MULTIVARIATE ANALYSIS APPROACH TO SELECTION OF PARENTAL MATERIALS FOR HYBRIDIZATION IN WINTER WHEAT

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CHAPTER I

INTRODUCTION

In self-pollinated crops, most of the cultivars consist of one or a limited number of related homozygous genotypes. For improving complex quantitative characters such as yield, choice of parents is critical. The conventional approaches are limited since they necessitate a considerable amount of labor and time. A knowledge of genetic diversity present among populations and its quantitative measurement helps a plant breeder in selecting desirable parents for his breeding program.

One of the important aims of plant breeding is to improve yield and quality by developing superior varieties. This is done by altering, to the best advantage, the genetic makeup of the existing cultivars. Such work should be facilitated if the plant breeder is able to classify the varieties broadly on the basis of a given set of genetic characters and further discriminate any two cultivars belonging to the same class or group. The objectives of this study were: (1) to set up a discriminant function for a number of cultivars grown at different areas during three years and use these functions to determine the best two-way and three-way crosses, and (2) to measure the genetic diversity among populations originating from different ecological areas as a basis for selecting parental materials and to see if there is any relationship between geographical distribution and genetic diversity.

CHAPTER II

LITERATURE REVIEW

The basic importance of genetic diversity in breeding for high yield has long been recognized. The magnitude of heterosis in wheat has been reported to be dependent on the degree of genetic diversity between parental stocks (20). This may be used as an indicator of the inherent yielding capacity of a cross. The breeder of small grains makes many crosses, each with a definite purpose, but he has no sure way of knowing their comparative value in advance. We know that certain cultivars have a higher value in combining ability than do others. Lindstrom (11) introduced the principle of "top crossing" in 1931 as a valuable technique in maize improvement. Coefficients of correlation for a number of different characters were determined between the mean performance of the single crosses of inbred lines of corn and the performance of these lines in crosses with a commercial variety. From a comparison of these correlations, Jenkins and Brunson (9) concluded that crosses with open-pollinated varieties may be used efficiently in the preliminary testing of new lines. Suneson (21) emphasized the importance of genetic diversity as a protection against plant diseases and insects. He proposed the breeding methods that give multigenic resistance in multiline varieties.

In self-pollinated species, a lack or a limited amount of genetic diversity is present within established cultivars, since most cultivars consist of one or a limited number of related homozygous genotypes and selection for uniformity is continually practiced. Genetically diverse populations have shown greater stability in performance over a number of environments (1). The productivity of ten lima bean populations representing three levels of genetic diversity was tested at four locations during four years by Allard (1). The purpose of the test was to determine whether productivity and stability of productivity are related to genetic diversity. Order of productivity was bulks $\geq$ pure lines > mixture. Order of stability of production was bulks > mixture > pure lines (1). The adaptation mechanism may be related to the degree of genetic variation for the characters influencing survival. In self-pollinated crops, the selection of parents for hybridization programs is based largely upon wide adaptation, high yield potential, and genetic diversity. Anand and Murty (2) mentioned that adaptation could be due to heterozygosity, genetic diversity of populations, past history of selection, and the degree of general combining ability. Genetic diversity might permit genetic variability which would have a buffering action in new environments. Finlay and Wilkson (6) reported the measurement of yield and stability of its performance in barley. For each variety a linear regression of individual yield on the mean yield of all varieties for each location and each season was computed. They suggested that the stability of productivity in different environments of the segregating generation could be due to the diversity of genotypes. The retention of genetic diversity within a population could be due to the presence of linkage equilibrium in breeding species. The introduction of alien genes from different geographical areas also has added to the genetic diversity (2). The cultivars which give relatively high yield and show considerable stability of performance over a large number of locations are classified as having good adaptation. Das and Jain (5) studied adaptation with respect to cytology of the plant. They analyzed a number of wheat cultivars with different adaptability for chiasma formation under different agronomic and environmental conditions. Cultivars well adapted in respect to yielding ability showed relative stability of chiasma frequency (5). Experimental findings reported in the literature indicate that crosses of unrelated, inbred lines of corn show greater heterosis than do crosses of related lines. The success of many double-cross hybrids over very wide areas is the result of their genetic diversity combined with their stability and consistency of performance (1, 12).

In spite of the importance of genetic diversity in hybridization, it is difficult to obtain a dependable estimate of such diversity before making crosses. In the past, ecological or geographical diversity has been used as an index of genetic diversity. A number of studies have shown that the divergence between populations could not be related to their geographical distribution (2, 3, 4). Harrington (8) suggested that bulk F_2 yield trials may be used to indicate the potential yield possibilities of a cross. He added that F_3 yield trials are of supplementary value as a support to the F_2 conclusions.

One of the statistical approaches for measuring genetic diversity which has been used by many workers is Mahalanobis' generalized distance D^2 (2, 3, 4, 15, 20). In a few studies, the relative contribution of different yield components to the total divergence showed that yield *per se* had a low contribution (2, 3, 13, 15). Thus, Sachan and Shorma (17) emphasized the type of component characters of yield that should be taken into account. These components should have economic importance under crop improvement programs (17). The genetic divergence as measured by the D^2 statistic is reflected to some extent in the combining ability effects. The crosses of most divergent varieties have shown larger specific combining ability effects for a majority of characters (14). Populations may be grouped into several clusters depending on their distances measured by average D^2. Somayajulu et al. (20) suggested that cultivars which are grouped together come under one or more of the following categories: (1) related by pedigree, (2) originating in the same or similar ecological regions, and (3) similar in characters such as maturity and plant height which are known to contribute to genetic divergence in wheat (20).

Another technique is the use of discriminant function, first developed by Fisher (7, 16). Both statistics deal with the problem in ways very closely related to each other (7, 16). Discriminant function was used in wheats for varietal selection (13, 18, 20), and Smith (19) mentioned it as a tool for selecting parents for hybridization.

CHAPTER III

MATERIALS AND METHODS

The cultivars used for this study were obtained from wheat architecture nurseries at the Agronomy Research stations, Stillwater and Lahoma, Oklahoma. The cultivars originated from the U.S.A., U.S.S.R., and European countries. The layout was a randomized complete block design as follows:

1. Thirty entries in 1976-77 with three replications at Stillwater.

2. Thirty entries in 1977-78 with three replications each at Stillwater and Lahoma.

3. Thirty entries in 1978-79 with four replications each at Stillwater and Lahoma (four entries in 1979, Stillwater, were eliminated because of late maturity). The cultivars used for each experiment were different in different years.

Each entry consisted of four 3-meter rows, with the rows being 30 cm apart. Grain yield and the three major components of yield, namely fertile tiller number per unit area, the average number of kernels per spike, and the average kernel weight, were measured as follows:

Tiller Number - Number of seed-bearing tillers along a random section of 900 cm^2. Two samples were taken from each entry.

Number of Kernels per Spike - Six randomly selected spikes from each plot were threshed separately and the kernels were counted.

Kernel Weight - The number of kernels obtained from the six spikes above and their weights were used to estimate the average kernel weight, expressed as weight (grams) per 1000 kernels.

Grain Yield - Plants in a 30-cm section at each end of the two center rows were discarded to eliminate possible border effects. The remaining 1.49 M^2 were harvested.

Analysis Procedure

An analysis of variance was carried out for yield and the yield components at each location separately. Two different methods of analysis were employed to attempt to identify superior yielding crosses among the cultivars. One method was discriminant analysis and the other was the determination of genetic divergence using Mahalonobis' D^2 measure. For each location and year, a discriminant analysis was used. The objective of the analysis is to obtain a discriminant function which is a linear combination of the components, to be used for classifying cultivars and their potential crosses into high, medium, or low yield groups. Linear discriminant analysis was developed by Fisher (7) for two-group classification. In such a case, there are two populations or groups and a set of P variables (X_1, X_2, . . ., X_p) associated with the individuals in each population. The population discriminant function is a score or index (Z) obtained as a linear combination of the variables:

$$Z = a_1x_1 + a_2x_2 \; . \; . \; . + a_px_p$$

The a's are determined in order to maximize the probability of correctly identifying the group membership of an individual. When a sample of individuals from each population is available, the a's are estimated by maximizing D^2/SS_w where D is the difference between mean Z scores of the samples, and SS_w is the pooled within-sample sum of squares of the Z scores.

If more than two populations are considered, the a's are estimated by maximizing $\frac{SS_a}{SS_w}$ where SS_a and SS_w are the sum of squares among and within groups, respectively (16).

To employ discriminant analysis, the group of cultivars in each experiment was partitioned into high, medium, and low yield groups based on observed mean yields over replications. Discriminant weights were determined as described above. The resultant discriminant function is represented as

$$\text{Score} = Z = a_1(\text{TLR}) + a_2(\text{kernels/spike}) + a_3(\text{Kwt})$$

The amount of contribution by each component to the score is represented by the a value. Another factor influencing variation in score is the amount of variability for each single component, more variability indicating more contribution.

Subsequent to the determination of the discriminant function, this function was used to predict the scores of all two-way and three-way crosses among the cultivars. To do this, it was assumed that gene actions of the yield components is additive, i.e., there is no dominance and no epistasis. Thus, the value of a yield component in a two-way cross was taken to be the average of the component values in the two parental cultivars. However, discriminant function was applied to the highest component of either parents to determine the score for that cross. It was assumed that by selecting in the further generations the high value of yield component would be recovered.

There is no assurance that the population discriminant function will result in a more correct classification method than simply using a random allocation method. This was investigated by using Wilks' likelihood ratio test for significance of the discriminant function. The sample discriminant function was applied as described previously only when it was found to be significant.

The second method used is Mahalanobis' generalized distance D^2, applied to 1979 experiments only. The application of the D^2 statistic is to measure the degree of divergence for individual characters or the pooled effect of several characters. Based on genetic diversity, a crossing program between genotypes may be initiated. The approach is based on the assumption that the best crosses are between parents showing the maximum genetic divergence. Genetic diversity between two genotypes is measured by

$$D^2 = (U_1 - U_2)'\Sigma^{-1} (U_1 - U_2)$$

where U_1 is a vector with three elements, each representing the average of one yield component in a cultivar. U_2 is defined similarly for a second cultivar. Σ is a symetric 3X3 genotypic variance, covariance matrix. Since the phenotypic variance (σ_P^2) is made up of genotypic (σ_G^2) and environmental (σ_E^2) components, then $\sigma_P^2 = \sigma_G^2 + \sigma_E^2$ (10). In estimating the variance, covariance components the expected entry mean square and mean products were partitioned as follows:

$$E[\text{entry (M.S.)}] = \text{error (M.S.)} + 4 \text{ entry (M.S.)} = \sigma_E^2 + 4\sigma_G^2$$

$$E[\text{entry (M.P.)}] = \text{error (M.P.)} + 4 \text{ entry (M.P.)} = \sigma_{GaGb} + 4\sigma^2_{Ga + Gb}$$

where σ_{GaGb} = the covariance of two characters, a and b. $\sigma^2_{Ga + Gb}$ = the joint genotypic variance of characters a and b. The genetic diversity was measured between any two cultivars by D^2, as mentioned above. Cultivars were grouped into a number of clusters, D^2 being treated as the square of generalized distance according to the method described by Tocher as cited by Rao (16).

CHAPTER IV

RESULTS AND DISCUSSION

Analysis of Variance

The average yield and yield components for different years and locations are shown in Tables I, II, III, IV, and V. Before using any of the approaches, it is necessary to first find out if the cultivars differ significantly among themselves with respect to yield components. The analysis of variance corresponding to each character for all experiments (Table VI) shows significant differences among entries at the 0.01 level of probability.

Discriminant Function Analysis

Genotypes were classified into high, medium, and low groups on the basis of observed mean yield over replications (Tables I, II, III, IV, and V) in order to obtain a discriminant function and evaluate their potential in crosses. The discriminant weights (a-values) were estimated by maximizing $\lambda = \frac{SS_a}{SS_w}$, where SS_a and SS_w are the sum of squares among and within group (Appendix A). The λ value (discriminant criterion) for each experiment is shown in Table VII. The significance of λ was tested using Wilks' likelihood ration criterion to determine if it was statistically different from zero. If λ is different from zero, it will permit the conclusion that the groups differ significantly on the basis of linear combination, Z, associated with λ. A V statistic corresponding to each λ value was computed according to Appendix A, and V's were treated as χ^2 with 6 d.f. The results of this test for all experiments show that the discriminant criterion (λ) for 1978 Stillwater and 1979 Lahoma are significant (Table VII). Therefore the three groups of high, medium, and low can be differentiated for the two above experiments on the basis of discriminant function. The λ values for the rest of the experiments are not sufficient to classify groups significantly. The λ value for 1978 Stillwater is 0.8159 (Table VII) while its V value (16.406) is significant at 0.025 level of probability. The discriminant weights (a-values) associated with each discriminant criterion λ were computed as explained in Appendix A, and the results are shown in Table VII. The score of Z value may be written as

$$\text{Score} = Z = 0.0292(\text{TLR}) + 0.0640(\text{seeds/spike}) + 0.0546(\text{Kwt})$$

The contribution of seeds per spike and kernel weight dominate the function, while the tiller number makes a lower contribution. Any cultivar now may be classified to the proper group by computing its score (assuming that it belongs to one of these groups).

For predicting the scores of all the two-way and three-way crosses among the cultivars, the discriminant function was applied to the highest component values of the parent in a cross. Among the 435 possible hybrids involving the 30 cultivars, those with the highest scores belong to the high group and would be promising. The top 30 scores for hybrids are shown in Table VIII. The hybrid obtained by crossing

Lovrin 6 (P16)* and F23-71 (P17) has the highest score. Table III shows that the yield components for the above cultivars are:

Name	TLR	Seeds/spike	Kwt	Index score
Lovrin 6	33	27	46	5.203
F23-71	29	43	31	5.291

The score for hybrid obtained by these two parents is computed as follows:

$$\text{Score} = Z = 0.0292(33) + 0.064(43) + 0.0546(46) = 6.239$$

The discriminant weights (a-values) associated with tiller number (0.0292), seeds per spike (0.064) and kernel weight (0.0546) are each multiplied by the highest corresponding component among the two parents. Since it was assumed that the gene action is additive, the discriminant weights should, in fact, be multiplied by the average of component values in the two parental cultivars, but by selecting in the hybrid population, the high value of yield components would be recovered. The hybrid obtained by Lovrin 6 (P16)* X TX71A562-6 (P26) has the second highest score, since the kernel weight of Lovrin 6 and seeds per spike of TX71A562-6 (P26) (Table III) are high. Meanwhile the tiller number of TX71A562-6 (P26) is intermediate and would be partly responsible for the high score. The hybrid score then may be shown as

$$\text{Score} = Z = 0.0292(40) + 0.064(39) + 0.0546(46) = 6.186$$

Tam W-101 (P2) is relatively high in tiller number (Table III) and

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*P in parentheses refers to parent number in Table VIII.

intermediate in kernel weight, and F23-71 (P17)* has the highest number of seeds per spike. The hybrid obtained by these two cultivars has the fourth highest score. Lovrin 6 (P16) with the highest kernel weight may combine with parents high in seeds per spike and tiller number such as Vona (P13), Tam W-102 (P21), and WA5829 (P24) to give high scores. Tam W-101)P2) is relatively high in tiller number and intermediate in kernel weight, but low in number of seeds per spike. The complementary parents are relatively high in number of seeds per spike, such as F23-71 (P17), Gurgas 2 (P11), Tam W-102 (P21), TX71A562-6 (P26), Vona (P13), and WA5829 (P24). Based on discriminant function associated with 1978 Stillwater and Table VIII, parents high in number of seeds per spike and/or kernel weight, such as Lovrin 6 (P16) and F23-71 (P17), would contribute in many of the top crosses.

The three-way crosses for 1978 Stillwater are shown in Table VIII. Lovrin 6 (P16), F23-71 (P17), and Tam W-103 (P27) combine to give the maximum score value. Their yield components are as follows (Table III):

Parent	TLR	Seeds/Spike	Kwt	Score
Lovrin 6	33	27	46	5.203
F23-71	29	43	31	5.291
Tam W-103	56	29	29	5.075

The score value is computed as

$$\text{Score} = Z = 0.0292(56) + 0.064(43) + 0.0546(46) = 6.9$$

Osage (P1) is second highest in tiller number (Table II) and

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*P in parentheses refers to parent number in Table VIII.

combines with Lovrin 6 (P16)* and F23 (P17) to give the second highest score. The next highest score is obtained by combining Lovrin 6 (P16), Plainsman V (P19) and F23-71 (P17), which are high in kernal weight, tiller number and seeds per spike, respectively.

Comparing parents involved in top two-way and three-way crosses (Table VIII), it is realized that cultivars classified as good parents for two-way crosses were also involved in top three-way crosses.

Cultivars used in 1979 Lahoma (Table IV) are not the same as 1978 Stillwater, but several of them occur in both nurseries. Parents 10, 18, 19, 20, 21, 22, 23, 24, 25, and 30 occur in 1978 Stillwater, but not in 1979 Lahoma. Conversely, parents 31 through 40 occur in 1979 Lahoma, but not in 1978 Stillwater (Tables III and IV).

The λ value (Table VII) for 1979 Lahoma (0.6739) was tested using Wilks' likelihood ratio test criterion (Appendix A). The related V value (14.326) was treated as χ^2 with 6 d.f. and it was significant at the .05 level of probability (Table VII). Discriminant weights were computed according to the illustration in Appendix A and

$$\text{Score} = Z = 0.0165(\text{TLR}) + 0.06104(\text{seeds/spike}) + 0.0239(\text{Kwt})$$

The contribution of seeds per spike dominates the function and kernel weight is second in this position. Compared to discriminant function associated with 1978 Stillwater, the discriminant weight (a values) corresponding to kernel weight is considerably lower.

The top 30 two-way crosses are shown in Table IX. The best

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*P in parentheses refers to parent number in Table VIII.

combination is F23-71 (P17)** and Tam W-101 (P2), which are high in number of seeds per spike and number of tillers, respectively (Table IV). F23-71 (P17) also combined with Lovrin 6/T-W-101F6 (P32), high in tiller number and kernel weight, to give the second highest score. Tam W-101 (P2), which is high in tiller number and kernel weight (Table IV), combined with NR31-74 (P28) and NR 391-76 (P38), high in number of seeds per spike, and resulted in the third and fourth highest scores (Table IX). Vona (P13), which is relatively high in tiller number and number of seeds per spike (Table IV), was also classified as a good parent. Tam W-103 (P27), high in tiller number, was combined with cultivars high in kernel weight and/or number of seeds per spike, such as F23-71 (P17), Lovrin 6 (P16) and Priboy (P6) to give relatively high scores (Table IX).

The three-way crosses for 1979 Lahoma is shown in Table IX, and they may be evaluated with the same reasoning. Lovrin 6 (P16), F23-71 (P17), and Tam W-103 (P27) have the highest kernel weight, number of seeds per spike, and tiller number, respectively (Table V). A three-way cross between these three cultivars gives the highest score. Tam W-103 (P27) and F23-71 (P17) may also combine with Lovrin 5/T-W-101F6 (P32), high in kernel weight, to give the same score. The combination of Tam W-101(P2)(high in tiller number), Lovrin 6 (P16)(high in kernel weight), and F23-71 (P17)(high in number of seeds per spike) was classified as good, three-way cross (Tables IV and IX).

A comparison between Tables VIII and IX shows that results of 1978 Stillwater are in general agreement with the 1979 Lahoma experiment. Lovrin 6 (P16), F23-71 (P17), and Tam W-103 (P27) contributed in the

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**P in parentheses refers to parent number in Table IX.

top score crosses in both experiments. Tam W-101 (P2) and Vona (P13)** were also classified as good parents.

Parental stocks giving a high hybrid score do not all need to be from the high yielding group. The combination of Tam W-103 (P27) Lovrin 6 (P16), and F23-71 (P17), which give the highest three-way cross score for both experiments, were from high, medium, and low yield groups, respectively. In a multiple comparison computed separately, these cultivars were significantly different in respect to yield.

D^2 Generalized Distance

The name and origin of cultivars used in 1979 for two locations are shown in Tables IV and V. Four cultivars with late maturity were not used in the Stillwater location. The D^2 statistic was used to measure the genetic divergence for the pooled effect of the three yield components. There are other characters contributing to genetic diversity in wheat, such as height, date of maturity, etc.; however, the yield components would give a good estimate of genetic diversity.

The Σ used for estimating genetic diversity was a 3X3 genotypic variance, covariance matrix as follows:

$$\Sigma = \begin{pmatrix} \sigma^2_{Gs} & \sigma_{GsGk} & \sigma_{GsGt} \\ & \sigma^2_{Gk} & \sigma_{GkGt} \\ & & \sigma^2_{Gt} \end{pmatrix}$$

where σ^2_{Gs}, σ^2_{Gk}, and σ^2_{Gt} are the genotypic variances for number of seeds per spike, kernel weight, and tiller number, respectively. σ_{GsGk},

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**P in parentheses refers to parent number in Table IX.

σ_{GsGk}, σ_{GsGt}, and σ_{GkGt} are the tenotypic covariances between each pair of components. The value for the genotypic variances and covariances are as follows:

	σ^2_{Gs}	σ^2_{Gk}	σ^2_{Gt}	σ_{GsGk}	σ_{GsGt}	σ_{GkGt}
Stillwater	21.19	34.42	51.81	-6.38	-13.24	-27.24
Lahoma	27.15	28.26	58.44	-9.98	-18.70	-17.57

All of the genotypic covariances are negative, indicating that variations of any two components are in the opposite direction.

The estimate of genetic diversity for each pair of cultivars was computed for 1979 Lahoma; the results are shown in Appendix B (Table XII). The 435 possible distances between the 30 cultivars are arranged in increased order of magnitude with respect to each cultivar. Cultivars in each experiment were grouped into a number of clusters, D^2 being treated as the squared generalized distance according to the method described by Tocher as cited by Rao (16). Rao (16) stated that there is no formal rule for finding the clusters because a cluster is not a well-defined term. The only criterion appears to be that any two groups belonging to the same cluster should, at least on the average, show a smaller D^2 than do those belonging to two different clusters. Based on these estimates of genetic divergence, the 30 cultivars in 1979 experiment could be grouped into nine clusters as follows:

1. Turkey, Triumph 64, Scout 66, Osage, Sturdy, Newton, TX71A562-6, TXR-Line 344-6, Dekalb 589, Pioneer HR940, Hart, and OK77827.

2. Bezostaia 1, Odesskaya 51, Burgas 2, Sodova I, NR173-75, and Russian.

3. Priboy and Lovrin 6/T-W-101F6.

4. Tam W-101.

5. NR72-837.

6. Lovrin 6.

7. F23-71 and NR391-76.

8. Vona, Payne, Tam W-103, and MS Tam 103/TXR 344-6F1.

9. NR31-74.

Tam W-101, NR72-837, Lovrin 6, and NR31-74 made single-cultivar clusters. Cluster 1 consisted of 12 cultivars, all originating from the U.S.A. except Turkey. Turkey may have been involved as parental stock for developing other members of the group. Cluster 2 consisted of six cultivars originating from the U.S.S.R., Bulgaria, and Austria. Cluster 3 consisted of two cultivars, one originating from the U.S.S.R., and one developed by the cross between two cultivars from the U.S.S.R. and U.S.A. The two cultivars in cluster 7 originated from Romania and Austria. Cluster 8 had four cultivars, all originated from the U.S.A.

The pattern of cultivars in different clusters shows that cultivars originated from the U.S.A. were all grouped into two clusters (1 and 8). This is not in agreement with some of the reports (2, 3, 4) that genetic diversity is not related to geographical distribution. On the other hand, the four cultivars that originated from Austria (NR72-837, NR31-74, NR173-75, and NR391-76) were in four different clusters (2, 5, 7, and 9), and the four cultivars that originated from the U.S.S.R. (Bezostaia I, Odesskaya 51, Russian, and Priboy) were in two different clusters. It may be interpreted that cultivars in one cluster are related to each other by a combination of factors. Somayajulu et al. (20) claimed that pedigree relationship, geographical distribution, and similarity in characters contributing to genetic diversity are three important factors in this respect.

The intra- and inter-cluster average D^2 values for 1979 Lahoma are shown in Table X. The largest distance is between clusters 4 (Tam W-101) and 5 (NR72-837). The second and third large D^2 values are between clusters 3 (Priboy and Lovrin 6/T-W-101F6 and 5 (NR72-837) and 4 (Tam W-101) and 7 (F23-71 and NR391-76). Hybrids developed by crossing members of corresponding groups should give promising results. Bhatt (4) stated that in choosing among the genotypes of a cluster, other practical considerations, such as disease reaction, quality and lodging, should be taken into account. Other clusters with high distances are 5 (NR72-837) and 9 (NR31-74), 5 (NR72-837) and 6 (Lovrin 6), and 6 (Lovrin 6) and 8 (Vona, Payne, Tam W-103, and MS Tam 103/TXR 344-6F1). These results are generally in agreement with the discriminant function analysis.

The generalized distance for each pair of cultivars grown at Stillwater in 1979 are shown in Appendix B (Table XIII). Based on these distances, all 26 cultivars were grouped into nine clusters as follows:

1. Sturdy, Burgas 2, TXR-line 344-6, and OK77827.
2. Bezostaia 1, Priboy, Sadova 1, Lovrin 6/T-W-101F6, NR173-75, and Russian.
3. Triumph 64.
4. Scout 66, Tam W-101, and Hart.
5. TX71A562-6.
6. Lovrin 6.
7. NR391-76.
8. Vona, Payne, Tam W-103, Osage, Newton, MS Tam 103/TXR344-6F1, and Dekalb 589.
9. Odesskaya 51, and NR31-74.

Four cultivars (Triumph 64, TX71A562-6, Lovrin 6, and NR391-76) made single-genotype clusters. Cluster 1 had four cultivars originating from the U.S.A. and Bulgaria. The six cultivars in cluster 2 originated from the U.S.S.R., Austria, Bulgaria, and the U.S.A. The three cultivars in cluster 4 and seven cultivars in cluster 8 were all originated from the U.S.A. This may indicate the pedigree relationship between the members of each cluster. Cluster 9 had two cultivars originated from the U.S.S.R. and Austria. The distribution of cultivars in different clusters shows that geographical diversity may be one of the factors grouping cultivars in the same cluster.

Comparison of cluster composition between Lahoma and Stillwater shows that some of the cultivars grouped together in both locations. Clusters 1 and 2 in Lahoma and Stillwater have three and four cultivars in common, respectively. The only cultivar which made single-genotype cluster in both locations was Lovrin 6. Cultivars in cluster 8 Lahoma were all in cluster 8 from Stillwater.

The intra- and inter-cluster average D^2 for 1979 Stillwater is shown in Table XI. Clusters 3 (Triumph 64) and 7 (NR319-76) had the largest distance followed by clusters 1 (Sturdy, Burgas 2, TXR-line 344-6, and OK77827) and 5 (TX71A562-6). Crosses between members of corresponding clusters should be promising. Other clusters with high distances are 1 (Sturdy, Burgas 2, TXR-line 344-6, and OK77827) and 7 (NR391-76), and 3 (Triumph 64) and 5 (TX71A562-6.

CHAPTER V

SUMMARY AND CONCLUSIONS

The material for the present study was taken from a cultivar performance trial with 26-30 cultivars. The experiment was conducted at Stillwater, Oklahoma, during 1976-77 and at two locations--Stillwater and Lahoma, Oklahoma--during 1977-1978 and 1978-79. All of the experiments were laid out in a randomized complete block design with three replications during 1976-77 and 1977-78, and four replications during 1978-79. Cultivars used for each experiment were different in different years. Four cultivars were eliminated from the Stillwater location during 1978-79 because of later maturity.

The characters chosen for study were yield and yield components, viz., number of tillers per unit area, number of seeds per spike, and kernel weight. Before using any of the techniques, it was necessary to determine if the cultivars differed significantly among themselves with respect to yield components. This was tested by analysis of variance for each component. The results of this test showed that cultivars differ significantly with respect to each component. Two methods of choosing parents for hybridization aiming at yield improvement were discussed. In the first approach, a discriminant function analysis, as developed by Fisher, was applied. To employ discriminant analysis, the group of cultivars in each experiment was partitioned into high, medium, and low-yield groups based on observed mean yields over replication. A discriminant function was computed for each experiment and its significance was tested by Wilks' likelihood ratio criterion.

Two discriminant functions corresponding to 1978 Stillwater and 1979 Lahoma were significant. The discriminant weights (a-values) were determined and the resultant discriminant functions for 1978 Stillwater and 1979 Lahoma were

$$\text{Score} = Z = 0.0292(\text{TLR}) + 0.0640(\text{seeds/spike}) + 0.0546(\text{Kwt})$$

$$\text{Score} = Z = 0.0165(\text{TLR}) + 0.06104(\text{seeds/spike}) + 0.0239(\text{Kwt})$$

respectively. The order of contribution of yield components in both experiments were seeds per spike, kernel weight, and tiller number. For predicting the scores of all of the two-way and three-way crosses among the cultivars, the discriminant function was applied to the highest component values of either parents. Since it was assumed that the gene action is additive, i.e., there is no dominance and no epistasis, the discriminant function should, in fact, be applied to the average of component values in the parental cultivars. Thus, it is also assumed that by selecting in the further generations the high values of yield components would be recovered. Cultivars involved in top two-way crosses were also involved in top three-way crosses in both locations. These genotypes were more often high in number of seeds per spike and/or kernel weight.

Besides the distinct differences between the two locations, the results of 1978 Stillwater were in general agreement with the 1979 Lahoma results. Cultivars classified as good parents in two-way and three-way crosses were from different yielding groups (high, medium, low), indicating that parental materials chosen on only one single complex character such as yield may not necessarily provide transgressive segregates for yield potential. The reliability of this procedure may be determined by making crosses predicted to be promising.

The second method applied was Mahhalanobis' generalized distance known to be effective in measuring the degree of divergence for individual character or pooled effect of several characters. Genetic diversity measured by this approach was based on three characters (yield components). There are other characters contributing to genetic diversity in wheat, such as height, date of heading, date of maturity, etc.; however, the yield components would give a good estimate of genetic diversity. D^2 distance, which is closely related to discriminant function, was used only for 1979 Stillwater and 1979 Lahoma.

The amount of divergence based on the yield components was computed for each genotype, and the closely related cultivars as expressed by their distance were grouped together according to the method described by Tocher. The analysis of inter-cluster and intra-cluster average D^2 values showed that the cultivars in each location could be grouped into nine clusters. Four cultivars classified as more divergent in each location made single-cultivar clusters. Lovrin 6 was the only single-cultivar cluster in both locations. A comparison of cluster composition between Lahoma and Stillwater showed that some genotypes grouped together in both locations.

Cultivars grouped together more often originated from the same ecological area, indicating that geographical distribution could be one of the factors influencing genetic diversity. A close study of other cultivars grouped together indicated that pedigree relationship and similarity in characters contributing to genetic diversity may be other factors influencing diversity.

The results of 1979 Lahoma were in general agreement with the discriminant function analysis. A study of genotypic covariances for yield components showed that all of the covariances were negative. This indicates that yield components are not mutually independent, and that an increase in one could be accompanied by a decrease in another.

TABLE I

AVERAGE YIELD AND YIELD COMPONENTS FOR ENTRIES GROWN IN 1977, STILLWATER

Parent No.	Entry	Tiller (no./900 cm^2)	Seeds/ Spike	Kernel Weight (gm/1000 seeds)	Yield* (gm/plot)
1	Osage	52	35	37	493.33
2	Tam W-101	60	29	41	558.33
3	Centurk	68	38	31	476.67
4	Bezostaia 1	49	39	43	566.67
5	F26-70	37	46	43	525.00
6	Odesskaya 51	54	38	41	520.00
7	Turkey	63	34	34	403.33
8	Scout 66	62	31	38	426.67
9	Triumph 64	62	32	39	471.67
10	Lovrin 6	41	35	54	491.67
11	Burgas 2	37	46	42	536.67
12	Dwarf Bezostaia	45	44	36	545.00
13	Newton	66	43	31	543.33
14	Trison	54	31	40	521.67
15	Vona	68	43	32	628.33
16	David	51	43	31	435.00
17	NR31-74	53	43	36	601.67
18	Predgornia	34	44	47	570.00
19	Payne	53	41	31	473.33
20	TX69A 330-1	73	38	32	535.00
21	Tam W-103	84	38	31	586.67
22	David 10	55	40	34	521.67
23	NR173-75	43	35	44	620.00
24	F23-71	40	53	41	433.33
25	Sturdy	54	39	33	495.00
26	OK711248-1	52	39	37	485.00
27	Tam W-102	48	58	29	491.67
28	Oasis	52	36	39	545.00
29	TRS 237	43	29	42	456.67
30	Blueboy	47	42	35	553.33

* High group included parents with yields greater than 540 grams/plot, medium group between 495 and 540 grams/plot, and low group less than 490 grams/plot.

TABLE II

AVERAGE YIELD AND YIELD COMPONENTS FOR ENTRIES GROWN IN 1978, LAHOMA

Parent No.	Entry	Tiller (no./900 cm^2)	Seeds/ Spike	Kernel Weight (gm/1000 seeds)	Yield* (gm/plot)
1	Osage	39	29	32	465.00
2	Tam W-101	48	21	39	500.00
3	Sturdy	32	32	35	433.33
4	Bezostaia 1	26	32	37	450.00
5	Odesskaya	43	29	36	515.00
6	Priboy	34	29	38	490.00
7	Turkey	44	27	30	325.00
8	Scout 66	48	25	35	405.00
9	Triumph 64	45	22	38	448.33
10	Predgornia	25	35	36	398.33
11	Burgas 2	28	35	34	495.00
12	Sadova I	36	26	39	523.33
13	Vona	44	33	28	478.33
14	Newton	35	34	30	450.00
15	Payne	38	32	29	466.67
16	Lovrin 6	30	22	48	386.67
17	F23-71	29	42	33	341.67
18	Blueboy	38	35	32	450.00
19	Plainsman V	49	25	32	470.00
20	OK711248-176	45	26	30	435.00
21	Tam W-102	29	41	22	341.67
22	BPS	41	27	30	371.67
23	TRS237	30	27	35	345.00
24	WA5829	40	26	17	110.00
25	OK72271	46	28	33	463.33
26	TX71A562-6	37	32	28	433.33
27	Tam W-103	42	28	26	425.00
28	NR31-74	33	35	29	430.00
29	NR173-75	31	32	37	468.33
30	David	39	30	28	323.33

* High group includes parents with yields greater than 460 gm/plot, medium group between 420 and 460 gm/plot, and low group less than 420 gm/plot.

TABLE III

AVERAGE YIELD AND YIELD COMPONENTS FOR ENTRIES GROWN IN 1978, STILLWATER

Parent No.	Entry	Tiller (No./900 cm^2)	Seeds/ Spike	Kernel Weight (gm/1000 seeds)	Yield* (gm/plot)
1	Osage	49	28	30	278.33
2	Tam W-101	47	24	37	311.67
3	Sturdy	37	31	30	273.33
4	Bezostaia 1	29	31	35	230.00
5	Odesskaya	37	32	37	283.33
6	Priboy	40	33	38	293.33
7	Turkey	40	38	29	220.00
8	Scout 66	44	27	33	255.00
9	Triumph 64	44	27	35	283.33
10	Predgornia	29	31	36	231.67
11	Burgas 2	32	39	32	306.67
12	Sadova I	30	32	38	256.67
13	Vona	40	38	29	308.33
14	Newton	42	34	32	305.00
15	Payne	37	33	27	291.67
16	Lovrin 6	33	27	46	291.67
17	F23-71	29	43	31	301.67
18	Blueboy	33	35	32	273.33
19	Plainsman V	48	27	29	273.33
20	OK711248-176	44	30	31	313.33
21	Tam W-102	36	39	25	286.67
22	BPS	45	24	31	221.67
23	TRS237	26	31	30	205.00
24	WA5829	38	38	22	233.33
25	OK72271	44	30	33	268.33
26	TX71A562-6	40	39	30	355.00
27	Tam W-103	56	29	29	246.67
28	NR31-74	34	34	20	245.00
29	NR173-75	34	32	32	218.33
30	David	38	31	28	283.33

* High group includes parents with yield greater than 290 gm/plot, medium group between 250 and 290 gm/plot, and low group less than 250 gm/plot.

TABLE IV

ORIGIN AVERAGE YIELD AND YIELD COMPONENTS FOR ENTRIES GROWN IN 1979, LAHOMA

Parent No.	Entry	Origin	Tiller (No./ 900 cm^2)	Seeds per Spike	Kernel Weight (gm/ 1000 seeds)	Yield* (gm/ plot)
7	Turkey	Turkey	70	30	30	418.75
9	Triumph 64	USA (OK)	61	24	37	452.50
8	Scout 66	USA (NB)	66	25	36	475.75
4	Bezostaia 1	USSR	47	34	40	473.75
5	Odesskaya 51	USSR	55	31	41	462.60
6	Priboy	USSR	57	30	45	457.50
1	Osage	USA (OK)	63	31	33	488.75
3	Sturdy	USA (TX)	59	34	32	505.00
2	Tam W-101	USA (TX)	73	23	43	665.00
11	Burgas 2	Bulgaria	54	32	38	571.25
12	Sadovo 1	Bulgaria	48	29	44	498.75
31	NR72-837	Austria	51	38	29	480.00
13	Vona	USA	67	36	28	636.25
14	Newton	USA (KS)	58	33	35	545.00
15	Payne	USA (OK	72	30	32	600.25
16	Lovrin 6	Romania	50	27	47	492.50
17	F23-71	Romania	44	46	36	437.50
32	Lovrin 6/T-W-101F6	Rom./USA	62	25	47	473.75
26	TX71A562-6	USA (TX)	60	34	33	608.75
27	TAM W-103	USA (TX)	75	30	30	543.75
33	MS TAM 103/ TXR344-6 F1	USA	67	34	34	576.25
34	TXR-Line 344-6	USA (TX)	63	30	32	501.25
35	Dekalb 589	USA	58	24	39	437.50
36	Pioneer HR940	USA	70	25	36	438.75
37	Hart	USA (MO)	65	25	37	453.75
28	NR31/74	Austria	62	39	34	472.50
29	NR173/75	Austria	51	34	39	497.50
38	NR391/76	Austria	49	40	38	501.25
39	Russian	USSR	57	32	39	441.25
40	OK77827	USA (OK)	62	32	28	415.00

* High group includes parents with yield greater than 530 grams/plot, medium group between 460 and 530 grams/plot, and low group less than 460 grams/plot.

TABLE V

ORIGIN, AVERAGE YIELD, AND YIELD COMPONENTS FOR ENTRIES GROWN IN 1979, STILLWATER

Parent No.	Entry	Origin	Tiller (No./ 900 cm^2)	Seeds per Spike	Kernel Weight (gm/ 1000 seeds)	Yield* (gm/ plot)
9	Triumph 64	USA (OK)	50	34	38	618.75
8	Scout 66	USA (NB)	62	33	38	683.75
4	Bezostaia 1	USSR	41	43	41	695.00
5	Odesskaya 51	USSR	49	43	41	708.75
6	Priboy	USSR	44	38	44	720.00
1	Osage	USA (OK)	54	42	34	630.00
3	Sturdy	USA (TX)	50	40	32	591.25
2	TAM W-101	USA (TX)	63	32	41	692.50
11	Burgas 2	Bulgaria	37	43	38	656.25
12	Sadova I	Bulgaria	40	38	48	645.00
13	Vona	USA	59	43	31	705.00
14	Newton	USA	55	45	32	672.50
15	Payne	USA (OK)	55	41	30	567.50
16	Lovrin 6	Romania	46	37	51	735.00
32	Lovrin 6/T-W-101F6	Rom./USA	50	35	45	671.25
26	TX71A562-6	USA (TX)	63	44	32	725.00
27	TAM W-103	USA (TX)	59	41	31	636.25
33	MS TAM 103/ TXR344-6 F1	USA	50	42	35	681.25
34	TXR-Line 344-6	USA (TX)	46	40	33	525.00
35	Dekalb 589	USA	49	40	38	638.75
37	Hart	USA (MO)	59	37	37	736.25
28	NR31/74	Austria	52	46	36	751.25
29	NR173/75	Austria	37	45	42	721.25
38	NR391/76	Austria	40	54	40	786.25
39	Russian	USSR	44	41	42	702.50
40	OK77827	USA (OK)	56	41	26	327.50

* High group includes parents with yields greater than 715 grams/plot, medium group between 625 and 715 grams/plot, and low group less than 625 grams/plot.

TABLE VI

MEAN SQUARES FOR TILLER NUMBER, SEEDS PER SPIKE, KERNEL WEIGHT AND YIELD FOR 1977, STILLWATER AND 1978 AND 1979, LAHOMA AND STILLWATER

Year	Location	TLR	Seeds/Spike	Kwt	Yield
1977	Stillwater	395.60**	129.49**	101.12**	19714.80**
1978	Lahoma	151.14**	76.19**	98.02**	19376.25**
	Stillwater	149.29**	65.28**	61.80**	3716.87**
1979	Lahoma	537.90**	684.37**	698.34**	16879.16**
	Stillwater	497.33**	558.73**	842.50**	32453.24**

** Significant at the 0.01 level of probability.

TABLE VII

THE CHARACTERISTIC ROOTS, CHARACTERISTIC VECTORS AND V VALUES FOR ALL YEARS AND LOCATIONS

Year and Location	Characteristic root (λ)	Characteristic Vectors (a-values)			V
		Tiller No. (a_1)	Seeds/ Spike (a_2)	Kernel Weight (a_3)	
1977 Stillwater	.0310	0.0175	0.0342	0.0486	7.67
1978 Stillwater	.8159	0.0292	0.0640	0.0546	16.406*
1978 Lahoma	.2631	0.0371	0.0366	0.0378	6.318
1979 Stillwater	0.148	0.0056	0.0086	-0.0054	4.483
1979 Lahoma	.6739	0.0165	0.06104	0.0238	14.326**

* Significant at the .025 level of probability.
**Significant at the .05 level of probability.

TABLE VIII

THE 30 TOP TWO-WAY AND THREE-WAY CROSS SCORES FOR 1978 STILLWATER

Two-Way Crosses				Three-Way Crosses				
Rank	Parents*		Index Score	Rank	Parents*			Index Score
1	16	17	6.239	1	16	17	27	6.906
2	16	26	6.186	2	1	16	17	6.703
3	13	16	6.150	3	16	19	17	6.674
4	2	17	6.122	4	11	16	27	6.650
5	16	21	6.081	5	16	21	27	6.650
6	16	24	6.070	6	16	26	27	6.650
7	16	27	6.064	7	2	16	17	6.645
8	17	27	6.010	8	16	22	17	6.587
9	11	16	6.002	9	13	16	27	6.586
10	6	17	5.983	10	16	24	27	6.586
11	14	16	5.953	11	8	16	17	6.558
12	9	17	5.924	12	9	16	17	6.558
13	2	11	5.894	13	16	20	17	6.558
14	2	21	5.894	14	16	25	17	6.558
15	2	26	5.894	15	14	16	17	6.500
16	6	16	5.880	16	6	17	27	6.466
17	6	27	5.878	17	12	17	27	6.466
18	11	27	5.860	18	1	11	16	6.447
19	1	16	5.849	19	1	26	16	6.447
20	1	17	5.843	20	6	16	17	6.442
21	2	13	5.843	21	7	16	17	6.442
22	2	24	5.830	22	13	17	16	6.442
23	5	17	5.830	23	17	26	16	6.442
24	8	17	5.826	24	11	19	16	6.418
25	12	27	5.802	25	19	21	16	6.418
26	16	20	5.770	26	19	26	16	6.418
27	16	25	5.762	27	2	27	17	6.411
28	17	19	5.762	28	5	17	27	6.411
29	17	25	5.746	29	16	18	27	6.394
30	15	16	5.746	30	2	11	16	6.389

* Numbers used as parents represent the entry number.

TABLE IX

THE 30 TOP TWO-WAY AND THREE-WAY CROSS SCORES FOR 1979 LAHOMA

Two-Way Crosses				Three-Way Crosses				
Rank	Parents*		Index Score	Rank	Parents*			Index Score
1	2	17	5.012	1	16	17	27	5.241
2	17	32	4.975	2	17	32	27	5.241
3	2	38	4.817	3	2	16	17	5.200
4	2	28	4.785	4	2	32	17	5.200
5	32	38	4.780	5	15	16	17	5.180
6	6	17	4.778	6	15	32	17	5.180
7	13	16	4.752	7	6	17	27	5.147
8	13	32	4.752	8	7	16	17	5.139
9	2	31	4.752	9	7	32	17	5.139
10	16	28	4.747	10	16	36	17	5.139
11	32	28	4.747	11	32	36	17	5.139
12	16	17	4.729	12	6	2	17	5.106
13	17	27	4.724	13	12	17	27	5.100
14	16	27	4.721	14	6	15	17	5.086
15	32	27	4.721	15	13	16	17	5.077
16	31	32	4.715	16	13	32	17	5.077
17	2	13	4.687	17	16	33	17	5.077
18	16	33	4.687	18	32	33	17	5.077
19	32	33	4.687	19	2	12	17	5.059
20	15	17	4.663	20	8	16	17	5.057
21	15	16	4.660	21	8	32	17	5.057
22	15	32	4.660	22	2	27	17	5.053
23	6	13	4.658	23	16	38	27	5.046
24	6	28	4.653	24	32	38	27	5.046
25	6	27	4.627	25	7	6	17	5.045
26	27	38	4.623	26	6	36	17	5.045
27	4	2	4.622	27	12	15	17	5.039
28	3	2	4.622	28	16	37	17	5.036
29	2	26	4.622	29	32	37	17	5.036
30	2	33	4.622	30	16	28	27	5.140

* Numbers used as parents represent the entry number.

TABLE X

INTRA- AND INTER-CLUSTER AVERAGE D^2 IN LAHOMA 1979

	1	2	3	4	5	6	7	8	9
1	2.451	4.304	9.634	11.484	7.474	7.700	12.138	5.491	9.563
2		1.355	6.152	13.054	7.310	2.516	6.182	8.765	8.650
3			1.212	3.582	22.983	3.822	11.193	8.958	8.047
4				0.000	31.179	11.203	20.867	7.539	10.501
5					0.000	15.030	10.294	13.848	15.203
6						0.000	10.728	13.861	13.731
7							1.248	10.765	4.494
8								1.408	3.090
9									0.000

TABLE XI

INTRA- AND INTER-CLUSTER AVERAGE D^2 IN STILLWATER 1979

	1	2	3	4	5	6	7	8	9
1	0.000	6.863	4.587	8.445	4.053	28.626	13.688	24.150	12.904
2		1.913	5.992	6.223	7.340	12.971	3.942	8.312	11.342
3			2.165	9.231	7.574	14.602	6.616	18.241	6.210
4				1.417	16.544	23.322	7.192	8.375	6.661
5					2.600	24.978	15.281	26.845	21.856
6						0.000	2.298	12.160	15.545
7							1.007	4.316	6.313
8								0.000	13.910
9									0.000

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APPENDIX A

CALCULATIONS RELATED TO DISCRIMINANT FUNCTION

1. Discriminant Criterion

The score on a linear combination of PX's for an individual of group g (g = 1, 2, . . . G) may be written as

$$Z_g = a_1X_{1g} + a_2X_{2g} + \ldots + a_pX_{pg}$$

The values of the a's are chosen such that $\lambda = \frac{SS_a}{SS_w}$ is maximized, where SS_a and SS_w are the sum of squares among and within groups, respectively. The maximum values of λ are given by the largest root of $W^{-1}A$ where W and A are the sum of squares and cross products matrices within and among groups, respectively.

2. Test of Discriminant Criterion

The characteristic criterion λ may be tested by Wilks' likelihood ratio criterion. Wilks' Λ is expressed as

$$\frac{1}{\Lambda} = \frac{|W + A|}{|W|}$$

This can be expressed as

$$\frac{1}{\Lambda} = \left| W^{-1}(W + A) \right| = \left| I + W^{-1}A \right|$$

Since the determinant of a square matrix is equal to the product of its characteristic roots, and $(W^{-1}A + I)$ has $(1 + \lambda_i)$ as its characteristic roots, then

$$\frac{1}{\Lambda} = (1 + \lambda_1)\ (1 + \lambda_2)\ \ldots\ (1 + \lambda_r)$$

in which r is the number of nonzero characteristic roots of $W^{-1}A$.

Bartlett showed that

$$V = \left[n - 1 - \left(\frac{P + G}{2}\right)\right] 1_n \frac{1}{\Lambda}$$

where n = number of observations

P = number of variables

G = number of groups

is distributed approximately as chi-square with P(G - 1) degrees of freedom for large n.

3. <u>Characteristic Vectors</u> (a-values)

The significant λ's may be used to compute the characteristic vectors (discriminant weights) by solving the following system of equations:

$$(W^{-1}A - \lambda I)\ \underset{\sim}{a} = 0$$

where $\underset{\sim}{a}$ is a column vector with three elements (a_1, a_2, a_3). The score is calculated by the following formula:

$$Z = \text{score} = a_1X_1 + a_2X_2 + a_3X_3$$

APPENDIX B

D^2 VALUES BETWEEN EACH PAIR OF CULTIVARS

TABLE XII

VALUES OF D^{2*} BASED ON THE CHARACTERS ARRANGED IN INCREASING ORDER OF MAGNITUDE WITH RESPECT TO EACH VARIETY - 1979 LAHOMA

Parent Number	1		2		3		4		5
7	0.861	23	0.299	25	0.077	27	0.721	29	0.196
22	0.949	3	1.284	24	0.609	11	0.835	27	0.926
20	1.135	25	1.643	22	0.966	10	1.019	10	1.207
15	1.430	22	1.978	2	1.284	5	2.576	6	1.214
24	1.533	7	2.971	7	1.238	29	2.626	14	1.436
3	1.858	10	3.091	1	1.858	14	2.829	16	1.731
19	1.913	24	3.606	23	1.990	16	3.064	11	2.234
13	1.985	30	3.927	14	2.270	8	3.607	19	2.304
25	2.130	14	3.945	19	2.774	19	3.762	4	2.576
8	2.243	8	4.024	10	2.796	23	4.357	25	2.746
14	2.394	11	4.151	29	2.936	28	4.531	7	2.925
30	2.737	19	4.765	8	3.158	7	4.882	28	3.213
21	3.633	1	4.769	5	3.585	12	5.123	3	3.585
29	4.317	29	5.118	15	3.795	22	5.270	8	3.775
10	4.603	27	5.482	30	4.264	2	5.551	22	3.939
2	4.768	4	5.552	20	4.318	25	6.164	18	4.123
5	6.011	5	5.636	27	4.762	3	6.682	24	4.282
27	6.462	16	6.368	11	5.433	6	6.750	21	4.814
23	6.635	12	8.444	16	6.140	30	7.344	23	4.885
26	6.901	15	9.117	13	6.310	17	7.697	2	5.635
12	9.116	20	9.609	21	6.418	24	9.773	15	5.662
6	9.416	6	10.423	6	6.505	1	9.842	26	5.942
9	9.589	13	10.983	4	6.682	13	11.035	1	6.011
4	9.842	21	12.484	9	7.647	21	11.736	13	6.782
28	10.336	18	13.099	18	8.171	26	11.862	9	7.980
11	10.538	9	14.219	12	10.428	18	12.464	17	8.25
16	12.118	28	14.258	26	10.651	15	12.616	20	8.260
18	12.269	26	17.017	28	11.078	20	15.299	30	8.756
17	16.208	17	21.594	17	18.531	9	19.170	12	10.544

* D^2 is a measure of genetic diversity, as D^2 increases, the genetic diversity between parents increases.

TABLE XII (Continued)

Parent Number	6		7		8		9		10
18	1.212	22	0.185	19	0.371	18	2.264	27	0.364
5	1.214	19	0.404	7	0.602	24	4.568	14	0.548
29	1.951	14	0.466	14	0.604	6	4.901	29	0.809
16	2.750	8	0.602	22	0.783	15	5.197	4	1.019
27	3.986	1	0.861	10	1.261	21	6.061	19	1.110
28	4.758	3	1.238	30	1.312	25	6.633	5	1.207
14	4.622	25	1.272	27	2.130	20	6.942	8	1.261
10	4.833	10	1.492	1	2.243	3	7.647	7	1.492
9	4.901	29	1.750	29	2.390	5	7.980	11	1.575
21	4.926	24	1.913	12	2.861	29	8.320	22	1.826
25	5.179	30	2.074	13	3.035	1	9.590	25	2.476
11	5.491	13	2.595	3	3.158	7	10.329	23	2.793
19	5.764	15	2.666	25	3.253	26	10.501	3	2.796
24	5.913	27	2.705	4	3.607	14	10.766	2	3.091
26	6.065	5	2.925	5	3.775	16	11.203	16	3.290
3	6.505	2	2.971	2	4.024	19	11.634	30	4.173
7	6.538	20	3.258	24	4.649	22	11.715	28	4.204
15	6.592	23	3.430	23	4.881	13	11.957	1	4.603
4	6.750	21	3.944	15	4.962	10	13.062	24	4.683
22	8.214	4	4.882	28	5.456	29	13.842	6	4.833
8	8.559	11	5.468	11	5.468	2	14.219	12	4.929
23	9.316	12	5.912	21	5.644	23	14.549	13	6.153
1	9.416	26	6.275	20	5.672	8	15.335	15	6.703
13	9.465	28	6.537	26	6.871	11	15.950	21	6.787
20	9.864	6	6.538	16	8.463	28	16.041	26	8.023
2	10.423	16	7.375	6	8.559	4	19.170	17	8.470
17	10.672	18	10.231	17	8.985	30	20.821	20	8.528
30	15.492	9	10.329	18	13.940	17	25.649	18	9.337
12	18.544	17	11.607	9	15.335	12	31.179	9	13.062

TABLE XII (Continued)

Parent Number	11		12		13		14		15
4	0.835	30	2.723	21	1.510	19	0.136	20	0.362
16	1.068	8	2.861	15	1.616	7	0.466	21	0.907
10	1.575	10	4.929	20	1.900	10	0.548	1	1.430
27	1.690	19	4.955	1	1.985	8	0.604	13	1.616
5	2.234	4	5.123	19	2.065	29	0.611	24	1.921
23	2.604	14	5.431	26	2.307	27	1.00	7	2.666
29	2.833	22	5.565	7	2.595	22	1.025	19	3.205
14	3.816	27	5.706	8	3.035	5	1.434	25	5.538
2	4.151	7	5.912	14	3.071	25	1.998	26	3.596
25	4.841	2	8.444	22	3.714	3	2.270	22	3.652
19	5.271	29	8.685	29	4.799	1	2.394	14	3.656
3	5.433	11	8.872	24	5.258	4	2.829	3	3.795
8	5.468	1	9.116	30	5.345	13	3.071	29	4.302
6	5.491	23	9.175	10	6.153	24	3.194	8	4.962
7	5.618	13	9.504	25	6.189	30	3.362	9	5.197
22	5.778	28	9.799	3	6.310	15	3.656	5	5.662
28	7.141	25	10.910	28	6.326	28	3.725	6	6.592
24	8.360	3	10.428	27	6.642	21	3.775	10	6.703
12	8.872	5	10.544	5	6.782	11	3.816	30	7.639
30	9.355	17	10.790	6	9.465	2	3.945	27	7.734
18	9.459	24	14.168	12	9.504	23	4.297	18	8.206
1	10.538	15	14.953	17	9.696	6	4.622	28	8.984
17	12.193	16	15.030	2	10.983	20	5.019	2	9.117
21	12.950	26	15.203	4	11.035	26	5.049	23	10.805
15	13.035	21	15.406	9	11.957	16	5.274	16	12.494
13	13.663	20	15.530	23	12.893	12	5.431	4	12.616
26	14.435	6	18.599	11	13.663	17	7.960	11	13.035
20	15.872	18	27.367	18	13.821	18	8.837	12	14.953
9	15.950	9	31.179	16	15.104	9	10.766	17	14.041

TABLE XII (Continued)

Parent Number	16		17		18		19		20
11	1.068	28	1.248	6	1.212	14	0.136	15	0.362
5	1.731	27	5.750	9	2.264	8	0.371	1	1.135
6	2.750	26	5.769	5	4.123	7	0.404	13	1.900
29	2.912	29	7.541	16	4.894	22	0.949	21	2.153
27	3.030	19	7.693	29	5.289	10	1.110	24	2.337
4	3.064	4	7.697	24	6.574	29	1.173	7	3.258
10	3.290	14	7.960	25	6.717	27	1.605	22	3.931
23	4.443	5	8.251	21	7.330	1	1.913	19	4.286
18	4.894	10	8.470	3	8.171	13	2.065	3	4.318
25	5.125	8	8.985	15	8.206	5	2.306	25	4.363
14	5.274	13	9.696	14	8.837	25	2.593	14	5.019
3	6.140	21	10.016	27	8.924	3	2.774	26	5.486
2	6.368	6	10.672	10	9.337	30	2.806	8	5.672
19	7.080	12	10.790	11	9.459	15	3.205	29	6.466
7	7.375	7	11.607	26	10.029	21	3.324	9	6.942
28	7.614	11	12.193	7	10.23	24	3.518	30	7.114
24	7.961	16	13.842	19	10.337	4	3.762	5	8.260
22	8.031	22	14.027	28	10.592	28	3.855	10	8.528
8	8.463	15	15.041	20	11.458	20	4.286	2	9.609
9	11.203	30	15.991	22	11.898	26	4.411	6	9.864
21	11.916	1	16.208	23	11.962	2	4.765	27	10.162
1	12.118	25	17.312	1	12.269	12	4.955	18	11.458
15	12.494	20	18.497	4	12.467	11	5.271	23	11.899
26	13.731	3	18.531	2	13.099	23	5.460	28	12.133
17	13.842	18	18.750	13	13.821	6	5.764	4	15.299
30	14.012	24	19.592	8	13.940	16	7.080	12	15.530
20	15.931	23	20.885	17	18.750	17	7.693	11	15.872
12	15.030	2	21.594	30	21.249	18	10.337	16	15.931
13	15.104	9	25.694	12	27.367	9	11.634	17	18.497

TABLE XII (Continued)

Parent Number	21		22		23		24		25
15	0.907	7	0.185	2	0.299	25	0.546	3	0.077
26	0.973	8	0.783	3	1.990	3	0.609	24	0.546
13	1.510	1	0.949	25	2.140	1	1.533	22	1.200
20	2.153	3	0.966	11	2.609	7	1.913	7	1.272
19	3.324	19	0.999	10	2.793	15	1.921	2	1.643
1	3.633	14	1.025	22	3.048	22	2.022	14	1.998
29	3.683	25	1.200	7	3.930	20	2.337	1	2.130
14	3.775	30	1.397	14	4.297	14	3.194	23	2.140
7	3.944	10	1.826	4	4.357	19	3.518	29	2.271
24	4.371	2	1.978	16	4.443	29	3.550	10	2.475
5	4.814	24	2.022	24	4.656	2	3.606	19	2.593
6	4.926	29	2.687	29	4.807	5	4.282	5	2.746
28	5.427	23	3.048	27	4.811	21	4.371	8	3.253
8	5.644	27	3.490	8	4.881	9	4.568	15	3.538
22	5.653	15	3.652	5	4.885	8	4.649	27	4.155
25	5.733	13	3.714	30	5.611	23	4.656	20	4.363
9	6.061	20	3.931	19	5.460	10	4.683	11	4.841
3	6.418	5	3.939	1	6.635	13	5.258	30	4.994
27	6.675	4	5.270	12	9.175	6	5.913	16	5.124
10	6.787	12	5.565	6	9.316	30	6.334	6	5.179
18	7.330	21	5.653	15	10.805	27	6.563	21	5.733
17	10.016	11	5.778	20	11.899	18	6.574	4	6.164
30	10.169	16	8.031	18	11.962	16	7.961	13	6.189
4	11.736	6	8.214	13	12.893	11	8.360	9	6.633
16	11.916	28	8.557	28	13.592	26	8.783	18	6.717
2	12.484	26	8.567	21	13.668	4	9.773	26	9.692
11	12.950	9	11.715	9	14.549	28	11.656	28	9.942
23	13.668	18	11.848	26	17.887	12	14.168	12	10.910
12	15.406	17	14.027	17	20.885	17	19.592	17	17.312

TABLE XII (Continued)

Parent Number	26		27		28		29		30
21	0.973	10	0.364	17	1.248	5	0.196	8	1.312
13	2.307	4	0.721	27	2.340	14	0.611	22	1.397
28	3.219	29	0.724	29	2.851	27	0.724	7	2.074
15	3.596	5	0.926	5	3.213	10	0.809	12	2.723
19	4.411	14	1.00	26	3.219	19	1.173	1	2.737
29	4.775	19	1.605	14	3.725	7	1.750	19	2.806
14	5.049	11	1.690	19	3.855	6	1.951	14	3.362
20	5.486	8	2.130	10	4.204	25	2.271	2	3.927
17	5.769	28	2.340	4	4.531	8	2.390	10	4.173
5	5.942	7	2.705	6	4.758	4	2.626	3	4.264
6	6.065	16	3.030	21	5.427	22	2.687	25	4.994
7	6.275	22	3.490	8	5.456	11	2.833	13	5.345
27	6.863	6	3.986	13	6.326	28	2.851	23	5.614
8	6.871	25	4.155	7	6.537	16	2.912	27	6.263
1	6.901	3	4.462	11	7.141	3	2.936	24	6.334
10	8.023	23	4.811	16	7.614	24	3.550	29	6.709
22	8.567	2	5.482	22	8.557	21	3.683	20	7.114
24	8.783	12	5.706	15	8.984	15	4.302	4	7.344
25	9.692	17	5.750	12	9.799	1	4.317	15	7.639
18	10.029	30	6.263	25	9.942	26	4.775	5	8.756
9	10.501	1	6.462	1	10.336	13	4.799	11	9.355
3	10.651	24	6.563	18	10.592	23	4.807	21	10.169
4	11.862	13	6.642	3	11.078	20	5.113	28	11.949
30	12.654	21	6.675	24	11.656	18	5.289	26	12.654
16	13.731	26	6.863	30	11.949	20	6.466	16	14.012
11	14.435	15	7.734	20	12.133	30	6.706	6	15.492
12	15.203	18	8.924	23	13.592	17	7.541	17	15.991
2	17.017	20	10.162	2	14.258	9	8.320	9	20.821
23	17.887	9	13.842	9	16.041	12	8.685	18	21.249

TABLE XIII

VALUES OF D^{2*} BASED ON THE CHARACTERS ARRANGED IN INCREASING ORDER OF MAGNITUDE WITH RESPECT TO EACH PARENT - 1979 STILLWATER

Parent Number	2		3		4		5		6
23	2.226	25	0.777	27	0.263	26	1.007	11	0.502
8	2.569	9	1.308	29	0.477	14	2.149	29	0.515
22	2.781	18	2.709	23	1.494	7	2.163	18	1.015
6	3.051	20	3.928	6	1.840	13	3.396	23	1.231
29	3.591	7	4.952	21	1.933	25	3.493	4	1.840
18	3.883	23	5.086	11	2.233	29	3.699	27	3.024
21	3.919	6	6.004	10	2.853	16	3.938	2	3.053
15	4.113	2	6.298	8	3.981	21	4.098	21	4.092
4	4.980	13	6.420	7	4.058	23	4.118	16	4.246
11	5.068	21	6.471	15	4.807	20	4.255	5	4.398
30	5.172	15	6.656	2	4.980	6	4.398	7	4.435
10	5.692	5	7.009	22	5.055	18	4.565	25	4.771
3	6.298	14	7.571	5	5.069	4	5.069	3	6.004
25	6.690	16	7.606	18	5.218	19	5.499	15	6.051
7	6.832	29	7.637	14	6.367	11	5.708	8	6.101
27	6.953	11	9.412	20	7.024	28	6.123	20	6.746
20	7.317	26	9.711	26	7.538	27	6.490	10	6.783
14	11.605	19	10.110	30	7.715	3	7.009	22	7.427
5	11.646	8	10.934	25	8.234	9	7.442	14	7.670
13	12.032	4	11.468	13	8.666	15	7.476	26	8.530
9	12.348	30	11.823	16	9.190	2	11.646	9	9.074
16	12.904	22	14.881	28	11.461	8	11.920	13	9.252
26	15.730	27	15.097	3	11.468	30	14.384	30	10.355
19	24.150	10	19.915	9	16.341	10	15.180	28	16.246

* D^2 is a measure of genetic diversity, as D^2 increases, the genetic diversity between parents increases.

TABLE XIII (Continued)

Parent Number	7		8		9		10		11
20	0.574	22	0.675	3	1.308	22	1.809	6	0.502
14	0.635	30	0.945	25	2.167	27	2.582	29	1.179
21	0.824	15	1.459	18	4.338	4	2.853	18	2.186
13	0.969	21	2.149	16	5.970	8	2.971	4	2.233
23	1.653	23	2.520	20	7.342	29	4.668	27	2.846
15	1.745	2	2.569	5	7.442	23	5.343	23	3.023
25	2.037	10	2.971	7	8.133	21	5.651	16	4.045
5	2.163	4	3.981	19	8.739	2	5.692	2	5.068
26	2.215	29	4.359	13	8.846	30	6.681	21	5.417
29	3.086	7	5.203	6	9.074	6	6.783	5	5.078
4	4.058	27	5.368	23	9.465	11	7.197	10	7.197
6	4.435	20	5.678	14	10.060	15	7.289	7	7.210
18	4.907	6	6.101	26	10.455	7	10.607	25	7.920
3	4.952	14	8.454	21	11.324	18	12.292	8	8.768
8	5.203	11	8.768	29	11.508	20	13.542	3	9.412
30	5.763	18	8.948	11	12.173	14	14.455	22	9.522
27	5.994	25	9.082	2	12.348	5	15.180	15	9.541
19	6.413	13	9.111	15	12.623	25	16.948	20	10.546
2	6.832	3	10.934	4	16.341	13	17.061	14	10.686
11	7.210	5	11.920	8	18.865	26	18.027	26	10.702
9	8.133	26	13.273	27	20.258	3	19.915	9	12.173
16	9.110	9	18.865	30	20.265	16	20.826	13	13.020
22	9.147	16	19.288	22	24.006	28	22.283	30	14.343
10	10.607	19	22.579	28	26.273	9	28.530	28	16.348
28	10.640	28	23.178	10	28.530	19	32.995	19	21.247

TABLE XIII (Continued)

Parent Number	13		14		15		16		18
14	0.336	13	0.336	21	0.814	18	2.839	6	1.015
20	0.722	7	0.635	30	1.209	5	3.938	11	2.186
7	0.969	26	0.892	8	1.459	11	4.045	23	2.476
26	1.809	20	1.252	20	1.480	6	4.246	29	2.544
25	2.962	5	2.149	7	1.745	9	5.970	25	2.621
19	3.165	21	2.497	23	1.840	29	6.159	3	2.709
21	3.274	25	3.565	13	3.519	25	6.407	16	2.839
5	3.396	15	3.588	14	3.588	3	7.606	2	3.883
15	3.519	19	3.985	22	4.095	23	7.962	9	4.338
23	5.086	23	4.172	2	4.113	26	8.689	5	4.565
3	6.420	29	5.636	29	4.347	7	9.110	21	4.772
29	7.428	4	6.367	25	4.498	4	9.190	7	4.907
30	8.133	3	7.571	4	4.807	21	10.700	4	5.218
4	8.666	6	7.670	6	6.051	27	10.780	20	6.257
9	8.846	28	7.814	3	6.656	14	11.090	15	7.290
18	8.880	18	8.188	27	6.885	20	12.011	27	7.328
8	9.111	27	8.243	10	7.289	13	12.690	14	8.188
6	9.252	30	8.346	18	7.290	2	12.903	13	8.880
28	10.918	8	8.454	5	7.476	19	13.910	8	8.948
27	11.117	9	10.060	26	7.552	28	15.545	26	8.959
2	12.032	11	10.686	11	9.541	15	15.833	22	11.171
16	12.690	16	11.090	9	12.623	8	19.288	10	12.292
11	13.020	2	11.605	19	13.072	10	20.826	30	12.666
22	14.576	22	13.475	16	15.833	22	22.684	19	14.568
10	17.061	10	14.455	28	18.343	30	24.628	28	19.846

TABLE XIII (Continued)

Parent Number	19		20		21		22		23
26	3.133	7	0.574	15	0.814	8	0.675	21	0.498
13	3.165	13	0.722	23	0.498	10	1.809	29	0.657
14	3.985	14	1.252	7	0.824	30	2.520	6	1.231
5	5.499	15	1.480	29	1.615	2	2.781	4	1.494
20	5.966	25	1.667	20	1.794	15	4.095	7	1.653
25	6.276	21	1.794	4	1.933	23	4.450	15	1.840
7	6.413	23	2.897	8	2.149	21	4.604	2	2.226
9	8.739	26	3.787	14	2.497	4	5.055	18	2.476
3	10.110	3	3.928	6	3.092	29	5.836	8	2.520
21	11.826	5	4.255	13	3.274	27	6.046	20	2.897
28	12.160	30	5.015	30	3.327	6	7.427	27	3.007
15	13.072	29	5.536	27	3.411	7	9.147	11	3.023
23	13.758	8	5.678	25	3.792	11	9.522	25	3.288
16	13.910	19	5.966	2	3.919	20	10.082	5	4.118
18	14.568	18	6.257	5	4.098	18	11.171	14	4.172
29	16.023	6	6.746	22	4.604	25	13.438	22	4.450
6	17.231	4	7.024	18	4.772	14	13.475	30	4.774
4	18.632	2	7.317	26	4.937	13	14.576	13	5.086
30	21.218	9	7.342	11	5.417	3	14.881	3	5.086
11	21.247	27	9.665	10	5.651	5	16.440	10	5.343
27	21.744	22	10.082	3	6.471	26	18.856	26	6.347
8	22.579	11	10.546	16	10.700	16	22.684	16	7.962
2	24.150	16	12.011	9	11.324	9	24.006	9	9.465
22	30.588	10	13.542	19	11.826	28	28.500	19	13.758
10	32.995	38	15.016	28	12.970	19	30.588	28	15.094

TABLE XIII (Continued)

Parent Number	25		26		27		28		29
3	0.777	14	0.892	4	0.263	26	4.464	4	0.477
20	1.667	5	1.007	29	1.313	5	6.123	6	0.515
7	2.037	13	1.809	10	2.582	14	7.814	23	0.657
9	2.167	7	2.215	11	2.846	7	10.640	11	1.179
18	2.621	19	3.133	23	3.007	13	10.918	27	1.313
13	2.962	20	3.787	6	3.240	27	10.997	21	1.615
23	3.288	28	4.464	21	3.411	4	11.461	18	2.544
5	3.493	21	4.937	8	5.368	19	12.160	7	3.086
14	3.565	25	5.041	7	5.974	29	12.716	2	3.591
21	3.792	4	5.538	22	6.046	21	12.970	5	3.699
15	4.498	23	6.347	5	6.490	20	15.016	15	4.357
6	4.771	29	6.682	15	6.885	23	15.094	8	4.359
26	5.041	15	7.552	2	6.853	16	15.545	10	4.668
29	5.324	6	8.530	18	7.328	6	16.246	25	5.324
19	6.276	16	8.689	14	8.243	11	16.348	20	5.536
16	6.407	18	8.959	26	9.055	25	17.929	14	5.636
2	6.690	27	9.055	20	9.665	15	18.343	22	5.836
11	7.920	3	9.711	30	9.702	18	19.846	16	6.159
4	8.234	11	10.702	16	10.780	10	22.283	26	6.682
8	9.082	9	10.455	28	10.997	8	23.178	13	7.428
30	9.836	8	13.273	13	11.117	30	25.951	3	7.637
27	11.272	30	14.167	25	11.272	3	25.764	30	8.028
22	13.438	2	15.097	3	15.097	9	26.273	9	11.508
10	16.948	10	18.027	9	20.258	22	28.500	28	12.716
28	17.929	22	18.856	19	21.744	2	28.626	19	16.023

TABLE XIII (Continued)

Parent Number	30
8	0.945
15	1.204
22	2.520
21	3.327
23	4.774
20	5.015
2	5.172
7	5.763
10	6.681
4	7.715
29	8.028
13	8.133
14	8.346
27	9.702
25	9.836
6	10.355
3	11.823
18	12.666
26	14.167
11	14.343
5	14.384
9	20.265
19	21.218
16	24.628
28	25.951

VITA

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