	626.0	36.5^{de}	143.0^{cde}
Stephens	8.83^{d}	33.7^{d}	702.0	52.9^{a}	141.3^{e}
Riebesel 47-51	9.75^{abcd}	24.3^{d}	564.7	41.3^{cde}	149.0^{a}
F 60213-76	10.82^{abc}	60.1^{bc}	714.7	40.3^{cde}	145.3^{bc}
WWP 7147	9.78^{abcd}	65.9^{ab}	705.0	46.0^{bc}	144.7^{bcd}
BEZ/BT//PI 178383/WA4765	9.49^{bcd}	77.9^{a}	798.0	40.1^{cde}	144.0^{bcde}
Aspen	9.87^{abcd}	38.4^{cd}	733.3	46.6^{bc}	142.0^{de}
Hill	8.23^{d}	35.6^{d}	798.7	35.9^{e}	145.3^{bc}
F 60212-76	11.30^{a}	52.0^{cd}	566.3	42.5^{cd}	146.3^{ab}
Nugaines	8.89^{d}	34.2^{d}	547.3	37.9^{cde}	144.0^{bcde}

[1]Cultivars with the same letter are not significantly different at the 0.05 level using Tukey's test.

softest winter parent being Riebesel 47-51 with a score of 24.3. Even though there was no statistical difference in yield among the winter parents, the extremes were Hill at 798.7 grams and F60212-76 with 566.3 grams. Kavkaz had the highest kernel weight with 54.5 g/1000 kernel while Hill had the lowest with 35.9 g/1000 kernel. Bezostaja-1 was the earliest in heading at 135 days, while Riebesel was the latest at 149 days.

Significant differences were found among crosses for all of the traits measured (Table 5). The highest C.V. value was obtained for grain yield (20.19). The C.V. values for kernel hardness, percent protein, 1000 kernel weight, and heading date were 12.21, 8.33, 6.22, and 1.44, respectively. Septoria tritici infection in the 1980-81 crop year may have contributed to the high C.V. values.

A ranking was made based on the cross means for all traits with Tukey's test at the significance level of 0.05. As can be seen from Table 6, KVZ// KAL/BB gave the highest mean value for percent protein with 10.83% while SPN/NGS had the lowest mean value at 8.67%. The highest mean value for kernel hardness was obtained from the cross BEZ/BT// PI178383/WA4765/3/WWP7147 with a hardness score of 66.1. The lowest kernel hardness mean value was obtained from the cross SPN/NGS with a hardness score of 38.0. HYS-706/NAC had the highest average yield of 803.4 while the lowest yielding cross was KVZ// KAL/BB with 613.6 grams. On the other hand, SPN/NAC has the highest mean value for 1000 kernel weight of 46.7 grams with Hill being the lowest with 37.8 grams. BEZ-1/NAC population were the earliest heading at 121 days on the average, while RBS/F60213

TABLE 5. Summary of observed mean squares from analysis of variance for percent protein, kernel hardness, yield, 1000 kernel weight, and heading date for ten wheat crosses grown in 1981

Source of variation	df	Observed mean squares				
		Protein	Hardness	Yield	1000 K.W.	Heading date
Treatments	199	2.16**	673.19**	52054.65**	46.60**	288.62**
Crosses	9	26.60**	4780.31**	212260.71**	425.09**	5796.06**
Individuals	19	0.91	438.02**	38837.84**	12.63*	23.42**
C x I	171	1.02	483.16**	45091.29**	4.43**	28.23**
Replications	2	11.40	14471.67**	61729.74	4.49*	5.91
Error	398	0.66	41.70	20925.87	6.88	3.87
Coefficient of variation (%)		8.33	12.21	20.19	6.22	1.44
Mean		9.73	52.88	716.30	42.16	136.40
Standard deviation		0.81	6.46	144.66	2.62	1.97

* Significant at 0.05 level
** Significant at 0.01 level

TABLE 6. Mean values for protein, hardness, yield, 1000 kernel weight, and heading date for ten wheat crosses grown in 1981

		Protein (%)	Hardness	Yield (g/p)	1000 K.W. (g)	Heading date (Days)
WxS	BEZ-1/NAC	10.41[ab][1]	61.6[a]	647.3	42.1[ab]	120.9[c]
	KVZ//KAL/BB	10.83[a]	59.1[ab]	613.6	40.8[ab]	124.1[bc]
	HYS-706/NAC	9.85[ab]	53.7[abc]	803.4	41.6[ab]	127.8[b]
	SPN/NAC	9.23[ab]	56.3[ab]	704.2	46.7[a]	128.4[b]
WxW	RBS/F 60213	10.20[ab]	43.1[bc]	722.0	43.7[ab]	145.9[a]
	BEZ/BT//PI178383/WA4765/3/WWP7147	10.08[ab]	66.1[a]	755.0	40.4[ab]	144.3[a]
	BEZ/BT//PI178383/WA4765/3/SPN	9.02[ab]	52.5[abc]	725.5	42.9[ab]	143.4[a]
	WWP7147/ASP	9.49[ab]	43.3[bc]	745.1	40.3[ab]	142.7[a]
	HILL/F 60212	9.52[ab]	55.2[ab]	683.9	37.8[b]	144.6[a]
	SPN/NGS	8.67[b]	38.0[c]	763.6	45.7[a]	142.1[a]

[1]Crosses with the same letter are not significantly different at the 0.05 level using Tukey's test.

population were the latest at 146 days on the average.

Kernel hardness and percent protein will be discussed in detail below.

Kernel hardness:

The range and mean values of crosses of F_3 and F_4 generations in comparison to winter or high parent and the number of plants or lines exceeding the cross means and winter or high parent for kernel hardness are presented in Table 7. The largest variation observed was among individuals from the cross BEZ/BT// PI178383/WA4765/3/SPN with a range from 31.8 to 111.9. The cross mean values for kernel hardness for F_3 representing the ten crosses varied between 49.4 (RBS/F60213) and 91.5 (BEZ/BT// PI178383/WA4765/3/WWP7147). For the winter parents, Kavkaz had the lowest kernel hardness value (34.4) and BEZ/BT// PI178383/WA4765 had the highest kernel hardness value (79.0). Of the 20 individual plant tested, 10 plants exceeded the cross mean and 20 plants exceeded the winter parent in the cross KVZ// KAL/BB, whereas in the following F_4 generation, the largest variation was found in the cross HYS-706/NAC with a range from 25.7 to 88.4. The cross means for kernel hardness of the crosses varied between 38.0 (SPN/NGS) and 66.1 (BEZ/BT// PI178383/WA4765/3/WWP7147). Winter parents were between 26.6 (Kavkaz) and 77.9 (BEZ/BT// PI178383/WA4765). Nine lines exceeded the cross mean and twenty lines exceeded the winter parent in the cross KVZ// KAL/BB. Eighteen lines in the cross HYS-706/NAC and thirteen lines in the cross Hill/F60212 exceeded winter or high parent.

TABLE 7. Range and cross mean values for kernel hardness involving F_3 and F_4 populations, mean values for the winter or higher parent and the number of plants or lines exceeding the cross means and winter or higher parent.

		Ranges		Cross means		Winter or higher parent		Number of plants or lines exceeding: Cross means		Number of plants or lines exceeding: Winter or higher parent	
		F_3	F_4	F_3	F_4			F_3	F_4		
	Crosses	1980	1981	1980	1981	1980	1981	1980	1981	1980	1981
WxS	BEZ-1/NAC	55.4-95.1	47.0-76.0	70.5	61.6	74.7*	62.7*	11	10	4	10
	KVZ// KAL/BB	55.3-96.3	45.3-76.1	72.1	59.1	34.4*	26.7*	10	9	20	20
	HYS-706/NAC	35.7-107.7	25.7-88.4	64.7	53.7	42.9*	35.6*	7	6	18	18
	SPN/NAC	29.5-103.1	24.1-84.7	67.6	56.3	56.9*	33.7*	9	8	14	16
WxW	RBS/F60213	30.8-68.6	24.5-67.7	49.4	43.1	78.4	60.1	10	11	--	1
	BEZ/BT/PI178383/ WA4765/3/WWP7147	78.9-107.3	56.1-78.5	91.5	66.1	79.0	77.9	11	11	19	1
	BEZ/BT/PI178383/ WA4765/3/SPN	31.8-111.9	33.0-89.6	61.2	52.5	79.0	77.9	8	10	2	1
	WWP7147/ASP	45.7-124.9	28.3-71.6	66.7	43.3	77.7	65.9	8	9	5	3
	HILL/F60212	51.7-110.1	29.6-75.4	78.9	55.2	72.7	52.0	8	10	13	13
	SPN/NGS	39.9-90.3	27.6-69.0	59.6	38.0	56.9	33.7	8	8	9	12
	AVERAGES			68.2	52.9	65.3	52.6				

*Only winter parent value.

In the four winter x spring (WxS) crosses, superior segregates were observed for kernel hardness in the F_3 and F_4 generations. Mean values of crosses were higher than the winter parents in all winter x spring crosses with the exception of the cross BEZ-1/NAC in both generations. The cross mean values exceeded the higher parent in three of six winter x winter (WxW) crosses (BEZ/BT// PI178383/WA4765/3/WWP7147, HILL/F60212, and SPN/NGS) in the F_3 generation, while two of the six WxW crosses (HILL/F60212 and SPN/NGS) had the higher mean values than the higher winter parents in the F_4 generation. Transgressive segregation was observed in five of the six winter x winter crosses in the F_3 generation while all the six crosses showed transgressive segregation when both parents are considered. One cross (BEZ/BT// PI17838/ WA4765/3/WWP7147) in the F_3 showed segregates which exceeded only the higher parent.

The average kernel hardness values for crosses decreased from 68.2 in 1980 to 52.5 in 1981. Winter parents also decreased in kernel hardness from 65.3 to 52.6, respectively.

Among winter parents, Kavkaz regarded as a hard wheat failed to show a hard wheat score of above 50. Stephens, normally considered as a soft white cultivar, gave a hard wheat score (56.9) in 1980.

The percent grain protein with regard to the range and mean values of crosses of F_3 and F_4 generations in comparison to winter or higher parent and the number of plants or lines exceeding the cross means and winter or higher parent, are presented in Table 8.

TABLE 8. Range and cross mean values for percent grain protein involving F_3 and F_4 populations, mean values for the winter or higher parent and the number of plants or lines exceeding the cross means and winter or higher parent.

		Ranges		Cross means		Winter or higher parent		Number of plants or lines exceeding			
								Cross means		Winter or higher parent	
		F_3	F_4	F_3	F_4			F_3	F_4		
	Crosses	1980	1981	1980	1981	1980	1981	1980	1981	1980	1981
WxS	BEZ-1/NAC	10.79-14.96	9.71-11.86	12.25	10.40	12.34*	9.47*	9	8	8	20
	KVZ// KAL/BB	10.03-13.97	9.20-11.69	11.44	10.83	10.29*	11.16*	8	11	18	9
	HYS-706/NAC	9.24-11.32	8.85-10.88	10.30	9.85	11.31*	9.89*	10	9	1	7
	SPN/NAC	9.13-11.77	8.51-10.55	10.44	9.23	8.97*	8.83*	10	8	20	15
WxW	RBS/F60213	8.43-14.71	8.99-11.33	11.34	10.20	12.00	9.75	9	10	5	13
	BEZ/BT//PI178383/ WA4765/3/WWP7147	10.74-14.34	9.00-10.85	12.19	10.08	12.46	9.78	10	11	7	15
	BEZ/BV/PI178383/ WA4765/3/SPN	9.33-13.71	8.23-10.51	11.09	9.02	11.26	9.49	12	9	9	2
	WWP7147/ASP	9.96-12.70	8.78-10.59	11.28	9.49	12.46	9.78	9	11	2	4
	HILL/F60212	9.27-12.69	7.87-10.46	10.50	9.51	12.01	11.30	7	10	2	--
	SPN/NGS	7.59-10.61	7.91-9.28	8.77	8.67	9.53	8.89	6	12	4	6
	AVERAGES			10.96	9.73	11.26	9.83				

*Only winter parent value.

The greatest variation was found among the individuals in the F_3 generation for the cross RBS/F60213 with a range from 8.43 to 14.71 with nine of the twenty plants exceeding the cross mean and five of the twenty plants exceeding the higher parent. The cross mean values for F_3 seeds representing the ten crosses varied between 12.25 (BEZ-1/NAC) and 8.77 (SPN/NGS). For the winter parents, WWP 7147 had the highest percent protein (12.46) while Stephens had the lowest percent protein (8.97). For the cross KVZ// KAL/BB, eight of the twenty plants exceeds the cross mean and eighteen plants exceed the winter parent in percent protein. The greatest variation was observed among the individual plant rows in the F_4 generation in the cross HILL/F60212 with a range from 7.87 to 10.46. The cross means in the F_4 generations varied between 10.83 (KVZ// KAL/BB) and 8.67 (SPN/NGS). Winter parents varied between 11.30 (F60212) and 8.83 (Stephens). Eleven of the twenty plants exceeded the cross mean and fifteen plants exceeded the higher parent in the cross BEZ/BT// PI178383/WA4765/3/WWP7147.

Superior segregates were observed for percent protein over the winter parents in the F_3 generation in all four winter x spring crosses. The cross mean values were higher than the winter parent in two of the four crosses (KVZ// KAL/BB and SPN/NAC); whereas the cross mean values were between the parent values in all six of the winter x winter crosses. Transgressive segregates were observed beyond both parents in five of the six crosses. The other winter x winter cross (BEZ/BT// PI178383/WA4765/3/SPN) showed transgressive segregation only exceeding the higher parent. In the subsequent F_4 generation in 1981, two crosses (BEZ-1/NAC and SPN/NAC) had higher mean values than winter parents in four winter x spring crosses. The cross mean values for percent protein were higher than the high protein parent in two of the six winter x winter crosses (RBS/F60213 and BEZ/BT// PI178383/WA4765/3/WWP7147). Transgressive segregates were observed beyond both parents in five of the six crosses, while HILL/F60212 showed a transgressive segregation only below the low protein parent.

The average percent protein values for crosses decreased from 10.96 in 1980 to 9.73 in 1981. Winter parents also decreased in percent protein from 11.26 (1980) to 9.83 (1981).

Highly significant correlation (0.902) was observed for the parents for kernel hardness between years (Table 9). A highly significant correlation (0.902) was also found between the predicted and observed values when comparing the parents grown in 1980 and subsequently in 1981. However a significant association was not found for percent protein for either comparison 0.417 and 0.417, respectively.

A highly significatn correlation (0.8) was found between F_3 and F_4 kernel hardness values for overall crosses (Table 10). In terms of correlation coefficients, the crosses varied between 0.149 for the cross BEZ/BT// PI178383/WA4765/3/WWP7147 and 0.935 for the cross SPN/NAC. The predicted and observed kernel hardness values, for predicting F_4 hardness values in 1981 based on 1980 results, gave significant overall correlation (0.800), the only cross where a significant association was not found was BEZ/BT// PI178383/WA4765/3/WWP7147.

Although highly significant correlation (0.546) was found

TABLE 9. Correlation coefficients for the winter parents grown in 1980 and 1981, between observed and predicted values for kernel hardness and percent protein.

	Correlation coefficients[1]	
Traits	1980 and 1981	Observed and predicted
Kernel hardness	0.902**	0.902**
Percent protein	0.417	0.417

[1]N=12

** Significant at 0.01 level.

TABLE 10. Correlation coefficients between F_3 and F_4, and observed and predicted values for hardness and percent protein in ten wheat crosses

Crosses		Correlation coefficients[1]			
		F_3 and F_4		Observed and predicted	
		Hardness	Protein	Hardness	Protein
WxS	BEZ-1/NAC	0.667**	0.350	0.666**	0.350
	KVZ// KAL/BB	0.706**	0.176	0.706**	0.176
	HYS-706/NAC	0.880**	0.272	0.880**	0.272
	SPN/NAC	0.935**	0.558*	0.935**	0.558*
WxW	RBX/F60213	0.525*	0.223	0.525*	0.223
	BEZ/BT// PI178383/WA4765/3/WWP7147	0.149	0.289	0.149	0.289
	BEZ/BT// PI178383/WA4765/3/SPN	0.907**	0.645**	0.907**	0.644**
	WWP7147/ASP	0.805**	0.322	0.805**	0.322
	HILL/F60212	0.788**	0.597**	0.788**	0.597**
	SPN/NGS	0.859**	0.103	0.859**	0.103
	Overall crosses[2]	0.800**	0.546**	0.800**	0.543**

[1] N=20

[2] N=200

* Significant at 0.05 level.

** Significant at 0.01 level.

between F_3 and F_4 percent protein values when overall crosses are compared, only three of the ten crosses gave significant correlations between F_3 and F_4 percent protein values (Table 10). These crosses are SPN/NAC (r = 0.558), BEZ/BT// PI178383/WA4765/3/SPN (r = 0.645), and HILL/F60212 (r = 0.597). When the predicted and observed associations were considered the crosses SPN/NAC (r = 0.558), BEZ/BT// PI178383/WA4765/3/SPN (r = 0.644) and HILL/F60212 (r = 0.597) were found significant.

The comparison of percent grain protein and yield with the cross means and winter or higher parent with the number of lines exceeding the cross means and winter or higher parent in both percent protein and yield in 1981 are presented in Table 11. The highest mean value for percent grain protein was found in the cross KVZ// KAL/BB with a value of 10.83 while the lowest value was in the cross SPN/NGS with a value of 8.67; whereas, the highest yielding cross was HYS-706/NAC with a mean yield of 803.4 grams, while the lowest yielding cross was KVZ// KAL/BB with a mean yield of 613.6 grams. Four lines exceeds the cross means in both percent protein and yield in the cross HYS-706/NAC. In the same cross, eight lines exceeded the winter parent for both traits; whereas in the cross BEZ/BT// PI178383/WA4765/3/WWP7147, four lines exceeded the cross means and five lines exceeded the higher parent in both percent protein and yield. For overall crosses, a total of 36 lines exceeded the cross means and 38 lines exceeded the winter or higher parent in both traits.

The correlations between kernel hardness and percent grain

TABLE 11. Comparison of percent protein with grain yield with the cross means and winter or high parent and the number of lines exceeding the cross means and winter or high parent in both percent protein and yield in 1981

	Crosses	Mean		Winter or high parent		Number of lines exceeding	
		Protein (%)	Yield (gram/p)	Protein (%)	Yield (gram/p)	Both means	Both winter or high parent
WxS	BEZ-1/NAC	10.40	647.3	9.47*	710.7*	2	9
	KVZ// KAL/BB	10.83	613.6	11.16*	795.7*	3	2
	HYS-706/NAC	9.85	803.4	9.89*	626.0*	4	8
	SPN/NAC	9.23	704.2	8.83*	702.0*	3	7
WxW	RBS/F60213	10.20	722.0	10.82	714.7	2	2
	BEZ/BT// PI178383/ WA4765/3/WWP7147	10.08	754.9	9.78	798.0	4	5
	BEZ/BT// PI178383/ WA4765/3/SPN	9.02	725.5	9.49	798.0	6	-
	WWP7147/ASP	9.49	745.1	9.87	733.3	3	1
	HILL/F60212	9.51	683.9	11.30	798.7	4	-
	SPN/NGS	8.67	763.6	8.89	702.0	5	4
	AVERAGES	9.73	716.3	9.95	737.9		
	TOTALS					36	38

*Only winter parent value.

protein were small in 1980 and 1981 which were 0.31 and 0.11 for winter parents (Table 12); whereas the correlations between kernel hardness and percent grain protein were small in both F_3 (0.071) and in F_4 (0.077) for overall crosses. Among the crosses, BEZ/BT// PI178383/WA4765/3/WWP7147 gave significant negative correlation (-0.444) between kernel hardness and percent grain protein in the F_3 generation; whereas in the subsequent F_4 generation, significan- negative correlations were obtained from four of the ten crosses. These crosses are BEZ-1/NAC (r = 0.535), KVZ// KAL/BB (r = -0.496), SPN/NAC (r = 0.493), and RBS/F60213 (r = -0.549).

The correlation coefficient between the five traits measured involving the winter parents are given in Table 14. A significant negative correlation was noted between 1000 kernel weight and heading date. All other correlation coefficients were low being either positive or negative.

The correlations between the five traits measured for ten crosses can be found in Table 15. For overall crosses, significant negative correlations were observed for protein and yield, 1000 kernel weight and protein, heading date and protein, heading date and hardness with values of -0.36, -0.29, -0.37, and -0.26, respectively. On the other hand, 1000 kernel weight and yield, heading date and yield gave significant positive correlations of 0.33 and 0.17, respectively.

TABLE 12. Correlation coefficients between kernel hardness and percent protein for winter parents in 1980 and 1981

Year	Mean values		Correlation[1] coefficient
	Kernel hardness	Percent protein	
1980	54.16	10.93	0.3119
1981	45.59	9.79	0.1113

[1]N=12

TABLE 13. Mean values and correlation coefficients between kernel hardness and percent protein in ten wheat crosses in 1980 and 1981

	Crosses	Hardness means		Protein means		Correlation cefficients[1]	
		1980	1981	1980	1981	1980	1981
WxS	BEZ-1/NAC	70.53	61.63	12.25	10.41	-0.291	-0.535*
	KVZ// KAL/BB	72.12	59.08	11.44	10.83	-0.066	-0.496*
	HYS-706/NAC	64.72	53.66	10.30	9.85	-0.284	-0.163
	SPN/NAC	67.57	56.27	10.44	9.23	-0.365	-0.493*
WxW	RBS/F60213	49.37	43.09	11.34	10.20	-0.200	-.0549*
	BEZ/BT// PI178383/WA4765/3/WWP7147	91.46	66.07	12.19	10.08	-0.444*	-0.057
	BEZ/BT// PI178383/WA4765/3/SPN	61.16	52.47	11.09	9.02	0.023	-0.223
	WWP7147/ASP	66.74	43.28	11.38	9.49	-0.287	-0.150
	HILL/F60212	78.87	55.20	10.50	9.51	-0.085	-0.016
	SPN/NGS	59.58	37.98	8.77	8.67	0.268	-0.184
	Overall crosses[2]	68.21	52.87	10.96	9.73	0.071	0.077

[1] N=20

[2] N=200

* Significant at 0.05 level.

TABLE 14. Correlations between the five traits measured for twelve winter parents grown in 1981

Traits	Correlation[1] coefficient
Hardness and protein	0.111
Protein and yield	-0.112
Hardness and yield	0.290
Protein and 1000 kernel weight	0.266
Protein and heading date	-0.011
Hardness and 1000 kernel weight	-0.084
Hardness and heading date	-0.078
Yield and 1000 kernel weight	0.309
Yield and heading date	-0.425
1000 kernel weight and heading date	-0.648*

[1]N=12

* Significant at 0.05 level.

TABLE 15. Summary of correlation coefficients between five traits measured for ten wheat crosses in 1981[1]

		Hardness and protein	Protein and yield	Hardness and yield	1000 K.W. and protein	1000 K.W. and hardness	1000 K.W. and yield	H. date and protein	H. date and yield	H. date and 1000 K.W.	H. date and hardness
WxS	BEZ-1/NAC	-0.54*	-0.69**	-0.50*	0.21	0.26	0.21	-0.20	0.36	-0.02	-0.14
	KVZ// KAL/BB	-0.50*	-0.37	0.12	-0.11	0.08	0.52*	-0.17	0.21	-0.01	-0.44*
	HYS-706/NAC	-0.16	0.22	0.46*	0.29	0.57**	0.53*	-0.42	-0.24	-0.36	-0.01
	SPN/NAC	-0.49*	0.02	-0.11	-0.38	0.50*	0.46*	-0.37	0.21	0.24	-0.02
WxW	RBS/F60213	-0.55*	-0.67**	0.32	-0.35	0.14	0.39	-0.14	-0.25	-0.41	0.10
	BEZ/BT// PI178383/ WA4765/3/WWP7147	-0.06	-0.22	-0.05	-0.51*	0.32	0.37	0.31	-0.30	-0.42	0.13
	BEZ/BT// PI178383/ WA4765/3/SPN	-0.22	-0.39	-0.21	-0.44	0.01	0.45*	-0.29	-0.43	-0.29	0.14
	WWP7147/ASP	-0.15	-0.06	0.24	0.01	-0.19	0.24	-0.02	-0.17	-0.57**	-0.21
	HILL/F60212	-0.02	-0.53*	-0.08	-0.47*	-0.11	0.59**	-0.04	-0.34	-0.26	-0.37
	SPN/NGS	-0.18	-0.27	-0.17	-0.45*	0.28	0.40	0.03	-0.23	0.22	0.13
	Overall crosses[2]	0.08	-0.36**	-0.03	-0.29**	-0.002	0.33**	-0.37**	0.17*	-0.10	-0.26**
	R^2	0.06	0.13	0.001	0.08	0.000	0.11	0.14	0.03	0.01	0.07

[1] N=20

[2] N=200

* Significant at 0.05 level.

** Significant at 0.01 level.

V. DISCUSSION

Wheat is one of the most important food crops. With continuous increases in human population, its importance will become even greater as a source of both calories and protein. To fulfill this need, wheat must have a desired level of protein depending on the end product use. Therefore, wheat breeders must not only be concerned with increasing grain yield per hectare, but also achieve the desired quality such as percent grain protein. Hard wheats with high protein content are desirable for bread-making. Such wheats provide a flour which has high water absorption and strong gluten giving a higher loaf volume; whereas, soft wheats with low protein content provide a flour which has weak gluten and short mixing time. The latter wheats are generally preferable for pastry-making. Because of low protein of soft wheats, cookie diameter and crust which determine the quality of cookies, are desired. There are many end-product uses of wheat depending on the country and the preference of the people. However, to predict possible end-product uses it would be desirable to have a hard kernel with high protein and conversely a soft kernel with low protein.

To achieve high yield and desirable quality properties, there must be adequate usable genetic variability for these traits. Genetic variability can be created by crossing diverse cultivars within specific gene pools such as making winter x winter or spring x spring crosses, or between different gene pools by hybridizing winter x spring types. Crossing winter by spring cultivars may represent more diverse germplasm, thus resulting in broader genetic variability. Winter and spring types have been developed and grown under different environmental conditions. Therefore, they may be expected to be both physiologically and genetically different in terms of how they develop grain yield, kernel hardness and grain protein.

Once the desired genetic variability is created, then the problem facing the breeder is in selecting and identifying the most promising plants in segregating populations. To be effective the breeder must also determine the nature of this genetic variability and how it is transmitted to the progeny. The breeder must determine if a particular trait is qualitatively or quantitatively inherited and, if the latter, the nature of the gene action involved. In self-pollinating species such as wheat, the breeder can only utilize that portion of the total genetic variability that behaves in an additive manner. Also of importance is the evaluation of environmental influence which will determine if selection is to be effective. Based on the nature of the genetic variability and the relative environmental influence, it is then possible to decide if early generation selection will be effective for the traits to be improved.

To determine if early generation selection would be effective for kernel hardness and percent grain protein, ten crosses involving seed of the F_3 and F_4 generations and their respective winter parents involving four winter x spring and six winter x winter populations were studied. In addition, grain yield was obtained from the F_3 plant rows which provided the F_4 seed.

Significant differences were found among the winter parents and among the crosses for kernel hardness and percent grain protein. Significant differences were also found among the crosses for yield. High coefficient of variation (C.V.) for grain yield may be attributed by the Septoria tritici infection in 1980-81 crop year. Relatively high C.V. values for kernel hardness may come from sampling errors in preparing the samples for analysis.

Yield:

The largest variation for grain yield was observed in the cross of BEZ-1/NAC where nine of the twenty progeny rows exceeded winter parent. However, for KVZ// KAL/BB all the progeny had higher yield than the winter parent; whereas, for the cross of SPN/NGS, 80% of the progeny had a higher yield than either of two parents.

Superior segregates were observed over winter parents in all of the four winter x spring crosses, whereas transgressive segregation was observed above the high-yielding parent in all of the six winter x winter crosses. Therefore, in the populations selected for this study, there appeared to be adequate genetic variability for improvement of grain yield. However, due to the quantitative inheritance of grain yield and the large environmental variation, realistic data regarding which segregates were genetically superior would have to be delayed until the F_5 or F_6 generation.

Kernel hardness:

The largest variation was observed in the F_3 seed for kernel hardness. In this generation, BEZ/BT// PI178383/WA4765/3/SPN gave the largest variation for kernel hardness. In the subsequent F_4 generation HYS-706/NAC gave the largest variation. The first cross was a winter x winter, whereas the second cross involved a winter x spring cross. Stephens and Hyslop 706 are both soft white cultivars. These results indicate that the greatest amount of variability can be created by crossing diverse cultivars either within winter x winter or between winter x spring; however, this may not necessarily represent the most promising crosses in terms of obtaining high percentage of hard or soft kernel progeny. In the F_3, two winter x spring populations (BEZ-1/NAC, KVZ// KAL/BB) and two winter x winter populations (BEZ/BT// PI178383/WA4765/3/WWP7147, HILL/ F60212) produced progeny which all had kernels above the value of 50 indicating they were hard according to the infrared analyzer. A winter x winter cross (RBS/F60213) produced 50% of the progeny with soft kernels (values below 50). In the subsequent F_4 generation, one winter x spring (BEZ-1/NAC) and one winter x winter (BEZ/BT// PI178383/WA4765/3/WWP7147) cross gave progeny where all were graded as having hard kernels; whereas two winter x winter (RBS/F60213 and SPN/NGS) crosses produced progeny reflecting soft kernels (85% and 90%, respectively). This would be expected since in the latter cross both parents are regarded as having soft kernels.

Transgressive segregation was observed for kernel hardness above the winter parent in all four winter x spring crosses. This was also true for this trait in five of the six winter x winter crosses in both the F_3 and F_4 generations where the progeny exceeded both parents.

Percent grain protein:

Significant differences were found among the winter parents and among all crosses for percent grain protein, suggesting that cultivars used were quite diverse for this trait.

The largest variation for percent protein was found from winter x winter crosses (RBS/F60213 in F_3 and HILL/F60212 in F_4); the cultivars Riebesel and Hill had low protein 9.25 and 8.23, respectively, and F60212 and F60213 had relatively high protein 11.30 and 10.82, respectively. However, in the F_3 generation two winter x spring (BEZ-1/NAC and KVZ// KAL/BB) and one winter x winter (BEZ/BT// PI178383/WA4765/3/WWP7147) produced progeny all having above 10.00% grain protein; whereas SPN/NGS, a winter x winter cross, resulted in 95% of the progeny having below 10.00% grain protein. In the subsequent F_4 generation, two winter x spring crosses (KVZ// KAL/BB and BEZ-1/NAC) produced 90% and 70% of the progeny, respectively, where above 10.00% grain protein. A winter x winter (SPN/NGS) produced progeny which had less than 10.00% grain protein. The latter cross is a cross between two low protein cultivars.

A superior segregation over winter parents was observed for percent grain protein in all four winter x winter crosses in both F_3 and F_4 generations. Transgressive segregation beyond both parents was also observed for this trait in five of the six winter x winter crosses, suggesting that selection for either high or low protein levels may be made.

Associations between generations:

High correlation coefficient (r = 0.800) for crosses between the F_3 and F_4 generations for kernel hardness suggests that the evaluation of F_3 kernels may be effective in predicting the most promising F_4 progeny. Although relatively high and significant correlation (r = 0.546) was found for percent protein for overall crosses, when F_3 and F_4 generations are compared. However, only three of the ten crosses gave significant correlations (SPN/NAC, BEZ/BT// PI178383/WA4765/3/SPN, and HILL/F60212). These represent one winter x spring and two winter x winter populations. Stephens and Hill both had low protein 8.83 and 8.23, respectively, whereas the other two winter parents, BEZ/BT// PI178383/WA4765 (9.49) and F60212 (11.30) had relatively high protein. This indicates that early generation selection for grain protein may be effective for certain crosses but cannot be depended on as a routine selection tool.

Since percent grain protein in wheat is generally regarded as being largely influenced by the environment, correlation between years for winter parents also was small, further suggesting the difficulty in early generation selection. Even though small correlation coefficients between F_3 and F_4 generations were observed for percent grain protein, it did appear that superior segregates were present depending on the particular cross. For example, 75% of the progeny exceeded winter parent in the cross of SPN/NAC in both F_3 and F_4 generations, whereas 60% of the progeny had lower grain protein than the winter parent in the cross of HYS-706/NAC.

Associations between traits:

When percent grain protein and grain yield are compared, it appears possible to obtain high yielding and high protein segregates. For the cross BEZ-1/NAC, 45% of the progeny exceeds the winter parent in both percent protein and grain yield even though significant negative association was found between these traits for this cross; whereas 25% of the progeny exceeded higher parent in both protein content and grain yield in the cross of BEZ/BT// PI178383/WA4765/3/ WWP7147.

The correlation coefficients were calculated between kernel hardness and percent grain protein to determine whether selection could be effective for both traits simultaneously. Low positive associations were observed between these two traits in both F_3 and F_4 generations when all crosses were considered. Among crosses a significant negative association was obtained for the cross BEZ/BT// PI178383/WA4765/3/WWP7147 in the F_3 where 30% of the progeny exceeded the higher parent in grain protein and were noted as being hard. In the subsequent F_4 generation, associations were found to be negative and significant in four crosses. Among these crosses, 95% of the progeny of the cross BEZ-1/NAC had hard kernels and also exceeded the winter parent in percent protein.

When kernel hardness and yield are compared, a small negative correlation was found for overall crosses. Among crosses BEZ-1/NAC and HYS-706/NAC gave significant negative associations between kernel hardness and yield. However, even within these crosses BEZ-1/NAC, 95% of its progeny had hard kernels while 45% of the progeny were graded as hard with all the progeny exceeded winter parent in yield.

In assessing the amount of variation and association of the three traits, it would appear that the winter x spring cross BEZ-1/NAC would be the most promising for kernel hardness, evaluated protein and yield. The cross BEZ/BT// PI178383/WA4765/3/ WWP7147 also appears promising in obtaining promising segregates for these traits. If the wheat breeder desires soft kernels, low protein combined with grain yield then the winter x winter cross of SPN/NGS would offer the best opportunity to find the desired types.

When winter x spring and winter x winter crosses were compared for the traits measured no consistent differences were observed in terms of greater variation between these populations.

It would appear that of the traits measured early generation selection would be effective for kernel hardness based on using F_3 data to predict subsequent generation performance.

Quality of wheat means different things for different people. To the farmer it is yield, to the miller and baker it is the end product and to the consumer a source of food. It is important that the wheat breeder understands this and the breeding objectives reflect these goals.

VI. SUMMARY AND CONCLUSIONS

Ten wheat crosses involving F_3 and F_4 generations were used with their respective winter parents to determine whether early generation selection would be effective for kernel hardness and percent grain protein. The populations derived from four winter x spring and six winter x winter crosses. Both the populations and the winter parents were grown either at or close to Hyslop Agronomy Farm.

Twenty individual F_2 plants and their respective F_3 progeny rows were evaluated for each cross with their respective winter parents for kernel hardness and percent grain protein. A near infrared reflectance analyzer was used to determine kernel hardness and percent grain protein. Grain yield was also determined from the replicated F_3 progeny rows.

An analysis of variance was conducted to evaluate if significant differences existed for the traits measured. The associations between generations were determined for both kernel hardness and percent grain protein for each cross. Possible associations for the winter parents and across years were also evaluated.

From this study the following conclusions were made:

1. Variation for the traits measured can be created by crossing diverse cultivars either within specific gene pools (winter x winter) or between different gene pools (winter x spring). Analysis of variance indicated that significant differences existed between crosses but not between parents for grain yield. For

kernel hardness and protein content significant differences were obtained between both crosses and parents.

2. High correlation coefficient between generations for kernel hardness indicates that early generation selection may be effective for this trait.

3. Low correlation coefficient between generations for percent grain protein shows that early generation selection cannot be used effectively for this trait.

4. Low correlation between years for winter cultivars for percent grain protein indicates that the environment played a major role in determining this trait.

5. When the associations were compared for the traits measured for overall crosses, it was found that a small negative relationship was observed between grain yield and kernel hardness. While a significant negative association was noted between grain yield and grain protein. A small positive association was found between kernel hardness and grain protein.

6. When all crosses were considered heading date and 1000 kernel weight were found to be significant and negatively associated with grain protein content and kernel hardness. However, there were significant association between all the traits measured when individual crosses were observed. The two exceptions were heading date and protein, heading date and grain yield despite the fact that significant correlations were noted when overall crosses were considered.

7. Positive associations were found between 1000 kernel weight and heading date with grain yield.

8. When winter x spring and winter x winter populations were compared for the traits measured no consistent difference was observed in terms of greater variation.

9. Transgressive segregation was noted for both kernel hardness and percent grain protein over winter parents in all of the winter x spring crosses and in five of the six winter x winter crosses. This suggests that it may be possible to select for high or low protein and hard or soft kernels which exceeded the respective winter parent or parents.

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APPENDICES

APPENDIX TABLE 1

DESCRIPTION OF WINTER WHEAT CULTIVARS
USED IN THIS STUDY

BEZOSTAJA-1 (Lutescense 17/Skorospelka 2): A hard red winter wheat released in Kuban region in U.S.S.R. It has good winter hardiness, low tillering capacity, approximately 120 cms in height, and awnless spikes. Moderately susceptible to stripe and leaf rust, susceptible to stem rust with the capacity for wide adaptation and reasonable yield, good milling and baking quality.

KAVKAZ (Lutescense 314-h-147/Bezostaja-1): A hard red common winter wheat cultivar released in Russia in 1971. Large spikes, cylindrical, white and awnless. It is mid-early, tall, with a high yield potential, poor tillering, large seed with good milling and baking qualities. This cultivar has good stripe rust resistance moderate susceptibility to leaf rust in Mexico and Turkey.

RIEBESEL 47-51: A soft red winter wheat cultivar released in Germany. This cultivar is tall, late heading and maturity, intermediate winter hardiness and good protein content. Riebesel has been used extensively in crossing to transfer its resistance genes for stripe, stem and leaf rust. It also has good tolerance to barley yellow dwarf virus and Septoria tritici.

ASPEN (HN4/4/KT54A/N10B/KT54B/3/NAR): Soft white winter wheat named by O.S.U., tested in international nurseries and utilized in new hybrid combinations. This cultivar is awned, semi-dwarf in height, low level of winter hardiness and intermediate protein content. It is resistant to stripe rust in Oregon but moderately susceptible to leaf and stem rust in Mexico and Turkey.

HYSLOP 706 (Nord Desprez/Pullman Selection 101^2): An awned semi-dwarf, soft white winter wheat selection out of the cultivar Hyslop. It has low protein, good yield potential, and intermediate winter hardiness. This cultivar is moderately susceptible to stripe rust and susceptible to leaf and stem rust in Mexico and Turkey.

STEPHENS (Nord Desprez/Pullman Selection 101): An awned, standard height and low protein cultivar released by O.S.U. It is a soft white winter wheat with medium to high tillering levels, moderate head fertility, high yield potential, and high seed weight. It has resistance to stripe rust but is susceptible to leaf and stem rust in Mexico and Turkey.

NUGAINES (Noris 10-Brevor// Orfed/Brevor sib/3/Burt): A sib line of Gaines. Awned, semi-dwarf, low protein content (relatively high when compared to Stephens) soft white winter wheat. It has moderate to high tillering capacity and moderate to low head fertility and seed weight. This cultivar was released by W.S.U.

HILL (Yamhill/Hyslop (2M6)): A soft white winter wheat cultivar released by O.S.U. in 1981. This semi-dwarf, awned cultivar has high yield potential, good test weight, good winter hardiness, intermediate maturity, and strong straw. It has adequate resistance to stripe rust, good tolerance to barley yellow dwarf virus in Oregon but is susceptible to leaf and stem rust in Mexico and

Turkey. It has excellent soft white wheat quality with low protein content.

PROBSTDORFER KARAT (WWP 7147) (Probstdorfer Extrem/Bezostaja-1): A hard red winter wheat cultivar from Austria. It has high yield and test weight, high protein content, tall but good lodging resistance. This cultivar has good winter hardiness and frost tolerance, but is late in flowering and maturity. It is resistant to stripe rust and powdery mildew but susceptible to leaf and stem rust.

BEZ/BT// PI 178383/WA 4765: A hard red winter wheat cross made at O.S.U. to combine disease resistance and yield potential and intermediate winter hardiness. It is resistant to stem and stripe rust but susceptible to leaf rust.

F 60212-76: A Rumanian winter wheat cultivar which has hard red seed and high protein content. It is resistant to stem rust, moderately resistant to leaf rust and stripe rust, late in maturity with good resistance to mildew.

F 60213-76: A Rumanian hard red winter wheat cultivar which has high protein content. It is resistant to stem rust, powdery mildew, moderately resistant to leaf and stripe rust and late maturity.

APPENDIX TABLE 2

MONTHLY PRECIPITATION IN CORVALLIS, OREGON
FOR 1979-80 AND 1980-81 CROP YEARS

Months	Precipitation (mm)	
	1979-80	1980-81
September	55	24
October	183	48
November	104	160
December	159	288
January	170	58
February	99	113
March	102	76
April	92	60
May	37	76
June	44	66
July	6	3
August	0	0
TOTAL	1051	972