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Title: EVALUATION OF PARENTAL PERFORMANCE FOR GRAIN YIELD IN TWO POPULATIONS OF WHEAT (*TRITICUM AESTIVUM* VILL., HOST)

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Six winter wheat cultivars were evaluated for their breeding value in transmitting superior genetic factors for grain yield to subsequent progeny. The cultivars were selected on the basis of their potential grain yield and divided into two populations. Population I was comprised of three cultivars which have been in commercial production for several years and are regarded as intermediate for grain yield. Population II was represented by three recently developed cultivars which have superior grain yielding potential. Each of the three parents within each population were crossed in a diallel manner Hence, the parents and subsequent F_1, F_2, and BC progeny made up the experimental populations. These populations were grown at two environmentally diverse sites within the state of Oregon. Morphological characters measured were: (1) tillers per plant; (2) kernels per

spike; (3) plant height; (4) weight of 300 kernels; and (5) grain yield.

To detect which parental combination had the greatest potential for transmitting superior performance to the subsequent progeny for the components of yield and grain yield, the following parameters were determined for both populations: (1) the amount and nature of the genetic variance associated with each population; (2) average combining ability of each parent within the populations; (3) estimates of heterosis and heterobeltiosis in the F_1 and (4) the possible influence of the genotype-environmental interactions on the parameters measured. Also information concerning the desirability of using top crosses and double crosses rather than single crosses was obtained.

In an effort to compare the relative performance between the populations, Pullman Selection 101, which is a good general combining winter wheat cultivar, was used as a tester for both populations. The values obtained in this investigation reflect the properties of the populations studied and should not be interpreted as applying to all wheat populations.

Considerable genetic variability was found within both populations for the characters studied. This variability was largely due to genetic factors which were additive. Tillers per plant and grain yield were influenced by both additive and nonadditive genetic variance.

The higher yielding parents in Population II were found to be higher in their average combining ability for kernels per spike and grain yield per plant whereas the lower yielding parents in Population I were higher for tiller number, weight of 300 kernels and plant height.

Parental combinations identified as being promising for grain yield in a conventional program, where nearly homozygous lines are desired, were also the same parental combinations which resulted in a maximum expression of heterobeltiosis and would be of most interest in a hybrid program.

The desirability of using multiple crosses to maximize the number of favorable factors need further study including additional parents and different combinations plus an evaluation of the performance of such crosses in later generations.

In this investigation, the single crosses appeared to be the most promising; however, inbreeding depression due to segregation within top and double crosses influenced the values obtained. Also, the population sizes should be increased to measure the total potential of such crosses.

Significant genotype-environmental interactions were observed between locations for plant height and weight of 300 kernels. The estimates obtained for average combining ability, heterosis and heterobeltiosis for the other characters measured also suggested that it will be necessary to identify the most promising hybrid combinations based on the performance of the parents at the specific location.

To make the most rapid progress in developing high yielding cultivars in either conventional or hybrid programs, the wheat breeder needs to emphasize crosses between unrelated high yielding cultivars. However, the need to provide superior parental lines which include such factors as disease resistance, should be evaluated. The development of elite germ plasm by geneticists will be mandatory if plant breeders are to continue to improve grain yield.

Evaluation of Parental Performance for
Grain Yield in Two Populations of
Wheat (*Triticum aestivum*
Vill., Host)

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My parents, for their prayers and moral support.

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INTRODUCTION

The main effort in a plant improvement program is the development of superior cultivars which are adapted to the soil, climatic and biotic conditions which exist in a particular growing region. In addition to superior agronomic characteristics, these cultivars must combine high grain yield with the quality characteristics required by farmers, millers, and consumers.

The effectiveness of identifying superior progeny depends upon the amount and nature of the genetic variation which is created through hybridization. Thus, one of the major problems encountered by the plant breeder involves the selection of parents which when hybridized will produce the highest number of superior yielding segregates. Thus the question arises, should the breeder utilize only parental lines which represent the highest yielding, newly developed cultivars of diverse genetic background, or should he cross well adapted medium yielding cultivars to provide the more promising genetic variability? This means that it is extremely important to characterize populations in terms of their genetic parameters if the breeder is to have some guidance in the selection of parents.

In the selection of potential cultivars in a segregating population, a plantbreeder mustwork with both qualitatively and quantitatively inherited characters. Qualitatively inherited characters are influenced by a single or limited number of genes, and as a result, the phenotypic variation can be classified into discrete classes for the desired character. It is therefore usually not difficult to identify the most promising parents when working with qualitatively inherited characters. Quantitatively inherited characters which are controlled by many genes with small accumulative effects are usually influenced by the environment and the resulting phenotypic variance in the population reflects a normal distribution for the specific character. The total genetic variability is then described in terms of estimates of gene action which include additive and nonadditive genetic variance. Because most of the characters of economic value are quantitative in their inheritance, a plant breeder is mainly concerned with continuous variation and the selection of the most desirable hybrid combinations is much less clear.

The breeder of self pollinating species is mainly concerned with that portion of the total genetic variation which involves additive gene action (the type of gene action that remains the same generation after generation). If his problem is to maximize grain yield in the F_1 generation, the nonadditive gene action, that which deviates from the additive scheme, is of chief concern.

Statistical approaches for studying the nature of gene action involved in quantitative characters have been developed. Narrow sense heritability estimates and average combining ability are measures of the additive genetic effects while heterosis and heterobeltiosis (superior performance over the best parent) are frequently used to determine the nonadditive genetic effects.

The phenotype of quantitatively inherited characters such as grain yield and adaptability are largely influenced by the environment. Thus, it is necessary to know also to what extent the genetic-environmental interaction is affecting the genetic variation expressed for a specific character.

The purpose of this investigation was (1) to evaluate the amount of genetic variation and the breeding value of six winter wheat cultivars representing two different populations, with regard to number of tillers per plant, plant height, number of kernels per spike, weight of 300 kernels, and grain yield per plant; (2) to obtain information about the nature of gene action in two populations by determining the additive and nonadditive genetic variances; (3) to observe the performance of single crosses in contrast to two top crosses versus one four-way cross for plant height and grain yield per plant; and (4) to observe if the genetic-environmental interactions might influence the potential performance for grain yields involving genotypes comprising two populations when grown at two diverse locations.

LITERATURE REVIEW

With an estimated 28,000 different wheat cultivars available for utilization as potential parents in a breeding program, it is necessary for the plant breeder to make correct choices based on the probability as to which hybrid combination will result in the highest number of desirable progenies in subsequent segregating populations and/or the best F_1 combination. The dilemma as to whether one should cross high yielding cultivars of diverse origin to maximize yield or perhaps lower yielding lines in order to bring together the most favorable combination of genes is always present in the plant breeder's mind. To increase the chances of success, selection of possible parents must be based on reliable genetic parameters to identify the most promising parents.

The selection of possible parents in a conventional program should be based on the genetic variability of the progeny following hybridization and the contribution of each parent to the progeny. This can be achieved by observing genetic parameters in the progeny which indicate the magnitude of the type of gene action that remains constant generation after generation. Heritability estimates in the narrow sense provide an estimate of the additive genetic variance, while the average combining ability of the respective parents would provide an indication as to how much additive genetic variability each parent may contribute to the resulting progeny. The best specific combinations of parents in the development of a hybrid program should be based upon the performance of the F_1. Heterotic effects both with respect to the mid-parent (heterosis) and higher parent (heterobeltiosis) provide an estimate of the nonadditive genetic variance. Genotype-environmental interactions obtained from parents and resulting progeny are also important in the parental evaluation as such interactions may influence the genetic expression for specific traits.

Heritability

Heritability estimates can influence the identification of parental material because such estimates aid in determining the degree of selection pressure that can be applied to a given population and in determining in what generation effective selection can be practiced.

Heritability has been described as the ratio of the genotypic variance to the total variance (Lush, 1940), the ratio of the additive genetic variance to the phenotypic variance (Falconer, 1960), the inherited portion of the variability (Briggs and Knowles, 1967), as well as the ratio of the genotypic variance divided by the total variance (Allard, 1960).

The total genetic variance is actually the sum of the following variances; (1) additive genetic variance; i.e. the effect produced by two alleles that is intermediate to the effect produced by the same alleles in the homozygous condition; (2) variance due to dominance; i. e. the deviation from the additive scheme; (3) variance due to the interaction of nonallelic genes; i. e. the suppression of the action of a gene or genes by a gene or genes not allelomorphic to those suppressed; (4) variance due to the environment; and (5) variance due to the interaction of the genotype and environment.

In this literature review only narrow sense heritability estimates; i. e. that portion of the total genetic variability which is influenced by additive genetic variance involving wheat for some of the components of yield and grain yield will be reported.

Reddi *et al.* (1969) estimated heritability by the regression of F_4 means on means of F_3 for tillering ability and plant height in two winter wheat crosses. The heritability values were 17 and 81 percent, respectively.

Using the regression of the F_4 on F_3 and F_3 on F_2, Merkle and Atkins (1964) obtained heritability estimates for plant height ranging from 71 to 101 percent. Using the regression of the F_2 on F_1 in four winter wheats, Daaloul (1972) reported heritability estimates for plant height ranging from 65 to 85 percent.

Among several agronomic characters studied, Johnson *et al.* (1966) found heritability in the narrow sense for plant height to be 65 percent when the standard unit method was used. They pointed out that selection for plant height could be practiced in the F_2 due to the large amount of additive genetic variance which was present.

Kronstad and Foote (1964) using a diallel analysis in winter wheat found heritability estimates from the regression of F_1 on the mid-parent for plant height, spikes per plant, kernel weight, and grain yield per plant to be 83, 40, 47, and 26 percent, respectively.

Fonseca and Patterson (1968b) studied heritability values for six agronomic characters in seven diallel crosses involving winter wheat cultivars. They utilized hill and nursery plots and obtained the following heritability values: plant height, 55 percent; spikes/930 cm^2, 34 percent; kernels/spike, 47 percent; kernel weight, 15 percent; and grain yield/hill plot, 17 percent.

Anwar and Chowdry (1969) calculated narrow sense heritability using Warner's method for plant height and grain yield in four spring wheat crosses. The narrow sense heritability values ranged from 21 to 46 percent and from 12 to 41 percent for plant height and grain yield, respectively. They pointed out that in view of the low narrow sense heritability for grain yield, selection for this character would be difficult.

In estimating narrow sense heritability in three hard red spring crosses, Busch et al. (1971) reported that heritability of F_5 lines for grain yield ranged from 31 to 45 percent. Grain yield per plant was found to be controlled by both types of gene action, additive and non-additive.

Combining Ability

Combining ability is the relative capacity of an individual to transmit desirable characteristics to its progeny (Hayes and Immer, 1942). The application of the concept of combining ability in small grains, forages, tomatoes, sugar beets and other crops has been developed largely as a consequence of research with corn.

Whereas general combining ability (G. C. A.) designates the average performance of a line in a hybrid combination, specific combining ability (S. C. A.) refers to the performance of two specific lines in a particular cross (Sprague and Tatum, 1942). Specific combining ability is evaluated by the performance of the inbreds in a given cross in relation to the average performance of the lines in a series of crosses.

On the other hand, the average combining ability (A. C. A.) is the average performance of a line in a number of single crosses. There exists a direct relationship between G. C. A. and A. C. A. If the number of different parental lines are increased from a few to an infinite number, the A. C. A. will approximate the G. C. A. According to R. V. Frakes (personal communication) when the number of different parental lines is decreased, the A.C..A. will deviate from the G.C.A. depending upon the nature and degree of the genetic variance.

From the results obtained for plant height using the A.C.A. as the method of estimating indirectly the G.C.A., Daaloul (1972) postulated that this method may be used in the evaluation of complex characters like grain yield.

General combining ability was the major component of variance for grain yield and yield components in a diallel cross of winter wheats (Kronstad and Foote, 1964). The same authors pointed out that the combining ability analysis is useful in selecting possible potential parents in a hybridization program. Similar results in an analogous study were obtained by Bitzer et al. (1967).

Bitzer and Fu, 1972, studying G.C.A. and S.C.A. in six soft red winter wheats reported that G.C.A. was the major component of variation.

Heterosis

When the practical importance of hybrid vigor or heterosis was demonstrated by the development and use of hybrid corn, plant breeders naturally considered the possibility for utilization of hybrid vigor in other crops. Species such as wheat have a perfect flower requiring emasculation. However, with the discovery of the genetic factors which offset cytoplasmic male sterility in wheat (Wilson and

Ross, 1962; Schmidt et al., 1962) there has been an increased interest in the heterotic effect for grain yield and other agronomic characters for hybrid production.

When a large portion of the total genetic variance is due to non-additive gene action, it may present problems to a breeder of self-pollinating species. For example, it may prevent effective utilization of additive genetic variance particularly in the early generation selection (Daaloul, 1972).

In 1963, Briggle presented a literature survey concerning heterosis in wheat. Among the reports cited, heterosis values for different characters varied from 0 to more than 100 percent.

Brown et al. (1966) tested 16 F_1's for grain yield and the yield components in winter wheat. Five of the hybrids exhibited an increase over the better parent in grain yield and 12 of the 16 hybrids showed an increase over the mid-parent value. However, no hybrid was lower in grain yield than the highest of the mid-parent values. The other components measured had less hybrid vigor than did grain yield.

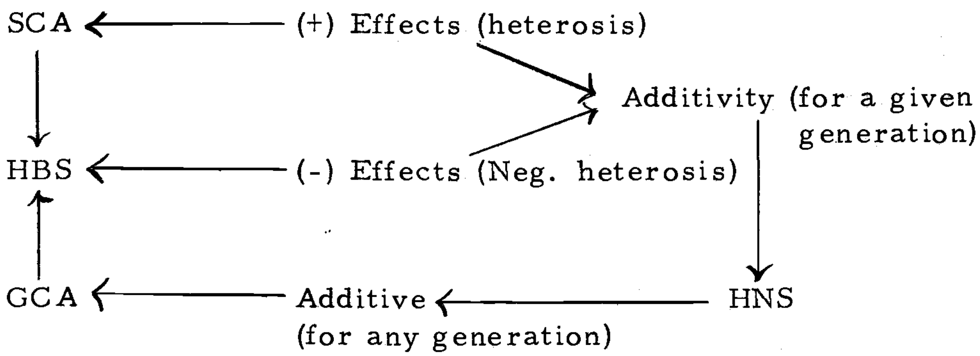
Heterosis for grain yield was demonstrated in inter-varietal crosses of winter wheat with space planted experiments (Gyawali, Quelset and Yamazaki, 1968). Ten of 21 F_1's exceeded their highest parent in yield. The average yield of all F_1's was 24 percent higher than the better parent for each combination.

In a diallel cross among six varieties of hard red spring wheat, there were no large differences in yield in the F_1 and F_2 with respect to the best parent (Knott and Sindagi, 1969). However, yields observed in other spring wheat hybrid populations varied from 14 to 82 percent more than the better parent (Wells and Lay, 1970). Similar observations were made by Anwar and Chowdhry (1969).

MacIlrath et al. (1968), using wheat varieties with broad genetic diversity noted that the F_1 yield ranged from 45 to 141 percent of the better parent.

Many other investigations have demonstrated hybrid superiority depending on the proper parental combination (Briggle et al., 1964; Shebeski, 1966 and Fonseca and Patterson, 1968a).

To relate heritability, combining ability and heterosis, R. V. Frakes (personal communication) proposed the following relationship:



where GCA is general combining ability; SCA is specific combining ability; HBS is heritability in a broad sense and HNS is heritability in the narrow sense.

General combining ability, S. C. A. and the positive and negative effects of heterosis all affect heritability in the broad sense. In terms of gene action, G. C. A. responds mainly to the additive gene action, whereas S. C. A. and heterosis respond to the type of gene action that deviates from the additive scheme. Narrow sense heritability is due mainly to the additive gene action, and consequently G. C. A. is directly associated with this estimate.

Genetic-Environmental Interactions

A plant breeder must be aware of the intimate association between genotype and environment. Hence, the phenotype is the expression of the interaction between the genetic and the environmental components. The most important consequence, however, of the genetic-environmental interactions is the reduction of the correlation between the phenotype and the genotype.

Dudley and Moll (1969) defined phenotypic variance as follows: "Phenotypic variance is the total variance among phenotypes when grown over a range of environments of interest to the plant breeder." The economically important characters as yield, quality and adaptability are subject to non-heritable variation, consequently breeding for these characters will depend upon the specific environment in which they were selected.

The degree of adaptability in crop plants can be divided into two main categories: specialized populations where their performance is better over a narrow range of environments and adapted populations in which a population performs well over a wide range of different ecological conditions (Frankel, 1958).

Using data of five years from oat varieties grown in different regions of Iowa, Horner and Frey (1967) observed a decrease in variety X location interaction. They used variety X location mean squares to test homogeneity between regions.

Sprague and Federer (1951) determined the average genetic advance in a single, double and top cross of corn over a seven year period by varying year, locations and replications. By observing a number of locations over a period of years, a better estimation of the genetic gain could be made.

The adaptability of 277 barley varieties for grain yield in seven different environments was studied to determine variety adaptation (Finlay and Wilkinson, 1963). Regression coefficient of means for each variety was regressed on the grand mean of all varieties in the trial. The authors suggested that this method could be used as an index for specific or general adaptation for varietal testing.

Walton (1968), working with spring wheat cultivars, pointed out that variety X location X season interactions should be considered as a factor for those lines that are to be grown under a wide range of environmental conditions.

Using Griffing's model with seven wheat cultivars, Jordaan and Laubscher (1969) reported that S.C.A. has a low repetability effect under different environments, and that G.C.A. is less influenced by genotype-environmental interaction.

An understanding of heritability, A.C.A., heterosis, plus information regarding the genotype-environmental interaction is important in determining the type and degree of genetic variation associated with a specific trait. By studying the type of gene action, a plant breeder is better able to manipulate a specific character in his breeding program through his choice of potential parents. Therefore, if the initial selection of parents can be based on this type of information, the probability of obtaining a higher number of promising progeny in segregating populations should be greatly increased.

MATERIALS AND METHODS

Parental materials used in this investigation were the following soft white winter wheat cultivars: Druchamp, Brevor, Moro, Yamhill, Paha and Selection 63-130-66-5. Even though Pullman Selection 101 was the recurrent parent for Selection 63-130-66-5 it was used specifically as a tester for top crosses because this selection has been found to be a good general combiner in previous studies. The pedigree and description of each cultivar is listed in the Appendix.

The first three parental cultivars have been in commercial production for several years and are intermediate for grain yield. They exhibit a wide degree of adaptability and make up Population I. In contrast, the latter three parents are recently developed cultivars and have superior yielding ability and are also adapted to the Pacific Northwest. The latter three parents make up Population II. Crosses between the three parental lines within each population were made. Generations consisting of F_1, F_2, and backcrosses to each parent were also obtained for each single cross. Two top crosses resulting from the cross of Selection 101//Druchamp/Brevor, and Selection 101//Yamhill/Selection 63-130-66-5 were made. A four-way cross resulting from the cross of Druchamp/Brevor//Yamhill/Selection 63-130-66-5 was also included.

F_1's were produced in the greenhouse in 1969-70 by hand emasculation. In 1970-71, the corresponding backcrosses for each cross, the two top crosses and one four-way cross were also made in the greenhouse. The experimental material was grown at two environmentally diverse sites in 1971-72. These experimental sites were located at the North Willamette Experiment Station, Aurora, Oregon and the Pendleton Experiment Station, Pendleton, Oregon.

The soil series at Aurora is Willamette Silt Loam which typically consists of very dark brown loam, A horizon and a dark silty clay B horizon (Simonson and Norgren, 1969). At Pendleton, the soil series is Walla Walla Silt Loam which is characterized as a very deep, well drained medium textured soil (Norgren and Simonson, 1969).

Differences in precipitation were observed between locations during the growing season. At Aurora, 1088 mm of rainfall were recorded during the growing season compared with 439 mm at Pendleton. The annual mean temperatures were very similar at both locations. The monthly temperatures, however, differed slightly, but large differences in monthly rainfall were observed between the two locations (Appendix Table 6).

The experimental design selected was a randomized block with four replications at Aurora and three replications at Pendleton. A replication consisted of nine experimental rows for each cross, one row for each parent, F_1, BC_1, and BC_2 and top cross and four-way cross. Each row consisted of 10 plants spaced 33.5 cm apart with 33.5 cm spacings between rows. Where missing plants occurred, barley was planted in the spring to provide uniform competition.

In early December, the herbicide Diuron was applied at a rate of 1.6 kg/ha at Aurora. Before planting, 20 kg/ha of nitrogen were applied and at the tillering stage an additional 120 kg/kg of the same element were broadcasted at Aurora. The experiment was later hand-weeded to reduce weed competition. At Pendleton, the herbicide Diuron was applied at a rate of 0.5 kg/ha. Prior to seeding 60 kg/ha of nitrogen were incorporated into the seed bed.

Data were collected on an individual plant basis. Tillers per plant were recorded by counting the number of spikes bearing culms at harvest. Plant height was obtained by measuring the length from the base of the crown to the top of the spike (awn excluded) of the tallest culm at maturity. The weight of 300 kernels was obtained by weighing 300 kernels randomly selected from each individual plant. Grain yield per plant was determined by the weight of grains in grams per plant.

Finally, the character kernels per spike was determined indirectly from the following characters: weight of 300 kernels, number of tillers per plant and yield of grain per plant. The formula used was as follows:

$$\text{Kernels per spike} = \frac{300 \times \text{grain yield per plant/weight of 300 kernels}}{\text{Number of tillers per plant}}$$

where 300 is the number of randomly selected kernels.

All the characteristics were subjected to analysis of variance, and the F test was utilized to determine possible significant differences (Snedecor, 1967). Plot means were used for the analysis.

Analyses of variance were determined for each character studied using individual crosses as a single group for each location and using the average of the parental lines, F_1's, F_2's, BC's and multiple crosses once in each replication as single groups.

Narrow sense heritability estimates were obtained for the five characters measured by the regression in standard units (Frey and Horner, 1957) of the performance of the F_1 on mid-parent, and the F_2 mean values on the corresponding F_1 mean values.

The following assumptions were made in estimating heritability: (1) normal behavior at meiosis, (2) no multiple alleles, (3) no linkage, (4) no epistasis and (5) no genetic-environmental interaction.

Average combining ability (A. C. A.) was determined for all characters for both locations. The formula for obtaining this estimate may be expressed in generalized terms as follows:

$$\text{A. C. A.} = \frac{\frac{(Pa+Pb)}{2} + \frac{(Pa+Pc)}{2} + \frac{(Pa+P..X)}{2}}{Na}$$

where Pa is a common parent in each single cross, and Pb, Pc, P..X are the non-common parents. Na is the number of single crosses involving the parent Pa.

Heterosis involving each cross for number of tillers per plant, plant height, weight of 300 kernels, number of kernels per spike, and grain yield per plant was calculated as the percentage increase of the F_1 above the mean of the parental lines. Heterosis was calculated using the formula described by Matzinger et al. (1962):

$$\text{Heterosis} = \frac{F_1 - MP}{MP} \times 100$$

where MP is the mid-parent value. Where characters had lower heterotic value in the F_1 generation than the mid-parent, they were considered negative in sign.

Hybrid performance superior to the better parent was calculated using the formula proposed by Fonseca and Patterson (1968a):

$$\text{Heterobeltiosis} = \frac{F_1 - HP}{HP} \times 100$$

where HP is the mean value of the better parent and F_1 is the first generation following the cross. As with heterosis, if a character expressed in the F_1 had lower values than the higher parent, they were considered negative in sign.

To detect significant differences among the means for two single crosses (Druchamp/Brevor) and (Yamhill/63-130-66-5), the two top crosses (Selection 101//Druchamp/Brevor) and (Selection 101//Yamhill/

63-130-66-5), and the four-way cross (Druchamp/Brevor//Yamhill/ 63-130-66-5) the Duncan's (1955) new multiple range test was used for plant height and grain yield for both locations.

An estimate of genetic environmental interaction was obtained to determine the relative magnitude of genotype X location and error variance for four components of yield and grain yield by the analysis of variance for two environments for all generations and for the parents separately.

EXPERIMENTAL RESULTS

The parental lines used in this investigation were selected for their grain yielding potential and genetic diversity. Population I comprised varieties still commercially grown to a limited extent in some areas of the Pacific Northwest. This population was represented by the cultivars Druchamp, Brevor, and Moro. Yamhill, 63-130-66-5 and Paha (Population II) represented improved cultivars that have been recently developed. The parental line, Pullman Selection 101, was used in the top crosses and was chosen for its good general combining ability.

An analysis of variance was computed to detect differences between and within the two populations for the characters studied at Aurora and Pendleton (Tables 1 and 2, respectively).

Significant differences were observed between genotypes for all characters studied at Aurora except tillers per plant (Table 1). At Pendleton all characters showed significant differences($p=0.01$) for genotypes (Table 2). Between populations significant differences ($p=0.01$) were observed for all characters except tillers per plant at Aurora. At Pendleton, significant differences were detected for all characters except grain yield per plant.

Within populations, significant differences were observed for kernels per spike, kernel weight and grain yield at Aurora. All the

Table 1. Observed mean squares for five agronomic characteristics of two populations of winter wheats grown at North Willamette Experiment Station, Aurora, Oregon.

Source of Variation	Degrees of Freedom	Tillers Per Plant	Plant Height	Kernels Per Spike	Weight of 300 Kernels	Grain Yield Per Plant
Reps	3	89.13**	609.52	313.96**	4.26**	1445.07**
Genotypes	38	26.96	892.13*	460.73**	2.55**	575.85**
Between populations	1	89.76	10854.20**	9084.20**	32.29	5060.29**
Within populations[1]	37	25.27	622.89	227.66**	1.75*	454.66**
Population I	19	27.58	1147.53	213.84**	2.37**	385.53**
Population II	18	22.84	69.10**	242.26**	1.09	527.63**
Reps X Genotypes[2]	144	18.13	578.71	84.56	0.84	159.52
Reps X Population I[3]	57	18.88	974.87	58.67	0.22	127.11
Reps X Population II[4]	54	13.77	13.15	99.28	1.22	173.24
Reps X Between Populations	3	82.55	3298.61	311.82	6.01	528.40
TOTAL	155	---	---	---	---	---

* significant at the 5 percent probability level
** significant at the 1 percent probability level
1 error term for between populations
2 error term for replications, genotypes and within populations
3 error term for within Population I
4 error term for within Population II

Table 2. Observed mean squares for five agronomic characteristics of two populations of winter wheats grown at Pendleton Experiment Station, Pendleton, Oregon.

Source of Variation	Degrees of Freedom	Tillers Per Plant	Plant Height	Kernels Per Spike	Weight of 300 Kernels	Grain Yield Per Plant
Reps	2	65.46*	215.93**	112.93*	0.00	51.33
Genotypes	38	83.59**	141.91**	369.18**	2.55**	200.57**
Between populations	1	935.17**	2009.70**	1664.70**	61.00**	725.47
Within populations[1]	37	60.58**	91.40**	154.20**	0.98	186.39**
Population I	19	67.61**	61.55**	107.63**	0.58	199.47**
Population II	18	53.17**	46.68**	203.35**	1.39**	172.59**
Reps X Genotypes[2]	76	19.45	20.83	28.80	0.65	71.79
Reps X Population I[3]	38	21.97	11.94	18.12	0.70	71.59
Reps X Population II[4]	36	10.15	7.21	13.72	0.09	44.95
Reps X Between populations	2	135.09	171.16	138.41	1.66	558.65
TOTAL	116	---	---	---	---	---

* significant at the 5 percent probability level
** significant at the 1 percent probability level
1 error term for between populations
2 error term for replications, genotypes and within populations
3 error term for within Population I
4 error term for within Population II

characters studied showed significant differences ($p=0.01$) at Pendleton except weight of 300 kernels. Within Population I at Aurora, significant differences ($p=0.01$) were observed for kernels per spike, weight of 300 kernels and grain yield per plant. At Pendleton, within Population I showed significant differences ($p=0.01$) for all characters at both locations except tillers per plant and weight of 300 kernels at Aurora.

At Aurora significant differences were observed among crosses for three characters analyzed: plant height, kernels per spike and weight of 300 kernels (Table 3). The same was true for within crosses except plant height. Druchamp/Brevor showed significant differences ($p=0.01$) for plant height, kernels per spike and weight of 300 kernels. Kernels per spike and grain yield were significantly different ($p=0.01$) in the cross Druchamp/Moro. Brevor/Moro showed significant differences for number of tillers per plant, weight of 300 kernels and grain yield per plant. All the characters studied were significantly different in the cross Yamhill/63-130-66-5 except weight of 300 kernels. No significant differences were observed for the other parental combinations with respect to the character measured.

At Pendleton, significant differences were observed for among crosses when each cross was considered as a single group for all characters except grain yield (Table 4). Within crosses (among parents, F_1, F_2, BC_1, BC_2, and top crosses and four-way cross

Table 3. Observed mean squares for five agronomic characteristics of six winter wheat crosses grown at North Willamette Experiment Station, Aurora, Oregon.

Source of Variation	Degrees of Freedom	Tillers Per Plant	Plant Height	Kernels Per Spike	Weight of 300 Kernels	Grain Yield Per Plant
Reps	3	89.13**	609.52	313.96**	4.26**	1445.07**
Genotypes	38	26.96	892.13*	460.73**	2.55**	575.85**
Among crosses	5	17.95	2170.87*	1816.84**	6.46*	1012.06
Within crosses[1]	33	28.33*	698.39	255.26**	1.96**	509.77*
Druchamp/Brevor	7	19.09	114.40**	167.70**	2.19**	353.94
Druchamp/Moro	5	42.18	4156.75	410.43**	3.83	591.01**
Brevor/Moro	5	35.88*	43.68	167.37	2.09**	378.48*
Yamhill/63-130-66-5	6	33.41*	147.07**	303.33*	0.78	667.96**
Yamhill/Paha	5	30.70	61.58	131.32	0.98	759.96
63-130-66-5/Paha	5	11.40	10.69	376.69	2.00	338.48
Reps X Genotypes[2]	114	18.13	578.71	84.56	0.84	159.52
Reps X Druchamp/Brevor[3]	21	24.22	21.36	54.28	0.31	182.33
Reps X Druchamp/Moro[4]	15	25.22	3658.14	75.87	0.38	101.24
Reps X Brevor/Moro[5]	15	12.12	16.45	71.06	0.15	126.52
Reps X Yamhill/63-130-66-5[6]	18	12.08	19.71	105.86	0.29	69.74
Reps X Yamhill/Paha[7]	15	17.47	14.81	101.67	1.34	298.49

Table 3. Continued.

Source of Variation	Degrees of Freedom	Tillers Per Plant	Plant Height	Kernels Per Spike	Weight of 300 Kernels	Grain Yield Per Plant
Reps X 63-130-66-5/Paha[8]	15	17.58	8.85	128.68	2.69	241.46
Reps X Among crosses	15	16.51	646.39	62.36	1.20	105.68
TOTAL	155	---	---	---	---	---

* significant at the 5 percent probability level
** significant at the 1 percent probability level
1 error term for Among crosses
2 error term for Replications, Genotypes and Within crosses
3 error term for within Druchamp/Brevor
4 error term for within Druchamp/Moro
5 error term for within Brevor/Moro
6 error term for within Yamhill/63-130-66-5
7 error term for within Yamhill/Paha
8 error term for within 63-130-66-5/Paha

Table 4. Observed mean squares for five agronomic characteristics of six winter wheat crosses grown at Pendleton Experiment Station, Pendleton, Oregon.

Source of Variation	Degrees of Freedom	Tillers Per Plant	Plant Height	Kernels Per Spike	Weight of 300 Kernels	Grain Yield Per Plant
Reps	2	65.46*	215.93**	112.93*	0.00	51.33
Genotypes	38	83.59**	141.91**	369.18**	2.55**	200.57**
Among crosses	5	187.03*	676.63**	1664.75**	12.20**	145.09
Within crosses[1]	33	67.93**	60.90**	172.89**	1.10	208.98**
Druchamp/Brevor	7	124.01**	34.60	93.99**	0.52	253.46
Druchamp/Moro	5	36.53	107.00*	126.58*	0.98	287.76
Brevor/Moro	5	46.76	78.34**	150.84**	4.99*	115.36
Yamhill/63-130-66-5	6	74.11**	61.92**	96.08**	0.62*	246.59**
Yamhill/Paha	5	44.87*	68.11	254.42**	2.61**	266.55*
63-130-66-5/Paha	5	57.59*	25.63**	362.34**	1.64**	58.74
Reps X Genotypes[2]	76	19.45	20.83	28.80	0.65	71.79
Reps X Druchamp/Brevor[3]	14	24.79	26.56	27.87	1.23	93.53
Reps X Druchamp/Moro[4]	10	29.54	21.36	35.22	0.79	96.64
Reps X Brevor/Moro[5]	10	19.23	9.50	29.05	1.45	44.45
Reps X Yamhill/63-130-66-5[6]	12	10.93	3.72	7.96	0.15	38.40
Reps X Yamhill/Paha[7]	10	9.99	31.85	35.01	0.21	70.56

Table 4. Continued.

Source of Variation	Degrees of Freedom	Tillers Per Plant	Plant Height	Kernels Per Spike	Weight of 300 Kernels	Grain Yield Per Plant
Reps X 63-130-66-5/Paha[8]	10	13.43	2.58	29.56	0.10	45.19
Reps X Among crosses	10	27.81	51.34	41.42	0.49	111.79
TOTAL	116	---	---	---	---	---

* significant at the 5 percent probability level
** significant at the 1 percent probability level
1 error term for Among crosses
2 error term for Replications, Genotypes and Within crosses
3 error term for within Druchamp/Brevor
4 error term for within Druchamp/Moro
5 error term for within Brevor/Moro
6 error term for within Yamhill 63-130-66-5
7 error term for within Yamhill/Paha
8 error term for within 63-130-66-5/Paha

when included) significant differences were noted for tillers per plant, plant height, kernels per spike and grain yield. Druchamp/Brevor was significantly different (p=0.01) for tillers per plant and kernels per spike at the one percent level. Plant height and kernels per spike were significantly different (p=0.05) for Druchamp/Moro. Brevor/Moro showed significant differences (p=0.01) for plant height and kernels per spike and weight of 300 kernels (p=0.05). The crosses, Yamhill/63-130-66-5, Yamhill/Paha and 63-130-66-5/Paha, showed significant differences for all characters studied except plant height in the Yamhill/Paha cross and grain yield per plant in the 63-130-66-5/Paha cross.

When parental lines were included only once in the analysis, significant differences (p=0.01) for genotypes were observed for kernels per spike, weight of 300 kernels and grain yield at Aurora (Table 5). At Pendleton (Table 6) significant differences (p=0.01) were observed for genotypes involving all characters studied. Among groups showed significant differences for tillers per plant, kernels per spike, weight of 300 kernels and grain yield per plant at Aurora and for tillers per plant, kernels per spike and grain yield at Pendleton. At both locations, significant differences were observed for within groups for all the characters studied except number of tillers per plant and plant height at Aurora.

When considering parents as a group, significant differences (p=0.05) were observed for all characters at Aurora (Table 5). The same was true for F_1's and F_2's except for tillers per plant and grain yield. Significant differences (p=0.01) for BC's were observed for kernels per spike and grain yield per plant. Multiple crosses showed significant differences (p=0.01) for weight of 300 kernels.

At Pendleton (Table 6) significant differences were observed for parents as well as F_1's, F_2's and BC's for all characters except grain yield within F_2's. For multiple crosses significant differences (p=0.01) were noted only for tillers per plant and grain yield.

The observed means were ranked for parents, F_1's, F_2's, BC's and multiple crosses for each of the characters studied in Population I and Population II at Aurora and Pendleton (Appendix Tables 1, 2, 3, 4, and 5).

To determine the amount of additive gene action in six winter wheat crosses, narrow sense heritability estimates were calculated for five agronomic characters by the regression of the F_1 on mid-parent values and the regression of F_2 on F_1 in standard units (Table 7).

In general, narrow sense heritability estimates of the F_1 on mid-parent values were lower and less consistent than those obtained by the regression of F_2 on F_1 values (Table 7).

Table 5. Observed mean squares for five agronomic characteristics for parents, F_1's, F_2's, BC's and multiple crosses grown at North Willamette Experiment Station, Aurora, Oregon.

Source of Variation	Degrees of Freedom	Tillers Per Plant	Plant Height	Kernels Per Spike	Weight of 300 Kernels	Grain Yield Per Plant
Reps	3	78.54*	641.94	254.81	3.37	1263.03**
Genotypes	32	26.84	987.11	489.67**	2.56**	613.68**
Among groups	4	68.36*	802.02	177.06*	2.27*	1424.32*
Within groups[1]	28	20.92	1013.56	534.33**	2.61**	497.88**
Parents	5	21.17*	300.29**	367.64*	2.87*	324.44**
F_1's	5	14.48	222.11**	608.38**	2.98**	444.90
F_2's	5	10.59	159.32**	391.79**	1.25**	147.50
BC's	11	31.13	2358.69	719.26**	2.70	778.98**
Multiple crosses	2	5.99	12.22	105.13	3.59**	393.80
Reps X Genotypes[2]	96	20.45	684.05	82.06	0.83	175.85
Reps X Parents[3]	15	5.74	9.59	112.52	0.93	71.74
Reps X F_1's[4]	15	18.26	19.17	63.18	0.24	232.05

Table 5. Continued.

Source of Variation	Degrees of Freedom	Tillers Per Plant	Plant Height	Kernels Per Spike	Weight of 300 Kernels	Grain Yield Per Plant
Reps X F_2's[5]	15	8.30	23.86	35.17	0.23	69.42
Reps X BC's[6]	33	34.97	1848.81	124.45	1.55	234.86
Reps X Multiple crosses[7]	6	13.31	35.25	31.72	0.32	130.28
Reps X Among groups	12	20.42	304.78	34.79	0.47	229.22
TOTAL	131	---	---	---	---	---

* significant at the 5 percent probability level
** significant at the 1 percent probability level
1 error term for Among groups
2 error term for Replications, Genotypes and Within groups
3 error term for within parents
4 error term for within F_1's
5 error term for within F_2's
6 error term for within BC's
7 error term for within multiple crosses

Table 6. Observed mean squares for five agronomic characteristics for parents, F_1's, F_2's, BC's and multiple crosses grown at Pendleton Experiment Station, Pendleton, Oregon.

Source of Variation	Degrees of Freedom	Tillers Per Plant	Plant Height	Kernels Per Spike	Weight of 300 Kernels	Grain Yield Per Plant
Reps	2	75.54*	156.44**	70.15	0.18*	132.05
Genotypes	32	81.69**	139.99**	341.81**	2.47**	210.72**
Among groups	4	190.34*	190.89	121.80*	0.43	809.51**
Within groups[1]	28	66.18**	132.72**	373.78**	2.77**	125.18*
Parents	5	74.27*	149.28**	602.85**	3.54*	94.69
F_1's	5	85.33*	142.77*	495.12**	2.42*	122.42
F_2's	5	29.37**	130.99**	347.61**	2.04**	70.74*
BC's	11	64.10*	141.64**	291.68**	3.39**	135.98
Multiple crosses	2	101.46**	21.66	0.75	0.08	284.96**
Reps X Genotypes[2]	64	18.89	23.80	25.77	0.61	71.84
Reps X Parents[3]	10	17.26	4.50	44.65	0.98	35.14
Reps X F_1's[4]	10	20.86	25.52	15.72	0.55	82.34

Table 6. Continued.

Source of Variation	Degrees of Freedom	Tillers Per Plant	Plant Height	Kernels Per Spike	Weights of 300 Kernels	Grain Yield Per Plant
Reps X F_2's[5]	10	4.76	16.54	11.39	0.15	14.57
Reps X BC's[6]	22	22.76	35.91	21.65	0.36	91.07
Reps X Multiple crosses[7]	4	1.94	13.11	56.73	2.45	11.91
Reps X Among groups	8	33.97	26.83	28.60	0.63	378.70
TOTAL	98	---	---	---	---	---

* significant at the 5 percent probability level
** significant at the 1 percent probability level
1 error term for Among groups
2 error term for Replications, Genotypes and Within crosses
3 error term for within parents
4 error term for within F_1's
5 error term for within F_2's
6 error term for within BC's
7 error term for within multiple crosses

Table 7. Narrow sense heritability estimates for five agronomic characteristics by the regression of the F_1 on mid-parent values and F_2 on F_1 values in standard units at North Willamette Experiment Station, Aurora, Oregon and Pendleton Experiment Station, Pendleton, Oregon.

Character	REGRESSION			
	F_1 on mid-parent		F_2 on F_1	
	Aurora (%)	Pendleton (%)	Aurora (%)	Pendleton (%)
Tillers	7	62	77	84
Plant height	86	83	97	88
Number of kernels per spike	77	92	97	91
Weight of 300 kernels	29	94	71	75
Grain yield per plant	56	9	97	60

Narrow sense heritability estimates obtained by the regression of the F_2 on F_1 for number of tillers per plant were fairly high ranging from 77 to 84 percent at Aurora and Pendleton, respectively. A value of 7 percent at Aurora and 62 percent at Pendleton was obtained by the regression of the F_1 on mid-parent.

Plant height heritability estimates were high and very similar using the two methods for both locations. Values of 97 and 88 percent were obtained by the regression of the F_2 on the F_1 and 86 and 83 percent by the regression of the F_1 on the mid-parent for Aurora and Pendleton, respectively.

For number of kernels per spike, heritability estimates obtained by the regression of the F_2 on the F_1 values were extremely high with values of 97 and 91 percent, whereas estimates of 77 and 92 percent were obtained when the F_1 was regressed on the mid-parent at Aurora and Pendleton, respectively.

Heritability estimates for weight of 300 kernels were consistent when the F_2 was regressed on the F_1 (71 and 75 percent), whereas when the F_1 was regressed on the mid-parent, sizeable differences were noted at the two locations (29 and 94 percent).

Narrow sense heritability estimates for grain yield per plant were extremely high when the F_2 was regressed on the F_1. Values ranged from 97 percent at Aurora to 60 percent at Pendleton. When the F_1 was regressed on the mid-parent, an estimate of 9 percent was obtained at Pendleton and 56 percent at Aurora.

The relative contribution of each parent was evaluated in terms of additive gene action as measured in terms of A. C. A. ability (Tables 8 and 9). Many of the differences between parents for A. C. A. were quite small for several of the traits measured and perhaps do not represent true differences in A. C. A.

In Population I Moro had better A. C. A. for the characteristics studied except plant height and weight of 300 kernels in the F_1 and F_2 at Aurora (Table 8).

For plant height the A. C. A. for Moro was less than Brevor in both F_1 and F_2, but these differences were not apparent. Moro

Table 8. Average combining ability (A. C. A.) and rank (R) for five agronomic characteristics of six winter wheats in the F_1 and F_2 generations grown at North Willamette Experiment Station, Aurora, Oregon.

Population and Generation	Parent	Tillers Per Plant		Plant Height (cm)		Kernels Per Spike		Weight of 300 Kernels (gm)		Grain Yield Per Plant (gm)	
		A. C. A.	R	A. C. A.	R	A. C. A.	R	A. C. A.	R	A. C. A.	R
Population I	Druchamp	25.11	2	110.14	3	51.62	3	14.51	1	62.78	3
	Brevor	24.24	3	112.04	1	56.74	2	14.21	2	65.04	2
	Moro	26.19	1	111.09	2	60.27	1	13.77	3	72.74	1
F_1	AVERAGE	25.18		111.09		56.21		14.16		66.85	
	Druchamp	21.15	3	105.12	3	49.88	3	13.20	1	46.85	3
	Brevor	21.91	2	106.62	1	50.58	2	13.15	2	48.66	2
	Moro	22.05	1	106.60	2	55.25	1	12.61	3	51.69	1
F_2	AVERAGE	21.70		106.11		51.90		12.98		49.06	
Population II	Yamhill	22.63	2	100.75	1	75.83	2	14.21	1	80.94	2
	63-130-66-5	22.94	1	99.22	2	77.20	1	13.62	2	81.41	1
	Paha	22.31	3	96.05	3	75.82	3	13.19	3	74.53	3
F_1	AVERAGE	22.62		98.67		76.28		13.67		78.96	
	Yamhill	19.49	1	95.86	2	67.57	3	13.31	2	57.80	2
	63-130-66-5	19.42	2	95.97	1	68.69	2	13.36	1	59.14	1
	Paha	18.59	3	93.67	3	69.35	1	12.84	3	55.14	3
F_2	AVERAGE	19.17		95.16		68.53		13.17		57.36	

Table 9. Average combining ability (A. C. A.) and rank (R) for five agronomic characteristics of six winter wheats in the F_1 and F_2 generations grown at Pendleton Experiment Station, Pendleton, Oregon.

Population and Generation	Parent	Tillers Per Plant		Plant Height (cm)		Kernels Per Spike		Weight of 300 Kernels (gm)		Grain Yield Per Plant (gm)	
		A. C. A.	R	A. C. A.	R	A. C. R.	R	A. C. R.	R	A. C. R.	R
Population I	Druchamp	39.56	2	94.38	3	38.79	2	11.29	1	55.88	2
	Brevor	40.68	1	98.54	2	37.75	3	10.46	2	55.87	3
	Moro	35.52	3	100.79	1	47.34	1	10.62	3	58.49	1
F_1	AVERAGE	38.58		97.90		41.29		10.79		56.74	
	Druchamp	29.03	2	89.83	3	38.31	1	10.64	2	38.21	3
	Brevor	31.22	1	96.29	1	36.59	3	10.70	1	40.10	2
	Moro	27.75	3	95.35	2	36.59	2	9.97	3	40.91	1
F_2	AVERAGE	29.33		93.82		37.16		10.43		39.74	
Population II	Yamhill	31.05	2	90.22	1	61.59	2	10.84	1	68.13	1
	63-130-66-5	31.58	1	87.38	3	56.69	3	9.85	2	61.38	3
	Paha	30.93	3	87.74	2	62.12	1	9.57	3	62.10	2
F_1	AVERAGE	31.18		88.44		60.13		10.08		63.87	
	Yamhill	26.98	2	86.38	2	44.56	3	10.36	2	47.07	2
	63-130-66-5	30.13	1	86.57	1	51.34	2	10.76	1	45.77	3
	Paha	25.71	3	84.84	3	58.75	1	9.75	3	48.81	1
F_2	AVERAGE	27.60		85.93		51.55		10.29		47.21	

ranked third for weight of 300 kernels in the F_1 and F_2. In the F_1 and F_2 Moro was first for number of kernels per spike.

When Population II was considered, 63-130-66-5 in the F_1 had better A. C. A. for number of tillers per plant, number of kernels per spike and grain yield per plant. In the F_2, 63-130-66-5 had again the best A. C. A. for plant height, weight of 300 kernels and grain yield per plant; however, Paha was superior to 63-130-66-5 for kernels per spike.

At Pendleton, Brevor showed better A. C. A. in both the F_1 and F_2 for tillers per plant.

Selection 63-130-66-5 ranked first for number of tillers per plant in both the F_1 and F_2. For plant height, Yamhill was first in the F_1. Yamhill was first for grain yield per plant in the F_1.

A comparison was made between the two locations for A. C. A. involving the F_1 and F_2 (Tables 8 and 9). Regarding the generation and population, number of tillers per plant was higher at Pendleton, whereas the other characters were superior at Aurora.

Heterosis and heterobeltiosis percentages for number of tillers per plant at both locations were superior for Population I when compared with Population II (Table 10). Population I had a heterobeltiosis value of 18 percent at Aurora compared with 5 percent for Population II. At Pendleton, Population I showed heterobeltiosis of 25 percent compared to 12 percent in Population II.

Table 10. Heterosis as percentage of the mid-parent (MP) and higher parent (HP) for number of tillers per plant, plant height, and number of kernels per spike of six winter wheat crosses grown at North Willamette Experiment Station, Aurora, Oregon and Pendleton Experiment Station, Pendleton, Oregon.

CROSS	TILLERS PER PLANT				PLANT HEIGHT (cm)				KERNELS PER SPIKE			
	Aurora %		Pendleton %		Aurora %		Pendleton %		Aurora %		Pendleton %	
	M P	H P	M P	H P	M P	H P	M P	H P	M P	H P	M P	H P
Druchamp/Brevor	18.88	7.11	54.94	38.06	8.08	1.55	3.96	1.01	-11.32	-16.18	-25.14	-26.20
Druchamp/Moro	42.29	30.80	28.79	22.55	7.53	3.26	6.23	1.41	-11.79	-25.43	4.02	-11.33
Brevor/Moro	19.65	17.05	21.13	13.06	4.41	2.08	12.90	10.14	0.00	-11.59	-1.64	-15.14
AVERAGE	26.94	18.32	34.96	24.59	6.67	2.29	7.69	4.18	-7.70	-17.73	-7.58	-17.15
Yamhill/63-130-66-5	19.45	4.30	20.12	-0.01	16.39	15.18	15.12	14.14	24.14	19.97	13.18	0.01
Yamhill/Paha	19.65	9.45	41.53	35.29	7.82	5.32	13.94	10.99	6.40	-1.50	1.76	-11.91
63-130-66-5/Paha	6.65	1.38	14.90	-0.02	3.35	2.00	5.90	4.03	13.83	-2.13	0.04	-24.80
AVERAGE	15.26	5.04	25.51	11.75	9.18	7.50	11.65	9.72	14.79	5.44	4.99	-12.23

Table 11. Heterosis as percentage of the mid-parent (MP) and higher parent (HP) for weight of 300 kernels, and grain yield per plant of six winter wheat crosses grown at North Willamette Experiment Station, Aurora, Oregon and Pendleton Experiment Station, Pendleton, Oregon.

CROSS	WEIGHT OF 300 KERNELS (gm)				GRAIN YIELD PER PLANT (gm)			
	Aurora %		Pendleton %		Aurora %		Pendleton %	
	M P	H P	M P	H P	M P	H P	M P	H P
Druchamp/Brevor	10.57	10.32	3.99	2.53	15.52	0.24	26.17	8.83
Druchamp/Moro	11.76	4.22	1.53	-4.58	40.52	17.71	39.53	21.00
Brevor/Moro	6.66	0.00	-2.54	-9.61	30.62	25.27	20.21	19.47
AVERAGE	9.66	4.84	0.99	-3.88	28.88	14.40	28.63	16.43
Yamhill/63-130-66-5	6.61	3.23	5.25	2.61	60.13	48.86	46.69	35.79
Yamhill/Paha	0.00	-2.95	2.94	-8.89	26.24	11.14	51.40	41.47
63-130-66-5/Paha	0.05	0.00	-3.24	-12.31	19.39	12.56	12.96	11.48
AVERAGE	2.18	0.09	1.65	-6.19	35.25	24.18	37.01	29.58

Heterobeltiosis was observed for plant height (Table 10) at both locations for Population I and Population II; however, heterobeltiosis was higher in Yamhill/63-130-66-5 cross at Aurora with a value of 15 percent. The same cross had a 14 percent value for heterobeltiosis at Pendleton.

Nearly all the heterosis and heterobeltiosis values observed for number of kernels per spike were small or negative; however, Yamhill/63-130-66-5 showed a heterobeltiotic effect of 20 percent and heterotic effect of 13 percent at Aurora and Pendleton, respectively. Two yield components, weight of 300 kernels and number of kernels per spike, showed less heterosis than did grain yield at both locations and in each population (Table 11).

Heterosis in Population I was higher for weight of 300 kernels than those values observed in Population II at Aurora (Table 11); however, the reverse was true for heterosis at Pendleton. Druchamp/Brevor had the larger value for heterobeltiosis (10 percent) at Aurora, followed by Druchamp/Moro with a value of 4 percent at the same location.

Heterosis and heterobeltiosis for grain yield per plant (Table 11) were high for both populations at the two locations except Druchamp/Moro at Aurora where no expression of heterobeltiosis was noted. Population I had an average value for heterosis and heterobeltiosis of 29 and 14 percent, respectively at Aurora and a value of 29 and 16 percent, respectively at Pendleton. Population II had larger average values for heterosis and heterobeltiosis at Aurora and Pendleton. The range observed for heterosis for grain yield per plant in Population I varied from 16 to 40 percent at Aurora. In Population II, the heterotic effect varied from 19 to 60 percent at Pendleton. Yamhill/63-130-66-5 had the highest heterotic effect at Aurora with a value of 60 percent. At Pendleton Yamhill/Paha showed 51 percent for heterosis and 41 percent for heterobeltiosis.

To detect significant differences between two single crosses, two top crosses and one four-way cross, a Duncan's multiple range test was conducted for two characters, plant height and grain yield per plant at Aurora and Pendleton.

At Aurora, the two single crosses (Druchamp/Brevor and Yamhill/63-130-66-5), the two top crosses (Selection 101//Druchamp/Brevor and Selection 101//Yamhill/63-130-66-5), and the four-way cross (Druchamp/Brevor//Yamhill/63-130-66-5) all fell into a single group for plant height (Table 12). However, a difference of 12 cm was observed between the mean of the tallest cross (Druchamp/Brevor) and the mean of the shortest cross (Selection 101//Yamhill/63-130-66-5). At Pendleton, all the crosses analyzed also fell into a single group. The range observed for plant height was from 84 to 92 cm (Table 13).

Table 12. Mean statistical differences for plant height (cm) in two single crosses, two top crosses and one four-way cross grown at North Willamette Experiment Station, Aurora, Oregon.

Cross	Mean (cm)	Stat. Sig.*
Druchamp/Brevor	111.75	a
Yamhill/63-130-66-5	103.93	a
Druchamp/Brevor//Yamhill/63-130-66-5	103.24	a
Selection 101//Druchamp/Brevor	101.39	a
Selection 101//Yamhill/63-130-66-5	99.74	a
AVERAGE	104.01	

*Mean statistical significance. Means followed by different letters are significantly different at the 5 percent probability level

Table 13. Mean statistical differences for plant height (cm) in two single crosses, two top crosses and one four-way cross grown at Pendleton Experiment Station, Pendleton, Oregon.

Cross	Mean (cm)	Stat. Sig.*
Druchamp/Brevor	92.13	a
Yamhill/63-130-66-5	89.86	a
Selection 101//Yamhill/63-130-66-5	88.86	a
Selection 101//Druchamp/Brevor	84.61	a
Druchamp/Brevor//Yamhill/63-130-66-5	83.88	a
AVERAGE	87.87	

*Mean statistical significance. Means followed by different letters are significantly different at the 5 percent probability level

For grain yield per plant at Aurora, the two top crosses, (Selection 101//Yamhill/63-130-66-5 and Selection 101//Druchamp/Brevor), the four-way cross, (Druchamp/Brevor//Yamhill/63-130-66-5), and the single cross, (Druchamp/Brevor), did not differ significantly, so they were included into one group (Table 14). The single cross Yamhill/63-130-66-5 had the highest mean value for grain yield (88 gm) and it was significantly different from the crosses Druchamp/Brevor and Selection 101//Druchamp/Brevor. At Pendleton, the highest mean value was obtained from the cross Yamhill/63-130-66-5 and it was significantly different when compared with the four-way cross (Druchamp/Brevor//Yamhill/63-130-66-5) and the one top cross (Selection 101//Yamhill/63-130-66-5). The top cross, Selection 101//Yamhill/63-130-66-5, was significantly different (p=0.05) from Yamhill/63-130-66-5 and Selection 101//Druchamp/Brevor (Table 15).

Plant height and grain yield per plant were also utilized to determine the influence of the environment for both populations at the two locations. An overall average of the crosses for plant height of 104 cm was observed at Aurora compared with an overall average of 88 cm at Pendleton. An average of 53 gm was observed at Pendleton for grain yield per plant and 60 gm was the average at Aurora.

Additional information on the influence of two different environments on 33 genotypes comprising the two populations of this study as

Table 14. Mean statistical differences for grain yield per plant (gm) in two single crosses, two top crosses and one four-way cross grown at North Willamette Experiment Station, Aurora, Oregon.

Cross	Mean (gm)	Stat. Sig.*
Yamhill/63-130-66-5	87.83	a
Selection 101//Yamhill/63-130-66-5	69.68	a b c d
Druchamp/Brevor//Yamhill/63-130-66-5	67.77	a b c d
Druchamp/Brevor	55.09	c d
Selection 101//Druchamp/Brevor	51.62	d
AVERAGE	66.40	

*Mean statistical significance. Means followed by different letters are significantly different at the 5 percent probability level

Table 15. Mean statistical differences for grain yield per plant (gm) in two single crosses, two top crosses, and one four-way cross grown at the Pendleton Experiment Station, Pendleton, Oregon.

Cross	Mean (gm)	Stat. Sig.*
Yamhill/63-130-66-5	67.42	a
Selection 101//Druchamp/Brevor	59.97	a b
Druchamp/Brevor	53.27	a b c
Druchamp/Brevor//Yamhill/63-130-66-5	44.56	b c
Selection 101//Yamhill/63-130-66-5	41.92	c
AVERAGE	53.43	

*Mean statistical significance. Means followed by different letters are significantly different at the 5 percent probability level well as for the parental lines of each population was also obtained. Significant differences were observed between locations when 33 genotypes were analyzed for the characters, tillers per plant, plant height, weight of 300 kernels, and grain yield per plant (Table 16). The same was true when considering the locations for only the parental lines (Table 17).

Significant differences were observed for genotypes as well as parental lines for all characters analyzed. There was also a location X genotype interaction for tillers per plant and weight of 300 kernels. When the parental lines were included, there was a parental lines X location interaction for plant height.

Table 16. Observed mean squares for four agronomic characteristics attributed to the interaction of two locations and 33 genotypes.

Item	Degrees of Freedom	Tillers Per Plant	Plant Height	Weight of 300 Kernels	Grain Yield Per Plant
Locations	1	4617.19**	11970.46**	387.01**	2467.11**
Genotypes	32	73.48**	798.27*	3.48 **	497.01**
Loc. X Genotypes	32	33.23**	542.40	0.95*	176.49
Reps w/n Loc.	4	37.89	544.35	2.08	108.44
Error	128	16.52	458.18	0.59	120.46
Total	197	---	---	---	---

* significant at the 5 percent probability level
** significant at the 1 percent probability level

Table 17. Observed mean squares for four agronomic characteristics attributed to the interaction of two locations and six parental lines.

Item	Degrees of Freedom	Tillers Per Plant	Plant Height	Weight of 300 Kernels	Grain Yield Per Plant
Locations	1	535.22**	1321.32**	77.05**	406.89*
Parental lines	5	72.85**	402.69**	4.02*	294.64**
Loc. X Parental lines	5	16.19	25.08*	1.98	28.04
Reps w/n Loc.	4	23.69	49.19	1.12	119.59
Error	20	12.58	6.17	1.13	60.52
Total	35	---	---	---	---

* significant at the 5 percent probability level
** significant at the 1 percent probability level

DISCUSSION

The main concern of the plant breeder is to develop superior cultivars in as short a period of time as possible with the minimum of labor and capital. This urgency of developing new cultivars is prompted primarily by the rapid changes observed in the race patterns of certain plant pathogens, or the introduction of new pathogens. As a result, the commercial life expectancy of a new cultivar is approximately five years in the Pacific Northwest. In some parts of the world cultivars must be replaced in even a shorter period of time. In addition to continually breeding for disease resistance, any newly released cultivar must also have superior yielding capacity.

In breeding for simple or qualitatively inherited traits like verticle disease resistance, the choice of parents is obvious. This is in contrast to breeding for complex or quanitatively inherited characters such as grain yield where the choice of which hybrid combination is less clear.

To maximize the efficiency of his efforts in breeding for grain yield, the plant breeder needs to carefully select his potential parental material and to identify the most promising progeny in segregating generations. The probabilities of success in a program are proportional to the amount of material with "good genetic potentiality."

When deciding which cultivars to utilize in a crossing program for grain yield, it would be beneficial if the plant breeder could be guided by such information as: the amount and nature of the genetic variation in terms of the predominate type of gene action associated with various hybrid combinations; the relative combining ability of the parents; and the amount of genotype-environment interaction present. In considering a conventional program, the wheat breeder must be concerned with those genes which behave in an additive manner because this is the only type of gene action that can be fixed at high levels of performance in subsequent selfing generations as homozygosity is approached. If one is concerned with a hybrid program then the non-additive type of gene action is of major importance. Therefore, parents must be selected which will provide a maximum expression of heterobeltiosis in the F_1.

Most wheat breeders currently tend to cross between high yielding cultivars with the hope that by doing so a greater chance of combining more favorable genes for grain yield will be realized. This has been quite successful, particularly in major breeding programs where resources permit the evaluation of many crosses and large populations. However, in the majority of the breeding programs such resources are not available and now even where there are resources, yield plateaus are being encountered. If further progress is to be made, the breeder must have more guidance in selecting parental lines.

It was the major objective of this study to compare two populations which were selected for their grain yield potential. The parents utilized in the first population represented cultivars developed several years ago and are now grown on only a very limited acreage in the Pacific Northwest. They are classified as being intermediate in grain yield in comparison with the cultivars which currently are being grown on the majority of the wheat acreage. The second population was composed of very recently developed cultivars which are higher yielding than the cultivars now in commercial production and are expected to become the predominate cultivars grown in this region in the next few years.

Narrow sense heritability estimates were high, indicating there was considerable genetic variability for the components of yield, and to a lesser degree, for grain yield. Thus, effective progress could be made through selection. Estimates for plant height and number of kernels per spike were high and consistent between generations and over locations. Therefore, selection as early as the F_2 in a conventional program would be effective because neither of these characters were influenced greatly by nonadditive gene action. A similar conclusion could be made for weight of 300 kernels except there was more variation between the heritability estimates, particularly at the Aurora location.

There was considerable variation in the heritability estimates obtained for tillers per plant and grain yield when the F_1 was regressed on mid-parent. Even with this variation, there was considerable additive genetic variance associated with these two characters. However, because both tiller number and grain yield were influenced by nonadditive genetic variance as noted by the heterosis and heterobeltiosis values, selection for these characters would have to be delayed until the F_3 or F_4 generations in a conventional hybridization program. Such a delay would permit a loss of the nonadditive genetic variance through inbreeding so the additive genetic variance could be more clearly evaluated.

The narrow sense heritability estimates for the components of yield and grain yield were slightly higher than those reported by other investigators (Kronstad and Foote, 1964; Johnson et al., 1966; Fonseca and Patterson, 1968b; Gyawali et al., 1968). However, in all studies to date, lower narrow sense heritability estimates have been noted for grain yield than for the other components of yield. This was also true in this investigation.

The two populations can be compared with regard to the relative amount of additive genetic variance contributed by the respective parents. Population I had a higher A. C. A. in both the F_1 and F_2 for tillers per plant, plant height, and weight of 300 kernels; however, there was very little difference between the two populations for the latter character. Population II had a higher A. C. A. for kernels per spike and grain yield. These observations were consistent for both locations. Therefore, it would appear that an increase in kernels per spike would have a greater influence on grain yield. The importance of kernel number in influencing grain yield is in keeping with the investigations of Lukyanenko (1966).

When considering the parents within Population I at the Pendleton location, Moro appears to be the most promising parent for plant height, kernels per spike and grain yield. The cultivar, Moro, is tall and as a result of having a club type spike also has a large number of kernels per spike. This may account for the apparent association between kernels per spike, plant height and grain yield at this site. In Population II, a similar relationship existed with Paha which also is a club spike. At Pendleton it ranked number one for both kernel number and grain yield. Therefore, crosses between cultivars with a club type spike and those with common type spikes may provide the greatest amount of genetic variability and in turn result in the largest number of high yielding progeny in segregating populations under the growing conditions observed at the Pendleton location. However, in certain populations, it has previously been difficult to maintain large club heads in later generations.

At Aurora, Paha had the highest A. C. A. for kernel number, but was the lowest for grain yield. Selection 63-130-66-5 was either first or second in A. C. A. for the components of yield and first for grain yield. Even though Selection 63-130-66-5 had lower A. C. A. for kernels per spike than Paha, the difference was very small. In fact this was true for most comparisons involving the other measured characters at the Aurora location. However, under the conditions of higher rainfall at Aurora, tiller number might have a greater influence on grain yield, particularly if the other components of yield were approximately the same in magnitude.

In comparing Population I and II at both locations, the F_1 progeny exceeded the F_2 for all the components of yield and grain yield. Therefore, even though A. C. A. is considered to be a measure of additive genetic variance, there was a considerable amount of nonadditive genetic variance involved in these estimates. This could have been anticipated because a small number of parents were utilized in each population.

If a wheat breeder is concerned with a hybrid program, then those populations, or more specifically, those parental combinations which result in a maximum expression of heterobeltiosis are of most interest. Only two characters, tillers per plant and grain yield, were found to be influenced to any extent by nonadditive genetic variance. At both locations a higher percentage of heterobeltiosis was noted for tiller number in Population I than in Population II. However, there was a higher percentage of heterobeltiosis for grain yield in Population

II than in Population I. To obtain a maximum number of tillers at Aurora for Population I, the cross Druchamp/Moro would be selected; however, the cross Brevor/Moro resulted in the highest grain yield. At Pendleton, the cross Druchamp/Brevor gave a maximum expression for tiller number, but both Druchamp/Moro and Brevor/Moro were superior for grain yield. When considering Population II, the crosses between Yamhill/Paha and Yamhill/63-130-66-5 were similar in terms of heterobeltiosis for tiller number, but Yamhill/63-130-66-5 was superior for grain yield at Aurora. At Pendleton, Yamhill/Paha was superior in hybrid vigor for both tiller number and grain yield.

When considering the development of hybrids for commercial production for specific locations, tiller number may be an important criterion for grain yield, but this association will depend on the specific locations and the parental combinations involved.

A greater expression of heterobeltiosis was observed for both tiller number and grain yield at the Pendleton location. This is somewhat contrary to the concept that to obtain a maximum amount of heterobeltiosis, it is desirable to grow the F_1 population under environmental conditions which are optimum. If this were true, a greater expression of heterobeltiosis should have been observed at Aurora where a greater amount of moisture was available during the growing season.

Plant height and grain yield were selected to provide additional information regarding the parental combinations. Comparisons between single and top crosses along with one double cross were made for the respective F_1's. For plant height, no significant differences were noted at either location; however, the F_1 from the single cross, Druchamp/Brevor, from Population I was the tallest at both locations. When considering grain yield, the F_1 resulting from the single cross, Yamhill/63-130-66-5, from Population II was superior for grain yield at both locations. At Aurora Yamhill/63-130-66-5 was significantly different from the F_1 population Druchamp/Brevor or Selection 101//Druchamp/Brevor. This was not the case at the Pendleton site where there were no significant differences between these same populations.

The reason for using top or double crosses is to bring a larger percentage of desirable genes into a hybrid before it is allowed to fully segregate. Pullman Selection 101 has been found to be an excellent combining cultivar and hence its use as a tester in the top crosses. Several reasons may account for the top crosses and double cross not being superior to the single cross for grain yield in this study. It is possible that with top and double crosses, segregation may result in the immediate generation following the cross if the respective parents were heterozygous for certain alleles. This could reduce the amount of heterosis expressed in this generation as a result of an inbreeding depression. Secondly, the size of the top and double cross populations should be quite large, and it may well have been that a larger population size was needed in this study to adequately evaluate the value of top and double crosses. It is also quite conceivable that different parental combinations may perform differently.

The existence of genotype-environment interactions and the effect on quantitative characters has been reported in several crops. In developing cultivars for wide adaptability, a careful consideration needs to be made of the response of different genotypes to different environments. This would also be of major importance in selecting the most promising parents. There were significant differences for all characters measured between the two sites. The parental lines also differed significantly between the two locations for all characters measured. When the parental lines were analyzed with the F_1 and segregating populations, the significant differences were observed for all characters. There were significant location X genotype interactions for tillers per plant and weight of 300 kernels between the two experimental locations. In addition, when rankings were considered for A. C. A. values of the parents or the heterosis and heterobeltiosis extimates for the crosses, there were some interactions present between the two sites.

Those parental lines appearing to have the widest adaptations in this study included Moro and Yamhill, with Selection 63-130-66-5 quite specific for the Aurora location.

The fact that plant breeders have tended to hybridize high yielding cultivars in conventional breeding programs to maximize the opportunity of obtaining superior gene combinations for grain yield is supported by the information gained in this study. The high yielding parents making up Population II appear to be more promising in providing a higher percentage of promising segregates. This was reflected in the higher narrow sense heritability estimates and also in the A.C.A. values. More specifically, the cross Yamhill/63-130-66-5 would appear to be the most promising for grain yield, particularly at the Aurora location. At Pendleton Yamhill/63-130-66-5, or perhaps Yamhill/Paha would be the best choice.

The cross Yamhill/63-130-66-5 would also be identified as providing the greatest potential for heterobeltiosis. Therefore, it would appear that hybrid wheat breeders should utilize superior yielding cultivars because their initial yielding potential resulted from capitalizing on additive genetic variance. When again crossed they may have a high degree of additive genetic variance, but would also have nonadditive genetic variance involved resulting in the greatest expression of heterobeltiosis and thereby capitalizing on both types of gene action.

The most promising cultivars for both conventional programs and hybrid programs would be the cultivars from Population II which were represented by the highest yielding parents.

SUMMARY AND CONCLUSIONS

The objective of this investigation was to provide the wheat breeder with information concerning the identification of the most promising parental combinations for either a conventional or hybrid breeding program. To do this, two populations were selected which were represented by parents differing in their genetic potential for grain yield. Population I consisted of three parents which represented cultivars released several years ago and are regarded as intermediate for grain yield. In contrast, the parents involving Population II, included three cultivars which have just recently been developed and have a much greater potential for increased grain yield than those cultivars identified in Population I. Morphological characters measured included: (1) tiller number per plant; (2) kernel number per spike; (3) weight of 300 kernels; (4) plant height and (5) grain yield. The first four characters were regarded as the components of grain yield.

Information regarding the predominant type of genetic variance was determined by narrow sense heritability estimates, (A. C. A.), average combining ability, heterosis and heterobeltiosis values. In addition, an evaluation comparing the relative performance of single and top crosses along with one double cross was also made. Also, evidence of the possible influence of any genotype-environmental interaction was obtained.

The following conclusions were drawn:

1. Both Population I and II exhibited a high degree of genetic variability for all characters measured.
2. The components of yield; i.e. kernel number, weight of 300 kernels and plant height were largely controlled by additive genetic variance and effective selection could be initiated in the F_2.
3. Tiller number and grain yield were influenced by relative amounts of additive and nonadditive genetic variance and as a result, selection should be delayed until the F_3 or later generations for these characters.
4. Average combining ability values were the result of both additive and nonadditive genetic variance.
5. The superior yielding cultivars used as parents in Population II resulted in a higher A.C.A. for kernels per spike and grain yield. Parents representing Population I had a higher A.C.A. for tiller number, weight of 300 kernels and plant height.
6. The results from the populations utilized in this investigation suggest that crosses between cultivars with club and common spikes would be promising because these crosses were superior for both kernel number and grain yield.
7. Cultivars showing the most potential for a conventional breeding program would also be superior in a hybrid program.

8. Progeny resulting from single crosses appear to have a higher percentage of high yielding segregates than those progeny resulting from top crosses or double crosses. This may be attributed to inbreeding depression when double or top crosses were utilized.
9. A significant genotype-environmental interaction was observed for plant height involving the parents and for plant height and weight of 300 kernels when all genotypes were considered. Differences were also noted in the estimates of average combining ability, heterosis and heterobeltiosis for the parents depending on the location. It will therefore be necessary to select the most promising parental combinations based on their performance at specific locations.
10. Wheat breeders should concentrate their efforts on crosses between high yielding cultivars to obtain the largest number of promising progeny in segregating populations. However if progress is to be continued, it may be necessary to establish elite germplasm that exhibit good agronomic characters, disease resistance, adaptability and acceptable quality. When utilizing this elite germ plasm, the breeder could be more efficient in developing higher yielding cultivars.

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APPENDIX

PEDIGREE AND DESCRIPTION OF CULTIVARS

Druchamp. (Vilomorin 27/Fleche d'Or). A standard height, strong strawed, awnless soft winter wheat. It is resistant to lodging except in the high rainfall areas when heavily fertilized. Druchamp is highly resistant to *Puccinia striiformis*.

Brevor. (Turkey-Florence/Forty-fold-Federation). A standard height, awnless, white chaffed soft winter wheat which is resistant to lodging and shattering. Brevor is resistant to all races of common bunt *Tellitia caries* and *T. foetida* and moderately resistant to stripe rust.

Moro. (P. I. 178383/Omar^2). A mid-tall, awnletted club, soft white winter wheat which emerges very rapidly, has a certain degree of winterhardiness, is difficult to combine and thresh, is resistant to most races of stripe rust but susceptible to stem rust (*P. gramines*) and leaf rust (P. recondita).

Yamhill. (Heines VII/Redmon (Alba) Selection 61-1227-66-7). A mid-tall, stiff strawed, awnletted, high yielding, late maturing, soft white winter wheat which is resistant to stripe rust but very susceptible to common bunt.

63-130-66-5. (Nord Desprez/Pullman Selection 101). A semi-dwarf, strong strawed, awnletted white winter wheat which has good emergence, rapid growth and is resistant to stripe rust.

Paha. (Suwon 92/4* Omar). A short strawed, brown chaffed white winter wheat which is resistant to lodging and shattering and is easy to combine and thresh.

Pullman Selection 101. (C.I. 12697/Norin 10-Brevor). A semi-dwarf, strong strawed, awned white winter wheat that is a good combiner for several agronomic characteristics.

Appendix Table 1. Observed mean values for number of tillers per plant for parents. F_1's, F_2's, backcrosses, top-crosses, and four-way crosses of winter wheat grown at North Willamette Experiment Station, Aurora, Oregon and Pendleton Experiment Station, Pendleton, Oregon.

	Aurora		Pendleton	
	Mean	Rank	Mean	Rank
Druchamp	17.34	8	25.34	8
Brevor	21.63	5	32.40	5
Druchamp/Brevor	23.17	2	44.73	1
F_2 Druchamp/Brevor	21.37	6	32.50	4
Druchamp/Brevor//Druchamp	24.57	1	28.73	7
Druchamp/Brevor//Brevor	20.12	7	37.13	3
Selection 101//Druchamp/Brevor	22.47	4	38.76	2
Selection 101//Yamhill/63-130-66-5	22.58	3	27.94	6
Druchamp	17.34	6	25.34	6
Moro	20.68	5	28.07	3
Druchamp/Moro	27.05	1	24.40	1
F_2 Druchamp/Moro	21.65	4	25.56	5
Druchamp/Moro//Druchamp	21.72	3	27.86	4
Druchamp/Moro//Moro	23.90	2	31.20	2
Brevor	21.63	5	32.40	4
Moro	20.68	4	28.07	6
Brevor/Moro	25.32	2	36.63	2
F_2 Brevor/Moro	22.45	3	29.93	5
Brevor/Moro//Brevor	17.52	6	37.93	1
Brevor/Moro//Moro	25.45	1	35.76	3
Yamhill	16.65	7	20.49	7
63-130-66-5	22.31	3	32.29	2
Yamhill/63-130-66-5	23.27	2	31.70	3
F_2 Yamhill/63-130-66-5	20.32	4	26.40	5
Yamhill/63-130-66-5//Yamhill	18.97	5	23.13	6
Yamhill/63-130-66-5//63-130-66-5	18.27	6	33.56	1
Druchamp/Brevor//Yamhill/63-130-66-5	24.64	1	29.66	4
Yamhill	16.65	6	20.49	6
Paha	20.10	3	22.47	5
Yamhill/Paha	22.00	2	30.40	1
F_2 Yamhill/Paha	18.65	5	27.55	3
Yamhill/Paha//Yamhill	18.72	4	25.76	4
Yamhill/Paha//Paha	24.45	1	29.20	2
63-130-66-5	22.31	2	32.29	2
Paha	20.10	4	22.47	6
63-130-66-5/Paha	22.62	1	31.46	3
F_2 63-130-66-5/Paha	18.52	6	23.86	5
63-130-66-5/Paha//63-130-66-5	19.32	5	32.30	1
63-130-66-5/Paha//Paha	21.70	3	27.66	4

Appendix Table 2. Observed mean values for plant height, for parents, F_1's, F_2's, backcrosses, top crosses, and four-way crosses of winter wheat grown at North Willamette Experiment Station, Aurora, Oregon and Pendleton Experiment Station, Pendleton, Oregon.

	Aurora		Pendleton	
	Mean (cm)	Rank	Mean (cm)	Rank
Druchamp	96.74	8	86.62	7
Brevor	110.04	2	90.62	4
Druchamp/Brevor	111.75	1	92.13	2
F_2 Druchamp/Brevor	105.13	5	91.40	3
Druchamp/Brevor//Druchamp	106.52	4	88.90	5
Druchamp/Brevor//Brevor	109.27	3	95.41	1
Selection 101//Druchamp/Brevor	101.39	6	84.61	5
Selection 101//Yamhill/63-130-66-5	99.74	7	88.86	6
Druchamp	96.74	6	86.62	5
Moro	105.11	3	95.29	2
Druchamp/Moro	108.54	2	96.63	1
F_2 Druchamp/Moro	105.10	4	88.27	3
Druchamp/Moro//Druchamp	100.77	5	80.44	6
Druchamp/Moro//Moro	181.58	1	87.77	4
Brevor	110.04	4	90.62	6
Moro	105.11	6	95.29	5
Brevor/Moro	112.33	2	104.95	1
F_2 Brevor/Moro	108.10	5	102.44	2
Brevor/Moro//Brevor	114.64	1	97.96	4
Brevor/Moro//Moro	110.34	3	99.36	3
Yamhill	88.34	7	77.38	7
63-130-66-5	90.23	6	78.73	6
Yamhill/63-130-66-5	103.93	1	89.86	1
F_2 Yamhill/63-130-66-5	98.16	3	88.11	2
Yamhill/63-130-66-5//Yamhill	93.17	5	82.60	5
Yamhill/63-130-66-5//63-130-66-5	95.14	4	84.53	3
Druchamp/Brevor//Yamhill/63-130-66-5	103.24	2	83.88	4
Yamhill	88.34	6	77.38	6
Paha	92.65	5	81.61	4
Yamhill/Paha	97.58	2	90.58	1
F_2 Yamhill/Paha	93.55	4	84.66	2
Yamhill/Paha//Yamhill	97.23	3	78.44	5
Yamhill/Paha//Paha	98.75	1	82.90	3
63-130-66-5	90.23	6	78.73	6
Paha	92.65	5	81.61	5
63-130-66-5/Paha	94.51	1	84.90	3
F_2 63-130-66-5/Paha	93.78	4	85.03	2
63-130-66-5/Paha//63-130-66-5	93.98	3	86.98	1
63-130-66-5/Paha//Paha	94.46	2	83.20	4

Appendix Table 3. Observed mean values for number of kernels per spike, for parents, F_1's, F_2's, backcrosses, top-crosses, and four-way crosses of winter wheat, grown at North Willamette Experiment Station, Aurora, Oregon and Pendleton Experiment Station, Pendleton, Oregon.

	Aurora		Pendleton	
	Mean	Rank	Mean	Rank
Druchamp	51.08	4	38.46	4
Brevor	57.37	2	39.58	3
Druchamp/Brevor	48.09	7	29.21	8
F_2 Druchamp/Brevor	45.21	8	30.34	7
Druchamp/Brevor//Druchamp	50.95	5	33.89	6
Druchamp/Brevor//Brevor	50.56	6	36.30	5
Selection 101//Druchamp/Brevor	56.13	3	43.57	2
Selection 101//Yamhill/63-130-66-5	65.91	1	44.23	1
Druchamp	51.08	5	38.46	6
Moro	73.96	1	54.56	2
Druchamp/Moro	55.15	3	48.38	4
F_2 Druchamp/Moro	54.55	4	46.27	5
Druchamp/Moro//Druchamp	44.44	6	49.71	3
Druchamp/Moro//Moro	61.83	2	56.78	1
Brevor	57.37	5	39.58	5
Moro	73.96	1	54.56	1
Brevor/Moro	65.39	2	46.30	3
F_2 Brevor/Moro	55.94	6	42.84	4
Brevor/Moro//Brevor	62.41	4	34.93	6
Brevor/Moro//Moro	64.35	3	49.85	2
Yamhill	64.35	4	55.63	2
63-130-66-5	60.03	5	43.62	5
Yamhill/63-130-66-5	77.20	2	56.17	1
F_2 Yamhill/63-130-66-5	66.91	3	44.12	3
Yamhill/63-130-66-5//Yamhill	79.59	1	51.81	4
Yamhill/63-130-66-5//63-130-66-5	59.01	6	47.19	6
Druchamp/Brevor//Yamhill/63-130-66-5	58.34	7	43.25	7
Yamhill	64.35	6	55.63	5
Paha	75.58	2	76.08	1
Yamhill/Paha	74.45	3	67.02	2
F_2 Yamhill/Paha	68.23	4	58.56	4
Yamhill/Paha//Yamhill	67.23	5	49.89	6
Yamhill/Paha//Paha	79.17	1	59.53	3
63-130-66-5	60.03	6	43.62	6
Paha	75.58	3	76.08	1
63-130-66-5/Paha	77.19	2	57.21	4
F_2 63-130-66-5/Paha	70.47	5	58.93	3
63-130-66-5/Paha//63-130-66-5	78.01	4	53.64	5
63-130-66-5/Paha/Paha	89.83	1	65.62	2

Appendix Table 4. Observed mean values for weight of 300 kernels, for parents, F_1's, F_2's, back-crosses, top-crosses, and four way crosses of winter wheat grown at North Willamette Experiment Station, Aurora, Oregon and Pendleton Experiment Station, Pendleton, Oregon.

	Aurora		Pendleton	
	Mean (gm)	Rank	Mean (gm)	Rank
Druchamp	13.50	7	11.13	6
Brevor	13.56	6	11.45	3
Druchamp/Brevor	14.96	1	11.74	1
F_2 Druchamp/Brevor	13.74	3	11.37	4
Druchamp/Brevor//Druchamp	14.41	2	11.24	5
Druchamp/Brevor//Brevor	13.59	5	11.64	2
Selection 101//Druchamp/Brevor	12.40	8	10.71	7
Selection 101//Yamhill/63-130-66-5	13.71	4	10.56	8
Druchamp	13.50	2	11.13	1
Moro	11.67	6	9.79	6
Druchamp/Moro	14.07	1	10.62	3
F_2 Druchamp/Moro	12.65	4	9.90	5
Druchamp/Moro//Druchamp	13.46	3	10.98	2
Druchamp/Moro//Moro	11.81	5	10.07	4
Brevor	13.56	1	11.45	2
Moro	11.67	6	9.79	5
Brevor/Moro	13.46	2	10.35	3
F_2 Brevor/Moro	12.56	4	10.03	4
Brevor/Moro//Brevor	13.12	3	12.89	1
Brevor/Moro//Moro	12.38	5	9.44	6
Yamhill	14.22	3	11.13	4
63-130-66-5	13.22	7	10.56	6
Yamhill/63-130-66-5	14.68	1	11.42	2
F_2 Yamhill/63-130-66-5	13.83	5	11.36	3
Yamhill/63-130-66-5//Yamhill	14.15	4	11.59	1
Yamhill/63-130-66-5//63-130-66-5	13.71	6	10.85	5
Druchamp/Brevor//Yamhill/63-130-66-5	14.25	2	10.36	7
Yamhill	14.22	1	11.13	1
Paha	13.36	5	8.57	6
Yamhill/Paha	13.80	3	10.14	3
F_2 Yamhill/Paha	12.78	6	9.35	5
Yamhill/Paha//Yamhill	13.86	2	10.70	2
Yamhill/Paha//Paha	13.50	4	9.62	4
63-130-66-5	13.32	3	10.56	1
Paha	13.36	2	8.57	5
63-130-66-5/Paha	12.57	5	9.26	4
F_2 63-130-66-5/Paha	12.89	4	10.15	2
63-130-66-5/Paha//63-130-66-5	14.41	1	10.09	3
63-130-66-5/Paha//Paha	12.47	6	9.26	4

Appendix Table 5. Observed mean values for grain yield per plant for parents, F_1's, F_2's, back-crosses, top-crosses, and four-way crosses of winter wheat grown at North Willamette Experiment Station, Aurora, Oregon and Pendleton Experiment Station, Pendleton, Oregon.

	Aurora		Pendleton	
	Mean (gm)	Rank	Mean (gm)	Rank
Druchamp	40.42	8	35.49	8
Brevor	54.96	4	48.95	4
Druchamp/Brevor	55.09	3	53.27	2
F_2 Druchamp/Brevor	43.81	7	37.40	6
Druchamp/Brevor//Druchamp	59.94	2	36.40	7
Druchamp/Brevor//Brevor	46.63	6	52.48	3
Selection 101//Druchamp/Brevor	51.62	5	59.97	1
Selection 101//Yamhill/63-130-66-5	69.68	1	41.92	5
Druchamp	40.42	5	35.49	6
Moro	59.87	2	48.34	4
Druchamp/Moro	70.74	1	58.49	2
F_2 Druchamp/Moro	49.88	4	39.02	5
Druchamp/Moro//Druchamp	39.15	6	50.59	3
Druchamp/Moro//Moro	58.14	3	59.28	1
Brevor	54.96	4	48.95	4
Moro	59.87	3	48.34	5
Brevor/Moro	75.00	1	58.48	1
F_2 Brevor/Moro	53.50	5	42.79	6
Brevor/Moro//Brevor	48.54	6	57.10	2
Brevor/Moro//Moro	67.02	2	56.09	3
Yamhill	50.69	6	42.27	7
63-130-66-5	59.00	5	49.65	3
Yamhill/63-130-66-5	87.83	1	67.42	1
F_2 Yamhill/63-130-66-5	61.80	4	44.03	6
Yamhill/63-130-66-5//Yamhill	68.30	2	46.36	4
Yamhill/63-130-66-5//63-130-66-5	50.03	7	57.19	2
Druchamp/Brevor//Yamhill/63-130-66-5	67.77	3	44.56	5
Yamhill	50.69	6	42.27	6
Paha	66.63	3	48.66	4
Yamhill/Paha	74.05	2	68.84	1
F_2 Yamhill/Paha	53.80	5	50.11	3
Yamhill/Paha//Yamhill	59.05	4	45.90	5
Yamhill/Paha//Paha	87.34	1	55.78	2
63-130-66-5	59.00	5	49.65	4
Paha	66.63	3	48.06	5
63-130-66-5/Paha	75.00	2	55.35	3
F_2 63-130-66-5/Paha	56.47	6	47.51	6
63-130-66-5/Paha//63-130-66-5	64.51	4	47.97	1
63-130-66-5/Paha//Paha	80.35	1	55.98	2

Appendix Table 6. Average monthly temperatures (^{o}C) and total rain fall from October, 1971 to August, 1972 at North Willamette Experiment Station, Aurora, Oregon and Pendleton Experiment Station, Pendleton, Oregon. (NOAA, 1971, 1972).

		Aurora		Pendleton	
		Temperature (° C)	Precipitation (mm)	Temperature (° C)	Precipitation (mm)
October	1971	9.6	93.72	8.15	43.68
November	"	6.32	164.80	5.21	79.75
December	"	3.71	203.70	1.66	99.82
January	1972	3.21	155.87	0.16	29.21
February	"	5.55	121.41	2.05	43.18
March	"	8.49	146.55	7.54	53.59
April	"	7.54	91.69	7.65	34.29
May	"	13.93	67.31	14.09	3.81
June	"	16.03	15.24	17.92	23.11
July	"	20.14	11.93	20.47	19.30
August	"	20.14	16.51	21.47	8.89
Average		10.42	99.97	9.69	39.88
Total		-	1088.73	-	438.63