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Title: A Comparison of Four Methods of Selection for the Improvement of Grain Yield in Winter by Spring Wheat Crosses (*Triticum aestivum*, L. em Thell).

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Concerns regarding the most effective and economical means of handling segregating wheat populations prompted this investigation. The four methods employed represented the Pedigree, two Modified Bulks and the Bulk with three, two, one, and zero cycles of phenotypic selection used, respectively. F_5 selections derived from each method were compared for seven agronomic traits when grown in replicated yield trials. Qualitatively inherited traits, plant height, and flowering and maturity dates, along with the components of yield and grain yield which are more complex in their inheritance, were measured. Differences in response to phenotypic selection based on the four methods were observed depending on the trait and cross involved.

Phenotypic selection for grain yield gave inconsistent results; however, in general, superior performance of the F_5 selections obtained by the Pedigree, Modified Bulk 1, and Modified Bulk 2 methods was achieved when compared to the Bulk method.

Kavkaz and Cocoraque 75, the winter and spring parents, respectively, were most often involved in the highest yielding crosses. Under the environmental conditions in which this study was conducted, consistent negative correlations were observed for grain yield with flowering and maturity dates in all the crosses. Results suggested that in a winter x spring breeding program emphasis on visual selection for flowering and maturity dates should be given if increases in grain yield are to be realized. The two modifications of the Bulk method proposed in this study would appear to combine the advantages of the Pedigree and Bulk methods since many different crosses can be evaluated while still retaining a large number of plants per cross. Furthermore, the opportunity to select under both space planted and solid seeded conditions will be available with these methods.

A Comparison of Four Methods of Selection for the Improvement of Grain Yield in Winter by Spring Wheat Crosses (*Triticum* *aestivum* L. em Thell)

by

Guillermo Ortiz Ferrara

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Professor of Agronomy in charge of major

Redacted for Privacy

Head of Department of Crop Science

Redacted for Privacy

Dean of Graduate School

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Typed by Donna Lee Norvell-Race for Guillermo Ortiz Ferrara

· IN DEDICATION ·

To Lupita, my wife, and to Guillermo, Luis Arturo, and Juan Carlos, my sons, with the deep love of a man and father . . .

and

To a man who put hope in his children, and to his unequaled wife: my parents.

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INTRODUCTION

The development of cultivars with high grain yield potential is the major objective of most wheat breeding programs. With wheat providing nearly 41 percent of the total food supply for the world and with an ever-increasing human population, the need to increase grain yields per hectare is obvious. When breeding for increased productivity, the wheat breeder is faced with three major decisions. The first is to identify germplasms which have the desired attributes. Secondly, it is necessary to decide in what combinations the prospective parents should be used when hybridizing. Finally, the breeder must determine which method to use in handling the resulting segregating populations. When the breeding objective is to improve a simply inherited trait, these decisions are easily made. However, grain yield is influenced by many genes and also by various environmental factors making these major decisions much more difficult.

With regard to the expenditure of resources including time and labor, the third factor involving how to handle segregating populations is by far the most costly.

Selection is, without question, the major feature in plant breeding. Indeed, one of the ingredients of successful plant breeding is to recognize superior types in a limited or vast array of genetic variability.

There are no reliable methods available to the plant breeder for predicting the hybrid combinations from which the highest proportion of superior segregates will be derived. Consequently, the breeder is forced to evaluate the progeny of as many crosses as possible with the facilities available. Thus, breeding procedures which utilize the facilities as efficiently as possible must be chosen.

Few empirical studies comparing the efficiency of various selection methods are available. The Bulk and Pedigree methods both have been used extensively in the development of small grain cultivars. The Bulk system involves natural selection operating on solid seeded segregating populations followed by individual plant selection within the desired crosses in later generations. In contrast, the Pedigree method involves phenotypic selection between space planted individuals within crosses from the F_2 through F_5 before yield tests are conducted. Each method has several shortcomings: the Bulk method, for example, has had limited success due to the unpredicted direction of natural selection, while the Pedigree method involves the waste of considerable effort spent in propagating poor yielding strains. A modified plant breeding procedure involving the desirable features of each method would be highly beneficial to small grain breeders.

The study reported herein compares the efficiency of four breeding methods involving three, two, one, and zero cycles of phenotypic selection or the Pedigree, two modifications of the Bulk, and the Bulk method, respectively. The study using winter x spring wheat crosses includes the response to phenotypic selection for three simply inherited traits and four quantitative characters. It is hoped that the results obtained will enable breeders to decide which method of selection to adopt in a particular breeding program.

LITERATURE REVIEW

The plant breeder concerned with the improvement of varieties and their yielding ability face three main problems: (1) the choice of parents, (2) the choice of which hybrid combination to make, and (3) the choice of a selection method for handling segregating populations.

This study concentrated mainly on selection methods, thus the choice of parents and which combinations to make are given less consideration since they are not the main objectives of this research.

Selection is the most difficult part of plant breeding. It is relatively easy to develop genetic variability; it can be done by introducing new germplasm through (1) hybridization within or between species, (2) through mutagens, and (3) by changing chromosome number and structure. The task requiring time, effort, and all the plant breeder's skill is the identification of the plant or group of plants with the most desirable combination of genes and chromosomes. This is why plant breeding may be considered both an art and a science.

Efficient procedures to identify superior progeny from segregating populations must be developed if high yielding cultivars are to be obtained.

Bulk and pedigree systems and various modifications of the two have been used in breeding self-pollinated crops. The techniques involved and the advantages and disadvantages of the respective procedures were reviewed by Hayes, Immer, and Smith (26) and Love (33).

Comparison of Selection Methods

Few empirical studies comparing the efficiency of the pedigree and bulk methods of selection are available.

Raeber and Weber (42) working with four soybean crosses, determined the effectiveness of selection for seed yield by bulk and pedigree systems of breeding. They found no difference in the F_6 generation between the average performance of selections developed using these two methods for seed yield, plant height, and lodging resistance. However, unselected bulk populations matured considerably later than all the other plant material in their study, thus confirming that selection for maturity was effective. They concluded that the greatest genetic advance in selecting for yield could be made by a combination of pedigree testing and phenotypic selection.

Working with six soybean crosses, Torrie (53), found few significant differences in seed yield and no differences in plant height and lodging index in a comparison of F_6 lines selected by the pedigree and bulk methods. He reasoned that the non-significant difference in mean lodging indices between lines selected by the two procedures indicated that as much progress could be made in selecting for this character in one year as would be possible in several years, providing differential lodging occurred. Bulk selections averaged one to four days later in maturity than the pedigree selections.

Voigt and Weber (56) utilized segregating populations from five crosses involving five soybean varieties in the evaluation of three selection procedures for seed yield, maturity, height, and lodging resistance. The selection systems evaluated were the bulk, pedigree, and family methods. They found that the F_5 lines selected by the family method were superior in yield to those selected by bulk and pedigree methods. The lines selected by the family method were similar in maturity and height and superior or equal in lodging resistance to those selected by the bulk and pedigree methods of breeding. In this study they also observed that the pedigree method was superior to the bulk method for selection of the simple inherited traits maturity, height, and lodging, but equal for yield, indicating that little progress should be expected from phenotypic selection for seed yield in early generations of a cross.

Using 390 barley crosses, Harlan (23) compared the pedigree and the bulk methods and found no differences in the effectiveness of the methods for isolating superior yielding lines.

A comparison of the bulk, pedigree, and early generation testing selection methods in soybeans by Luedders, Duclos, and Matson (34) indicated no significant yield differences in the lines selected by the three methods. They suggested that plant breeders discard approximately 75 percent of their yield tested lines each year. This would permit larger populations to be evaluated and should result in the retention of more stable high yielding lines.

Matsuo et al. (36) compared the effectiveness of selection in one rice cross using the pedigree, mass selection and bulk methods. In the pedigree method 248 individuals were selected from 5,000 F_2 plants and these individuals were maintained up to the F_6. In mass selection, 5,000 plants were individually selected from mixed progenies from F_2 to F_6. For the bulk method 1,500 F_2 plants were used; however, the number was increased to 5,000 plants in subsequent generations. The results of their study showed that the pedigree system produced more plants with higher yield than the bulk method. They attributed this to the effect of competition in bulk population and the value of individual selection in early stages of the pedigree system.

Empig (16) made theoretical comparisons of bulk, pedigree, F_2 derived lines and single seed descent methods based on the amount of additive genetic variance available upon selection. Bulk and single seed descent methods had the highest available additive genetic variance (Va) followed by the pedigree and F_2 derived line methods, respectively. He suggested, based on his results, that for characters such as yield with low heritability, bulk breeding is useless if selection is to be terminated in the F_7 generation unless yield is correlated to some character with high selective value. He also stated that for characters with relatively high heritability values such as plant height, there is no point in using the pedigree and single seed descent methods. Both are too expensive when compared to the F_2 derived line procedure. In this study he further suggests that as a method for evaluating yield, the theoretical advantage of the pedigree method over F_2 derived lines is still debilitated by the costs and labor involved in the former. On the other hand, single seed descent with large F_2 populations (2,000 plants or more) can be an efficient system. Generations can be shortened and competition effects among heterogeneous individuals can be averted. He concluded that with the aid of visual selection against decidedly inferior genotypes, single seed descent is the best alternative for a breeder.

Grignac et al. (21) found no significant difference in the progeny from three bread wheat crosses, and from two durum wheat crosses, selected through the F_9 generation for grain yield using the pedigree, bulk and single seed descent methods. The bulk method produced lines with reduced protein content compared to the lines from the other methods of selection.

Seitzer and Evans (45) chose three crosses of spring wheat to compare the efficiency of three methods of selection for identifying high-yielding late generation lines. The three methods compared were (1) a pedigree method where visual selection was practiced in F_3, (2) an early generation yield test where F_3 plots were compared to adjacent controls, and (3) an early generation yield test wherein replicated tests with hill plots were used to evaluate the yield potential of F_3 families. The efficiency of these methods was evaluated in the F_5 generation. One hundred and eighty lines derived from 45, 6, and 3 selected F_3 families per cross in methods (1), (2), and

(3), respectively, were grown at two locations. They found that the methods did not differ significantly with regard to actual mean yield and line yield. They concluded that early testing procedures can assist in selecting for higher yield. Their predictive value, however, was dependent upon the precision of the yield estimates as well as on the inheritance of yield, known to be variable from cross to cross.

In soybeans, Boerma and Cooper (8), after extensive testing and comparing early generation yield testing with pedigree and single seed descent methods, found no significant differences between methods and concluded that the latter should be used where isolation of high-yielding lines is the primary objective.

A comparison of the efficiency of some selection methods in populations resulting from crosses between self-fertilizing plants was made by Van Der Kley (55). He concluded after extensive calculations that the pedigree, bulk, and mass pedigree methods are not the most efficient, due to the small frequency of desired genotypes and the possible loss of valuable genotypes through misdirected natural or human selection. He also pointed out that the efficiency of the "gradual selection" procedure he proposed was calculated to be high when compared to the above-mentioned methods.

Copp (15) reported the results of 26 years of work in New Zealand in which the pedigree and bulk methods were carried out simultaneously. He concluded that the pedigree method is preferable under conditions where diseases are not limiting factors. Five named varieties were obtained by the pedigree method: Fife Tuscan, Yielder, Hilgendorf, Arawa and Aotea. There were no named varieties produced by the bulk method of breeding.

Working with an individual wheat cross, Palmer (41) suggested that there is no clear-cut evidence in favor of either the pedigree or bulk methods of breeding. He concluded that where only a few genes of importance are segregating, or where speed is essential, the pedigree method is preferable. Where many genes are segregating, or where selection for recessive major genes is combined with polygenic selection, the bulked population method makes more economical use of the available facilities, while possibly enhancing the prospects of success.

In simulation studies, Casali and Tigchelaar (14) compared pedigree, bulk, and single seed descent selection methods in self-pollinated populations. Using heritability values of 100, 75, 50, 25, and 10 percent they found that pedigree selection was the most effective selection method at high (75%) and moderate (50%) heritabilities in terms of the best F_6 line. They suggested that under the simulated selection, the intensities of the responses to pedigree and bulk selection would be equal at some unknown heritability between 50 and 25 percent. Above this value, pedigree selection would be favored, whereas at lower heritabilities bulk selection would be recommended.

The reviewed literature shows that experimental evidence on this subject is scarce and contradictory. Each of the pedigree and bulk methods of breeding has its strong advocates, with opinions based on long experience in plant breeding. It would appear that both methods are used, sometimes by the same plant breeder. This testifies to the effectiveness of both methods of breeding. Actually, for any hybrid population, the choice is not one method to the exclusion of the other. Plant breeders have devised many different modifications and combinations of both methods.

Visual Selection, The Art

In the pedigree method of plant breeding for autogamous crops, rejection of lines in the early generations of a cross is mainly based on visual evaluation for seed yield and overall agronomic worth. Allard (3) referred to the need for quick visual evaluation rather than precise measurement when evaluating large numbers of individuals or lines in segregating generations. He emphasized that the breeder must be thoroughly familiar with his crop, otherwise visual selection of superior types would be unsuccessful.

Visual selection usually is not considered to be a very accurate method for discriminating yield and should be used to discard only the poorest lines (6,12,22,32).

Efforts to evaluate the ability of selectors to visually identify superior lines in a breeding nursery have been made in several crops. Using F_2 progenies grown in single-row plots, Frey (19) demonstrated that visual selection for high or low yield in oats was ineffective in one cross and effective only for low yield in a second cross. Positive visual selection in F_5 was effective in raising the mean yield beyond that of random selection.

McKenzie and Lambert (38) found a poor relationship between the visual rating of lines for yield and the actual yields, in both the F_3 and F_6 generations of two barley crosses. They concluded that visual yield scoring was unsatisfactory for evaluating barley lines. Results contrary to this were reported by Krull et al. (31). They visually evaluated 3,274 wheat lines for yield on the basis of agronomic characteristics, using a scale of 0 to 4. Over 1,700 lines were eliminated because of poor appearance prior to harvest, but a very close correlation was found between the actual and estimated performance of the remainder. Based on a study of 200 F_3 winter wheat progenies grown in small plots, Boyce et al. (10) concluded that selection by visual evaluation was as successful as evaluation by weight in raising mean yield. Briggs and Shebeski (12) compared the ability of fourteen plant breeders to visually select the highest yielding plots from a spring wheat nursery containing 828 F_3 lines, with results obtained by random selection. They found that when a positive selection pressure of 10 percent was applied, a significant improvement in yield over random selection was obtained.

Knott (30) working with wheat demonstrated that visual selection resulted in a significant increase in yield over random selection, but that selected lines showed a considerable range in yield. McGinnis and Shebeski (37) working with wheat could not demonstrate any differences in yield between random and visually selected lines.

Salmon and Larter (43) evaluated the efficiency of visual selection as a method for improving yield of triticale. In their study, lines from eight F_3 populations of hexaploid triticale were visually rated for yield by a group of selectors comprised of experienced (plant breeder), novice (graduate student), and inexperienced (summer student) workers. Comparisons of selector efficiencies indicated that the experienced selectors were more able to visually identify high-yielding lines than were the inexperienced selectors. They concluded that visual selection may be a useful method for identifying high-yielding lines of triticale.

Natural Selection

In the pedigree method, about 95 percent of the plants in the segregating generations are discarded each year, purely on visual judgment. In the bulk method, about 95 percent of the total seed harvested is discarded each year purely at random. Natural selection favors those lines capable of most rapid multiplication under conditions of competition.

The importance of natural selection among plant breeders has long been recognized, but the rate at which such changes occur in cultivated crops has only recently received attention.

Studies on bulk-population breeding have shown that natural selection exerts a dynamic influence on the composition of the population in each generation, resulting in changes in gene frequencies as the hybrid moves toward homozygosity (1,49). For example, short-statured wheat and rice have greater yield potential than tall types, especially in highly productive environments (9,4), but they do not compete favorably with tall plants and are progressively eliminated from bulk populations. Thus, natural selection can be in direct conflict with the plant breeder's objective (27,29).

Few results have been reported clearly showing changes in single hybrid populations in response to the pressures of natural selection. One of the classical papers showing the effect of natural selection was reported by Harlan and Martini (24). They determined the rate of natural selection in a mixture of 11 easily recognized cultivars of barley evaluated at 10 stations for a period of four to twelve years. There was a rapid elimination of the less adapted cultivars at all stations and the predominant cultivar in the population was quickly evident at most locations. The leading cultivar varied with the location of the station. A cultivar dominant at one station in some cases was eliminated at another and few survived at all stations. Some cultivars increased for a time and then decreased. They concluded that the success of a cultivar in a mixture could be used as a measure of adaptation and yielding ability under commercial conditions.

Mumaw and Weber (40) evaluated the effect of natural selection in soybean variety blends grown for five successive years. They found an increase of varieties possessing taller height, later maturity, more lodging, and greater branching habit.

A study by Atkins (5) to evaluate natural selection in bulk populations compared the yielding ability of two groups of random selections for each of eight barley crosses in the F_7 generation. Both groups were grown as bulk populations. However, one group was selected for desirable phenotypic types in the F_2, F_3, and F_4 generations, whereas the other group was unselected. He found that the mean yield of the selected lines was significantly greater at the one percent level than that of the unselected lines.

Taylor (50) grew bulk F_2, F_3, F_4, and F_5 populations of 20 barley crosses at four locations. He measured changes in gene frequency on simply inherited morphological characters, and concluded that natural selection, although shifting gene frequency very rapidly, was not necessarily in the desired direction. He concluded that bulk yield might have been used for discarding entire crosses without much loss of desirable germplasm.

Atkins and Murphy (7) tested 50 segregates for yield from each of ten oat crosses in the F_7 and F_8 generation. Low correlations were found for successive bulk generations. They concluded that natural selection was effective in maintaining disease resistance, and a change in disease prevalence during the period under investigation was suggested to account for inconsistency in bulk performance. They further concluded that considerable high-yielding germplasm may be lost if bulk crosses were discarded on the basis of early generation evaluations.

MATERIALS AND METHODS

Two winter and three spring wheat cultivars were chosen for this study. The winter cultivars were 'Kavkaz' and 'Weique Red Mace' and the spring cultivars were 'Siete Cerros 66', 'Cocoraque 75', and 'Torim 73'. These five cultivars differ genetically not only in growth habit but in plant height, grain yield, yield components and for other agronomic traits. Pedigrees and descriptions of the cultivars are presented in the Appendix Table 1.

This study was conducted over a five-year period (1976-1980) under environmental conditions observed in Mexico where two growing cycles per year can be obtained. Two experimental stations were used to handle the segregating populations. El Batan Experimental Station, located at 19° 31' N latitude and 98° 53' W longitude, at an elevation of 2,249 m above sea level. The type of soil is a sandy clay. The amount of rain during the wheat summer cycle (May to October) is between 450 to 700 mm. Irrigation (four times), fertilization (160 kg/ha of N and 80 kg/ha of P as P_2O_5), and chemical weed control (Tribunil, 2.0 kg/ha, pre-emergence) were applied to the experimental material. The second experimental station was the Northwest Agricultural Research Center (CIANO), located near Ciudad Obregon Sonora in the northwest part of Mexico. Northwest Agricultural Research Center is located at 27° 20' N latitude and 109° 54' W longitude, at an elevation of 39 m above sea level. The soil type is a brown clay loam developed as a coastal plain outwash under desert conditions.

The precipitation is 266 mm (average of 28 years); of the total annual precipitation 64 percent falls during the summer and only 46 percent during the crop cycle from fall through the spring. Irrigation (five times), fertilization (150 kg/ha of N and 80 kg/ha of P as P_2O_5), and chemical weed control (Carbyne, 4 lts/ha, post-emergence) were applied to obtain maximum genetic expression.

Six single crosses between the winter and spring wheats were made in the summer of 1976 at El Batan Experimental Station. During the fall of 1977, these F_1's were planted at the Northwest Agricultural Research Center (CIANO), and the F_2 generation was obtained.

In the summer of 1978, each of the six F_2 populations were planted at El Batan in six double rows five meters long. The plants were space planted 15 centimeters apart within the rows. Each F_2 population consisted of 420 plants.

Four methods of selection were followed: (a) the pedigree method (P), where three cycles of visual selection was applied; (b) modified bulk two (MB2), where two cycles of visual selection were practiced; (3) modified bulk one (MB1), where only one cycle of visual selection was exercised; and (d) the bulk method (B), where no visual selection was used and only natural selection was the selection force. For ease of understanding, a diagram showing the procedure followed in each method of selection is presented in the Appendix Figure 1.

Pedigree Method (P)

Each one of the six F_2 populations was divided in half to initiate the different selection methods. From the first three double rows of each F_2 population the pedigree method was followed by visually selecting the 10 best F_2 plants based on agronomic characteristics (good tillering, highly fertile and large spikes, early maturity, good straw and intermediate height). This was the first cycle of selection for the pedigree method. Two double rows, five meters long for each of the 10 best F_2 plants were space planted at CIANO in the fall of 1978. Each F_3 population consisted of approximately 140 plants. The second cycle of selection for the pedigree method was made by visually selecting the five best agronomic F_3 plants within each of the 10 F_3 families of each cross. A total of 50 F_4 lines in each of the six crosses were space planted at CIANO in the fall of 1979. Each F_4 line consisted of one double row five meters in length, with a total of 70 plants per line. The third cycle of selection in the pedigree method was made by selecting in bulk the five most desirable agronomic lines from each of the 50 F_4 populations in each cross. A total of 30 F_5 lines were obtained to evaluate the pedigree method, five lines from each of the six crosses.

Modified Bulk Two Method (MB2)

From the second three double rows of each of the six F_2 populations, the 10 best F_2 plants were visually selected based on agronomic characteristics. This constituted the first cycle of selection for the MB2 method. Two double rows, five meters long for each of these 10 F_2 plants, were space planted at CIANO in the fall of 1978. The second cycle of selection for the MB2 method was made by visually selecting the five most desirable F_3 plants within each of the 10 F_3 families of each cross. The F_4 seed from the five F_3 plants selected were mixed together and a random sample of seed was used to space plant four double rows five meters in length at CIANO during the fall of 1979. At harvest time, this F_4 population was handled in bulk and one F_5 population was obtained. A total of six F_5 populations were obtained to evaluate the MB2 method, one population from each of the six crosses.

Modified Bulk One Method (MB1)

For the MB1 method, the selection procedure followed was the same as the MB2 method up to the F_3. By then, one cycle of selection was completed. One F_3 plant was selected at random from each of the 10 F_3 families of each cross planted at CIANO in the fall of 1978. This was done by fixing the row as well as the plant number within each F_3 family, i.e., selecting the fifth plant from the second row within each F_3 family. The F_4 seed from each of the 10 randomly selected F_3 plants was mixed together and a random sample of seed was used to space plant four double rows five meters long at CIANO during the fall of 1979. At harvest time, this F_4 population was handled in bulk and one F_5 population was obtained. A total of six F_5

populations were obtained to evaluate the MB1 method, one population from each of the six crosses.

Bulk Method (B)

The bulk method of selection in each of the six F_2 crosses was followed by cutting the remaining (unselected) F_2 plants, plus the remaining seed from the selected F_2 plants of the other methods of selection. For each cross, a random sample of seed was used to space plant four double F_3 rows at CIANO during the fall of 1978. At harvest time, the F_3 populations were cut in bulk and a random sample of seed was used to space plant four double F_4 rows at CIANO in the fall of 1979. This F_4 population was cut in bulk and one F_5 bulk population was obtained. A grand total of six F_5 populations were obtained to evaluate the bulk method, one population from each of the six crosses.

The 30 F_5 lines from the pedigree method, and six F_5 populations each from the MB2, MB1, and bulk methods, were arranged in a six replication split plot design to be evaluated for several agronomic characters at El Batan Experimental Station during the summer of 1980. Crosses were considered as whole plots and methods of selection comprising the subplots. An experimental plot consisted of six single rows 5 m in length. Spacing between rows was 30 cm, and seeding rate was 120 kg/ha. Prior to seeding the experiment, 150 kg/ha of nitrogen and 80 kg/ha of phosphorus as P_2O_5 were applied. The plots were irrigated four times during the growing season to avoid any possible water stress. All plots were kept weed-free by using the herbicide Tribunil at the rate of 2.0 kg/ha with pre-emergence application.

Throughout the duration of this study the fungicide Bayleton at the rate of .75 kg/ha was sprayed to control the rust diseases as well as Fusarium. No attempt was made to select for disease resistance.

Three simply inherited agronomic traits and four quantitative characters were measured for each treatment in this experiment. These are:

Height. Plant height was obtained at maturity by measuring from the base of the crown to the tip of the spike of the main tiller, excluding awns, if present.

Flowering. Flowering date was obtained for each plot by recording the date when the spikes on the main tillers were 50 percent exposed. The number of days were recorded as days after planting.

Maturity. Plants within plots were considered physiologically mature when 50 to 60 percent of the stems had turned yellow. Maturity was recorded as the number of days after planting.

100 kernel weight. 100 kernel weight was recorded in grams, by weighing 100 kernels randomly selected from each plot.

Spikes per meter. Number of spikes per meter was recorded by counting the number of fertile heads in one linear meter.

Kernels per spike. Kernel number per spike was obtained by cutting five heads at random from each plot, counting the total number of seeds and dividing by five.

Yield. Grain yield was recorded in grams on a per plot basis. Seed was air-dried to uniform moisture before weighing.

Standard statistical procedures, including the analysis of variance, Duncan's Multiple Range, and the Least Significant Difference tests for multiple comparisons, were used throughout the course of this investigation.

EXPERIMENTAL RESULTS

The results of this investigation will be presented with regard to the performance of eight F_5 lines derived from each of six winter by spring wheat crosses. The performance of the F_5 lines was evaluated in terms of the effectiveness of 0, 1, 2, and 3 cycles of phenotypic or visual selection for seven agronomic traits. For all comparisons, the bulked lines where no artificial selection was practiced are regarded as the check or base population within each cross.

A favorable environment for plant growth and development was experienced during the final year of this study. No limiting factors such as disease or frost were present with the average grain yield of 5.2 tons per hectare being realized for the plots.

Analysis of Variance

To determine if statistically significant differences existed for the seven agronomic traits when crosses, lines within crosses, and methods (cycles of selection) were considered, an analysis of variance was conducted. The results of this analysis are presented in Table 1. The sources of variation consisted of replications, crosses as main plots, and its respective replication x crosses error (a) to test differences among crosses. The eight lines within each of the six crosses representing methods and cycles of selection were considered as sub-plots. In the same table, the methods x crosses interaction term is also presented. Since we were also interested in

TABLE 1. OBSERVED MEAN SQUARE VALUES FOR SEVEN AGRONOMIC CHARACTERS OBTAINED FROM THE COMPARISON OF EIGHT F_5 LINES REPRESENTING FOUR METHODS OF SELECTION WITHIN EACH OF SIX WINTER BY SPRING WHEAT CROSSES. EL BATAN, MEXICO, 1980.

Source of variation	df	Plant height	Flowering date	Maturity date	100 kernel weight	spikes per meter	kernels per spike	yield per plot
Replications	5	405.3**	160.5**	306.6**	0.43*	1885.6*	151.3*	922,501**
Crosses	5	2456.0**	81.2*	313.0**	0.56**	3482.8**	88.2$^{n.s.}$	539,983**
Error (a)	25	56.4	27.2	76.6	0.15	651.2	42.9	87,696
Lines/Crosses	42	478.2**	105.0**	131.4**	1.41**	952.6**	81.7**	233,257**
Methods	3	297.1**	54.6**	136.6**	1.46**	1262.3*	75.1**	62,703$^{n.s.}$
Methods x Crosses	15	435.6**	99.1**	126.0**	1.76**	772.0*	63.6**	164,002**
Lines/Pedigree/Crosses	24	527.4**	115.0**	134.2**	1.19**	1026.8**	93.8**	297,860**
Error (b)	210	29.8	2.3	6.8	0.08	407.6	18.9	58,688
TOTAL	287							
CV (a) %		7.1	8.6	7.4	9.9	17.9	15.4	16.0
CV (b) %		5.2	2.5	2.2	7.4	14.2	10.2	13.1

*Significant at the 5 percent probability level.

**Significant at the 1 percent probability level.

the comparison of each of the five lines resulting from the pedigree method for each cross, we computed the lines within the pedigree method within crosses interaction. Finally the error (b), to test differences among lines within crosses, methods, and their respective interactions, is also provided.

According to the observed mean square values, a significant replication effect for all seven agronomic characters was present. Differences were noted between crosses for plant height, flowering and maturity dates, 100 kernel weight, number of spikes per meter, and grain yield per plot. No difference was found between the crosses for number of kernels per spike. The lines within each of the crosses behaved differently for all seven agronomic traits. Differences were found between methods for plant height, flowering and maturity dates, 100 kernel weight, spikes per meter, and number of kernels per spike. However, the methods were not different for the quantitative character grain yield. The interactions methods x crosses and lines within the pedigree method within crosses were found to be significant for all seven agronomic characters.

Coefficients of variation (C.V.) for the main plots, crosses, were low for plant height, flowering, maturity, and 100 kernel weight: 7.1, 8.6, 7.4, and 9.9, respectively. The C.V. values for grain yield per plot, spikes per meter, and kernels per spike were relatively high: 16.0, 17.9, and 15.4, respectively.

Coefficients of variation (C.V.) for subplots were low for plant height, flowering, maturity, 100 kernel weight, and kernels per spike:

5.2, 2.5, 2.2, 7.4, and 10.2, respectively. The C.V. values for grain yield per plot and spikes per meter were relatively high, 13.1 and 14.2, respectively.

Performance of the Winter by Spring Crosses

Mean values for plant height, flowering, and maturity dates, for the F_5 lines involving all six crosses are shown in Table 2. The F_5 lines from the cross Kavkaz-Cocoraque 75 were the shortest (98.50 cm) with W. R. Mace-Torim 73 being the tallest. Crosses with Kavkaz as the winter parent were consistently shorter. There were only four days' difference in flowering date among the six crosses being evaluated. The cross W. R. Mace-Cocoraque 75 was the earliest in flowering date; however, it was not different from the crosses W. R. Mace-Siete Cerros 66, Kavkaz-Cocoraque 75 and W. R. Mace-Torim 73.

Maturity date averaged 118.73 days over all crosses. It is interesting to note that the crosses W. R. Mace-Cocoraque 75 and W. R. Mace-Siete Cerros 66 were consistently the earliest crosses for both flowering and maturity dates.

Mean values for 100 kernel weight, spikes per meter, kernels per spike, and grain yield per plot for the F_5 lines involving all six crosses are shown in Table 3. 100 kernel weight varied from 4.02 to 3.73 gm for W. R. Mace-Siete Cerros 66 and W. R. Mace-Torim 73, respectively. Cross W. R. Mace-Siete Cerros 66 had the heaviest 100 kernel weight (4.02 gm), however, three other crosses--Kavkaz-

TABLE 2. MEAN VALUES FOR PLANT HEIGHT, FLOWERING, AND MATURITY DATES FOR EIGHT F_5 LINES WITHIN EACH OF SIX WINTER BY SPRING WHEAT CROSSES GROWN AT EL BATAN, MEXICO, 1980.

Cross	Plant height (cm)	Cross	Flowering Date	Cross	Maturity Date
Kavkaz-Cocoraque 75	98.50 a*	W.R. Mace-Cocoraque 75	58.81 c	W.R. Mace-Cocoraque 75	115.54 c
Kavkaz-Torim 73	99.94 a	W.R. Mace-7 Cerros 66	59.40 bc	W.R. Mace-7 Cerros 66	116.83 bc
Kavkaz-7 Cerros 66	101.71 a	Kavkaz-Cocoraque 75	60.44 abc	Kavkaz-Cocoraque 75	117.51 bc
W.R. Mace-7 Cerros 66	105.69 b	W.R. Mace-Torim 73	61.13 abc	Kavkaz-Torim 73	119.84 ab
W.R. Mace-Cocoraque 75	112.33 c	Kavkaz-7 Cerros 66	61.56 ab	W.R. Mace-Torim 73	120.18 ab
W.R. Mace-Torim 73	116.23 d	Kavkaz-Torim 73	62.21 a	Kavkaz-7 Cerros 66	122.48 a
Average	105.73		60.59		118.73

*Duncan's multiple range test. Means with the same letter are not significantly different at the 5 percent probability level.

TABLE 3. MEAN VALUES FOR 100 KERNEL WEIGHT, SPIKES PER METER, KERNELS PER SPIKE, AND GRAIN YIELD PER PLOT FOR EIGHT F_5 LINES WITHIN EACH OF SIX WINTER BY SPRING WHEAT CROSSES GROWN AT EL BATAN, MEXICO, 1980.

Cross	100 kernel weight (gm)	Cross	Spikes per meter	Cross	Kernels per spike	Cross	Yield per plot (gm)
W.R. Mace-7 Cerros 66	4.02 a*	Kavkaz-Torim 73	151.13 a	W.R. Mace-Torim 73	44.25 a	Kavkaz-Cocoraque 75	1973.02 a
Kavkaz-Cocoraque 75	3.95 a	W.R. Mace-7 Cerros 66	149.84 a	W.R. Mace-Cocoraque75	43.39 a	Kavkaz-Torim 73	1921.10 ab
Kavkaz-Torim 73	3.88 ab	Kavkaz-Cocoraque 75	146.38 ab	Kavkaz-Cocoraque 75	43.11 a	Kavkaz-7 Cerros 66	1869.90 ab
W.R. Mace-Cocoraque 75	3.85 ab	Kavkaz-7 Cerros 66	139.80 abc	Kavkaz-7 Cerros 66	42.60 a	W.R. Mace-Cocoraque 75	1842.92 ab
Kavkaz-7 Cerros 66	3.77 b	W.R. Mace-Cocoraque75	135.20 bc	Kavkaz-Torim 73	41.25 a	W.R. Mace-7 Cerros 66	1800.94 b
W.R. Mace-Torim 73	3.73 b	W.R. Mace-Torim 73	129.83 c	W.R. Mace-7 Cerros 66	40.68 a	W.R. Mace-Torim 73	1667.50 c
Average	3.87		142.03		42.55		1845.90

*Duncan's multiple range test. Means with the same letter are not significantly different at the 5 percent probability level.

Cocoraque 75, Kavkaz-Torim 73, and W. R. Mace-Cocoraque 75--were not much different.

The F_5 lines from the cross Kavkaz-Torim 73 had the highest number of spikes per meter (151.13 spikes) with W. R. Mace-Torim 73 being the lowest. Crosses with Kavkaz as the winter parent were consistently high for this character. For the spring parent, Siete Cerros 66 was involved in the highest number of spikes per meter combination. When the character number of kernel per spike is considered no difference were observed among the crosses. Grain yield per plot ranged from low 1667.50 gm for W. R. Mace-Torim 73 to a high of 1973.02 gm for the cross Kavkaz-Cocoraque 75. The average yield for the six crosses was 1845.90 gm. Those crosses where Kavkaz was the winter parent were consistently higher yielding. For the spring parent Cocoraque 75 was involved in the highest yielding combinations.

Performance of F_5 Lines as Influenced by Methods or Cycles of Selection

In Table 4, the lines identified 1-5 resulted from the Pedigree (P) method with three cycles of visual selection. Line number 6 represents the Modified Bulk 2 (MB2) method or two cycles of selection. The 7th line is noted as Modified Bulk 1 (MB1) and had only one cycle of selection. The 8th line was derived according to the Bulk (B) method where no artificial selection was practiced. As previously noted this line is considered as the check or base population.

The mean values for grain yield for the eight F_5 lines

TABLE 4. GRAIN YIELD MEAN VALUES FOR THE EIGHT F_5 LINES REPRESENTING FOUR METHODS OF SELECTION WITHIN EACH OF THREE WINTER BY SPRING WHEAT CROSSES GROWN AT EL BATAN, MEXICO, 1980.

Kavkaz - 7 Cerros 66			Kavkaz - Cocoraque 75			Kavkaz - Torim 73		
Line	Method	$\bar{X}$ Yield per plot (gm)	Line	Method	$\bar{X}$ Yield per plot (gm)	Line	Method	$\bar{X}$ Yield per plot (gm)
2	P	2,337.50 a	3	P	2,258.33 a	8	B	2,128.33 a
5	P	2,162.50 a	5	P	2,180.00 ab	7	MB1	2,013.00 ab
7	MBI	2,105.83 a	8	B	2,174.17 ab	2	P	1,965.00 ab
4	P	1,789.17 b	7	MB1	2,026.67 ab	4	P	1,940.00 ab
8	B	1,788.33 b	6	MB2	1,895.83 bc	3	P	1,898.33 ab
3	P	1,683.33 b	4	P	1,893.33 bc	5	P	1,869.17 ab
6	MB2	1,597.50 b	1	P	1,696.67 c	1	P	1,786.67 b
1	P	1,495.00 b	2	P	1,659.17 c	6	MB2	1,768.33 b
	$\bar{P}$	1,893.50		$\bar{P}$	1,937.50		$\bar{P}$	1,891.83

Comparisons:

- Means with the same letter within a column are not significantly different by Duncan's Multiple Range Test at the 5 percent probability level.
- $LSD_{.05}$ = 212.35 is given for the comparison of $\bar{P}$ with B, MB1, and MB2 methods.
- $LSD_{.05}$ = 274.14 is given for the comparison of B, MB1, and MB2 methods.

representing the four methods and various cycles of pheotypic selection for each of the six crosses are presented in Tables 4 and 5. In the same tables, and within each cross, the average grain yield per plot of the five lines of the P method ($\bar{P}$) are shown.

For the cross Kavkaz-Siete Cerros 66 (Table 4), grain yield per plot varied from 1495.0 to 2337.5 gm for lines 1 and 2, both representing the P method. Lines 2 and 5 of the P method were the highest in yield, however they were not different from line 7 representing the MB1 based on Duncan's test. The average grain yield of the five lines of the P method ($\bar{P}$) was the same when compared to the MB1 and MB2 methods. In the cross Kavkaz-Cocoraque 75 (Table 4), line 3 of the P method was the highest yielding line (2258.33 gm). No differences were found between this line and lines 8 and 7 of the B and MB1 methods, respectively. The average grain yield of the five lines of the P method ($\bar{P}$) was the same when compared to the MB1 and MB2 methods.

For the cross Kavkaz-Torim 73 (Table 4), the superiority of line 8 representing the B method and zero cycles of selection was noted. However, yield per plot for the B method was not different from line 7 involving the MB1 method and one cycle of selection and from lines 2, 4, 3, and 5 representing the P method. No differences were found between the average yield of the five lines of the P method and the MB1 and MB2 modifications of the B method.

The effect of visual selection on yield was evident when in the cross W. R. Mace-Siete Cerros 66 (Table 5) line 6 of the MB2 and two cycles of selection, line 7 of the MB1 and one cycle of selection and

TABLE 5. GRAIN YIELD MEAN VALUES FOR THE EIGHT F_5 LINES REPRESENTING FOUR METHODS OF SELECTION WITHIN EACH OF THREE WINTER BY SPRING WHEAT CROSSES GROWN AT EL BATAN, MEXICO, 1980.

Weique Red Mace - 7 Cerros 66				Weique Red Mace - Cocoraque 75				Weique Red Mace - Torim 73			
Line	Method	$\bar{X}$ Yield per plot (gm)		Line	Method	$\bar{X}$ Yield per plot (gm)		Line	Method	$\bar{X}$ Yield per plot (gm)	
6	MB2	2,064.17	a	5	P	2,036.67	a	1	P	1,865.83	a
3	P	1,973.33	ab	6	MB2	2,018.33	ab	5	P	1,794.17	ab
1	P	1,968.67	ab	8	B	1,913.33	ab	3	P	1,738.33	ab
4	P	1,870.50	ab	7	MB1	1,840.83	ab	2	P	1,690.00	ab
7	MB1	1,829.17	ab	3	P	1,778.33	ab	6	MB2	1,610.00	ab
8	B	1,686.67	bc	1	P	1,740.83	ab	7	MB1	1,590.83	ab
2	P	1,525.00	c	4	P	1,709.17	b	8	B	1,566.67	ab
5	P	1,490.00	c	2	P	1,705.83	b	4	P	1,484.17	b
	$\bar{P}$	1,765.50			$\bar{P}$	1,794.17			$\bar{P}$	1,714.50	

Comparisons:

- Means with the same letter within a column are not significantly different by Duncan's Multiple Range Test at the 5 percent probability level.
- $LSD_{.05}$ = 212.35 is given for the comparison of $\bar{P}$ with B, MB1, and MB2 methods.
- $LSD_{.05}$ = 274.14 is given for the comparison of B, MB1, and MB2 methods.

lines 3, 1, and 4 of the P method and three cycles of selection were found to be the same. These lines were superior from the B method representing natural selection.

In the cross W. R. Mace-Cocoraque 75 (Table 5) grain yield varied from 1705.83 gm for line 2 representing the P method to 2036.67 gm for line 5 of the same method. Line 5 of the P method was the highest yield, however, it was not found different from lines 6, 7, and 8 of the MB2, MB1 and B methods, respectively. In both crosses, W. R. Mace-Siete Cerros 66, and W. R. Mace-Cocoraque 75, the average grain yield of the five lines of the P method ($\bar{P}$) was the same when compared to the MB1 and B methods of selection.

A clear superiority of the P method was noted in the cross W. R. Mace-Torim 73 (Table 5). In that cross four lines representing the P method were the highest yielding, however they did not differ from lines 6, 7, and 8 of the MB2, MB1, and B methods, respectively. No difference between methods was found when the average grain yield of the five lines of the P method was compared with the other three methods of selection.

Plant height mean values for the eight F_5 lines representing four methods of breeding and different cycles of visual selection for each of the six crosses are presented in Tables 6 and 7. In the same tables, and within each cross, the average plant height of the five lines of the P method ($\bar{P}$) are shown.

The superiority of the P method and the effectiveness of visual selection when dealing with this simple inherited agronomic character

TABLE 6. PLANT HEIGHT MEAN VALUES FOR THE EIGHT F_5 LINES REPRESENTING FOUR METHODS OF SELECTION WITHIN EACH OF THREE WINTER BY SPRING WHEAT CROSSES GROWN AT EL BATAN, MEXICO, 1980.

Kavkaz - 7 Cerros 66				Kavkaz - Cocoraque 75				Kavkaz - Torim 73			
Line	Method	$\bar{X}$ Plant height (cm)		Line	Method	$\bar{X}$ Plant height (cm)		Line	Method	$\bar{X}$ Plant height (cm)	
3	P	80.33	b	8	B	83.33	c	2	P	78.33	d
5	P	82.17	b	3	P	92.50	b	1	P	84.83	c
4	P	96.33	c	5	P	95.83	b	8	B	103.17	b
1	P	102.67	d	6	MB2	98.17	b	7	MB1	103.50	b
7	MB1	111.50	a	7	MB1	98.50	b	6	MB2	105.00	b
2	P	112.17	a	4	P	98.83	b	4	P	106.33	ab
6	MB2	114.00	a	2	P	110.17	a	5	P	106.50	ab
8	B	114.50	a	1	P	110.17	a	3	P	111.83	a
	$\bar{P}$	94.73			$\bar{P}$	101.60			$\bar{P}$	97.56	

Comparisons:

- Means with the same letter within a column are not significantly different by Duncan's Multiple Range Test at the 5 percent probability level.

- $LSD_{.05}$ = 4.78 is given for the comparison of $\bar{P}$ with B, MB1, and MB2 methods.

- $LSD_{.05}$ = 6.18 is given for the comparison of B, MB1, and MB2 methods.

TABLE 7. PLANT HEIGHT MEAN VALUES FOR THE EIGHT F_5 LINES REPRESENTING FOUR METHODS OF SELECTION WITHIN EACH OF THREE WINTER BY SPRING WHEAT CROSSES GROWN AT EL BATAN, MEXICO, 1980.

Weique Red Mace - Cerros 66			Weique Red Mace - Cocoraque 75			Weique Red Mace - Torim 73		
Line	Method	$\bar{X}$ Plant height (cm)	Line	Method	$\bar{X}$ Plant height (cm)	Line	Method	$\bar{X}$ Plant height (cm)
2	P	100.00 b	1	P	107.00 b	2	P	111.00 d
3	P	101.50 b	7	MB1	109.33 ab	1	P	111.83 cd
4	P	101.83 b	8	B	109.33 ab	8	B	112.50 cd
5	P	103.50 b	2	P	113.17 ab	6	MB2	115.33 bcd
1	P	105.33 b	6	MB2	113.33 ab	7	MB1	115.33 bcd
6	MB2	105.83 b	4	P	115.33 a	5	P	118.67 abc
8	B	113.50 a	5	P	115.33 a	4	P	121.00 ab
7	MB1	114.00 a	3	P	115.83 a	3	P	124.17 a
	$\bar{P}$	102.43		$\bar{P}$	113.33		$\bar{P}$	117.33

Comparisons:

- Means with the same letter within a column are not significantly different by Duncan's Multiple Range Test at the 5 percent probability level.
- $LSD_{.05}$ = 4.78 is given for the comparison of $\bar{P}$ with B, MB1, and MB2 methods.
- $LDS_{.05}$ = 6.18 is given for the comparison of B, MB1, and MB2 methods.

(plant height) were evident in three of the six crosses studied: Kavkaz-Siete Cerros 66, Kavkaz-Torim 73, and W. R. Mace-Siete Cerros 66 (Tables 6 and 7). Significant differences were found between the average plant height of the five lines of the P method ($\bar{P}$) and the other three methods of selection for the crosses Kavkaz-Siete Cerros 66 and Kavkaz-Torim 73. In the cross W. R. Mace-Siete Cerros 66, no difference existed between this averaged $\bar{P}$ method and the MB2.

The B method represented by line 8 in the cross Kavkaz-Cocoraque 75 (Table 6) was the shortest in plant height and was found to be different from the other methods of selection. In this cross, the average plant height of the five lines of the P method was found to be the same when compared to the MB2 and MB1 modification of the B method.

A lack of consistency regarding the best method in reducing plant height was evident in the crosses W. R. Mace-Cocoraque 75 and W. R. Mace-Torim 73 (Table 7). There were no clear differences noted between methods.

In Tables 8 and 9, the flowering date mean values for the eight F_5 lines representing four methods of breeding and different cycles of phenotypic selection for each of the six crosses are presented. The average flowering date of the five lines of the P method within each cross is also shown in the same tables.

A clear superiority of the P method over the other methods of selection was noted in the cross Kavkaz-Siete Cerros 66 (Table 8). In that cross, five lines of the P method were consistently earlier in flowering. The same results were found when the average flowering

TABLE 8. FLOWERING DATE MEAN VALUES FOR THE EIGHT F_5 LINES REPRESENTING FOUR METHODS OF SELECTION WITHIN EACH OF THREE WINTER BY SPRING WHEAT CROSSES GROWN AT EL BATAN, MEXICO, 1980.

Kavkaz - 7 Cerros 66				Kavkaz - Cocoraque 75				Kavkaz - Torim 73			
Line	Method	$\bar{X}$ Flowering Date		Line	Method	$\bar{X}$ Flowering Date		Line	Method	$\bar{X}$ Flowering Date	
2	P	57.2	d	7	MB1	52.0	c	8	B	58.2	d
5	P	59.8	c	3	P	57.8	b	4	P	61.2	c
1	P	60.3	c	2	P	58.0	b	7	MB1	61.2	c
3	P	60.3	c	6	MB2	59.8	a	1	P	62.0	bc
4	P	60.7	bc	5	P	60.2	a	2	P	63.3	ab
6	MB2	62.2	b	8	B	61.0	a	3	P	63.7	ab
7	MB1	65.8	a	4	P	65.2	d	5	P	63.8	ab
8	B	66.2	a	1	P	69.5	e	6	MB2	64.3	a
	$\bar{P}$	59.6			$\bar{P}$	62.1			$\bar{P}$	62.8	

Comparisons:

- Means with the same letter within a column are not significantly different by Duncan's Multiple Range Test at the 5 percent probability level.
- $LSD_{.05}$ = 1.34 is given for the comparison of $\bar{P}$ with B, MB1, and MB2 methods.
- $LSD_{.05}$ = 1.73 is given for the comparison of B, MB1, and MB2 methods.

TABLE 9. FLOWERING DATE MEAN VALUES FOR THE EIGHT F_5 LINES REPRESENTING FOUR METHODS OF SELECTION WITHIN EACH OF THREE WINTER BY SPRING WHEAT CROSSES GROWN AT EL BATAN, MEXICO, 1980.

Weique Red Mace - 7 Cerros 66				Weique Red Mace - Cocoraque 75				Weique Red Mace - Torim 73			
Line	Method	$\bar{X}$ Flowering Date		Line	Method	$\bar{X}$ Flowering Date		Line	Method	$\bar{X}$ Flowering Date	
3	P	48.8	b	7	MB1	54.8	e	5	P	56.3	e
4	P	49.2	b	1	P	57.2	d	2	P	59.7	d
6	MB2	56.2	c	5	P	57.8	d	3	P	60.7	cd
7	MB1	59.3	d	4	P	58.2	cd	8	B	61.3	bcd
2	P	63.7	a	8	B	59.8	bc	1	P	62.2	abc
1	P	65.2	a	6	MB2	60.2	b	6	MB2	62.7	ab
5	P	65.5	a	3	P	60.5	ab	4	P	62.8	ab
8	B	67.3	e	2	P	62.0	a	7	MB1	63.3	a
	$\bar{P}$	58.5			$\bar{P}$	59.1			$\bar{P}$	60.3	

Comparisons:

- Means with the same letter within a column are not significantly different by Duncan's Multiple Range Test at the 5 percent probability level.

- $LSD_{.05}$ = 1.34 is given for the comparison of $\bar{P}$ with B, MB1, and MB2 methods.

- $LSD_{.05}$ = 1.73 is given for the comparison of B, MB1, and MB2 methods.

date of the five lines of the P method was compared with the other three methods of selection.

For the cross Kavkaz-Cocoraque 75 (Table 8), flowering date ranged from 52.0 days for line 7 representing the MB1 method to 69.5 days for line 1 of the P method. Line 7 of the MB1 method was the earliest in heading and was found different from the other three methods. No difference in flowering date was found between the average of the five lines of the P method and the B method of breeding.

The B method represented by line 8 was found to be the earliest in flowering date for the cross Kavkaz-Torim 73 (Table 8). This line was different from the other lines of the other methods of selection. The average of the five lines of the P method for flowering date was found to perform differently from the other lines representing the other three methods of selection.

The effectiveness of visual selection in reducing the number of days to flowering was again noted in the crosses W. R. Mace-Siete Cerros 66 and W. R. Mace-Torim 73 (Table 9). Lines 3 and 5 of the P method were the earliest in flowering date in both crosses and were different from the other methods of selection. No difference was found between the average flowering date of the five lines of the P method and the MB1 method in the cross W. R. Mace-Torim 73, no significant differences were present between the averaged P method and the B method of breeding.

Within the cross W. R. Mace-Cocoraque 75 (Table 9) flowering date of line 7 for the MB1 method was much earlier than the lines of the other methods of selection. No difference was found between the average flowering date of the five lines of the P method and the lines from the MB2 and B methods.

The maturity date mean values for the eight F_5 lines representing the four methods and various cycles of visual selection for each of the six crosses are shown in Tables 10 and 11. In the same tables, and within each cross, the average maturity date of the five lines of the pedigree method is shown.

The effectiveness of visual selection when dealing with the qualitative character maturity date was again noted in four of the six crosses under investigation. In these crosses--Kavkaz-Siete Cerros 66, W. R. Mace-Siete Cerros 66, W. R. Mace-Cocoraque 75, and W. R. Mace-Torim 73 (Tables 10 and 11)--lines of the P method were the earliest in maturity and only in two crosses were they similar to the MB2 method. The effect of phenotypic selection in reducing maturity date was confirmed in the cross Kavkaz-Cocoraque 75 (Table 10). In this particular cross, even with one cycle of visual selection as represented by the superiority of line 7 of the MB1 method, it was possible to reduce the number of days to maturity. No evidence of the effect of visual selection was detected in the cross Kavkaz-Torim 73 (Table 10). Lines 1 and 4 representing the P method were the earliest in heading, however, they were not different from the B method or zero cycles of selection. When the average maturity date of the five lines of the P method was compared with the other

TABLE 10. MATURITY DATE MEAN VALUES FOR THE EIGHT F_5 LINES REPRESENTING FOUR METHODS OF SELECTION WITHIN EACH OF THREE WINTER BY SPRING WHEAT CROSSES GROWN AT EL BATAN, MEXICO, 1980.

Kavkaz - 7 Cerros 66			Kavkaz - Cocoraque 75			Kavkaz - Torim 73		
Line	Method	$\bar{X}$ Maturity Date	Line	Method	$\bar{X}$ Maturity Date	Line	Method	$\bar{X}$ Maturity Date
6	MB2	119.2 d	7	MB1	104.0 e	1	P	116.5 b
4	P	119.7 cd	5	P	111.7 d	4	P	117.3 b
1	P	120.5 bcd	3	P	114.8 c	8	B	117.5 b
3	P	122.7 abc	4	P	119.5 b	7	MB1	120.5 a
7	MB1	123.5 ab	2	P	120.3 b	6	MB2	120.7 a
2	P	123.7 ab	6	MB2	120.5 b	5	P	121.3 a
8	B	125.2 a	8	B	124.5 a	2	P	122.2 a
5	P	125.3 a	1	P	124.8 a	3	P	122.7 a
	$\bar{P}$	122.38		$\bar{P}$	118.22		$\bar{P}$	120.0

Comparisons:

- Means with the same letter within a column are not significantly different by Duncan's Multiple Range Test at the 5 percent probability level.

- $LSD_{.05}$ = 2.29 is given for the comparison of $\bar{P}$ with B, MB1, and MB2 methods.

- $LSD_{.05}$ = 2.96 is given for the comparison of B, MB1, and MB2 methods.

TABLE 11. MATURITY DATE MEAN VALUES FOR THE EIGHT F_5 LINES REPRESENTING FOUR METHODS OF SELECTION WITHIN EACH OF THREE WINTER BY SPRING WHEAT CROSSES GROWN AT EL BATAN, MEXICO, 1980.

Weique Red Mace - 7 Cerros 66			Weique Red Mace - Cocoraque 75			Weique Red Mace - Torim 73		
Line	Method	$\bar{X}$ Maturity Date	Line	Method	$\bar{X}$ Maturity Date	Line	Method	$\bar{X}$ Maturity Date
4	P	105.8 d	1	P	109.7 d	6	MB2	117.3 d
3	P	107.2 d	7	MB1	112.7 c	1	P	118.2 cd
6	MB2	112.2 e	5	P	114.7 bc	5	P	118.3 cd
7	MB1	118.5 c	6	MB2	116.0 b	2	P	119.8 bcd
5	P	120.3 bc	8	B	116.7 ab	3	P	120.2 bcd
1	P	123.3 ab	4	P	117.3 ab	8	B	121.3 abc
2	P	123.3 ab	3	P	117.5 ab	4	P	122.3 ab
8	B	124.0 a	2	P	119.7 a	7	MB1	124.0 a
	$\bar{P}$	115.98		$\bar{P}$	115.78		$\bar{P}$	119.76

Comparisons:

- Means with the same letter within a column are not significantly different by Duncan's Multiple Range Test at the 5 percent probability level.
- $LSD_{.05}$ = 2.29 is given for the comparison of $\bar{P}$ with B, MB1, and MB2 methods.
- $LSD_{.05}$ = 2.96 is given for the comparison of B, MB1, and MB2 methods.

methods, this averaged ($\bar{P}$) method was consistently the same to the MB1 and MB2 methods in the crosses having Kavkaz as the winter parent. In the crosses W. R. Mace-Cocoraque 75 and W. R. Mace-Torim 73, this averaged $\bar{P}$ was the same to the B and MB2 methods. No differences between the averaged $\bar{P}$ method and the other methods were found within the cross W. R. Mace-Siete Cerros 66.

The 100 kernel weight mean values for the eight F_5 lines representing the four methods and various cycles of phenotypic selection for each of the six crosses are shown in Tables 12 and 13. Lines 7 and 8 from the MB1 and B methods, respectively, were the heaviest in 100 kernel weight for the cross Kavkaz-Siete Cerros 66 (Table 12). Line 7 from the MB1 method was also the heaviest in 100 kernel weight for the cross Kavkaz-Cocoraque 75 (Table 12). This line was different from the other lines representing the other three methods of selection.

A lack of evidence regarding the effect of visual selection was noted in the cross Kavkaz-Torim 73 (Table 12). In this cross, no differences were found between lines 8, 7, 6, and 5 representing the B, MB1, MB2, and P methods, respectively.

A clear superiority of the P method and the effect of visual selection was noted in the crosses W. R. Mace-Siete Cerros 66 and W. R. Mace-Torim 73 (Table 13). For both crosses, lines 1 and 2 of the P method were the heaviest in 100 kernel weight and were found different from the other lines of the other methods.

The effect of phenotypic selection in raising 100 kernel weight was confirmed in the cross W. R. Mace-Cocoraque 75 (Table 13). Lines

TABLE 12. 100 KERNEL WEIGHT MEAN VALUES FOR THE EIGHT F_5 LINES REPRESENTING FOUR METHODS OF SELECTION WITHIN EACH OF THREE WINTER BY SPRING WHEAT CROSSES GROWN AT EL BATAN, MEXICO, 1980.

Kavkaz - 7 Cerros 66				Kavkaz - Cocoraque 75				Kavkaz - Torim 73			
Line	Method	$\bar{X}$ 100 Kernel weight		Line	Method	$\bar{X}$ 100 Kernel weight		Line	Method	$\bar{X}$ 100 Kernel weight	
7	MB1	4.55	a	7	MB1	4.83	c	8	B	4.46	a
8	B	4.24	ab	3	P	4.48	a	7	MB1	4.44	a
6	MB2	4.08	bc	4	P	4.44	a	6	MB2	4.38	a
2	P	3.75	cd	2	P	4.04	d	5	P	4.33	a
3	P	3.74	cd	1	P	3.67	b	3	P	3.81	b
1	P	3.61	d	5	P	3.59	b	4	P	3.81	b
5	P	3.16	e	6	MB2	3.45	b	2	P	2.97	c
4	P	3.01	e	8	B	3.11	e	1	P	2.87	c
	$\bar{P}$	3.45			$\bar{P}$	4.04			$\bar{P}$	3.56	

Comparisons:

- Means with the same letter within a column are not significantly different by Duncan's Multiple Range Test at the 5 percent probability level.
- $LSD_{.05}$ = 0.25 is given for the comparison of $\bar{P}$ with B, MB1, and MB2 methods.
- $LSD_{.05}$ = 0.325 is given for the comparison of B, MB1, and MB2 methods.

TABLE 13. 100 KERNEL WEIGHT MEAN VALUES FOR THE EIGHT F_5 LINES REPRESENTING FOUR METHODS OF SELECTION WITHIN EACH OF THREE WINTER BY SPRING WHEAT CROSSES GROWN AT EL BATAN, MEXICO, 1980.

Weique Red Mace - 7 Cerros 66				Weique Red Mace - Cocoraque 75				Weique Red Mace - Torim 73			
Line	Method	$\bar{X}$ 100 Kernel weight		Line	Method	$\bar{X}$ 100 Kernel weight		Line	Method	$\bar{X}$ 100 Kernel weight	
1	P	4.88	d	3	P	4.10	a	2	P	4.23	c
3	P	4.38	a	6	MB2	4.07	a	5	P	3.82	a
6	MB2	4.31	a	4	P	3.94	ab	7	MB1	3.76	a
8	B	4.11	ab	5	P	3.88	ab	4	P	3.73	ab
4	P	3.89	b	7	MB1	3.82	ab	1	P	3.69	ab
5	P	3.88	b	2	P	3.69	b	8	B	3.65	ab
7	MB1	3.50	c	1	P	3.66	b	6	MB2	3.56	ab
2	P	3.21	c	8	B	3.66	b	3	P	3.38	b
	$\bar{P}$	4.05			$\bar{P}$	3.85			$\bar{P}$	3.77	

Comparisons:

- Means with the same letter within a column are not significantly different by Duncan's Multiple Range Test.
- $LSD_{.05}$ = 0.25 is given for the comparison of $\bar{P}$ with B, MB1, and MB2 methods.
- $LSD_{.05}$ = 0.325 is given for the comparison of B, MB1, and MB2 methods.

3, 6, and 7 involving 3, 2, and 1 cycles of phenotypic selection, respectively, were the heaviest in 100 kernel weight when compared to line 8 of the B method. No differences were found between the average 100 kernel weight of the five lines of the P method and the other three methods of selection for the crosses Kavkaz-Cocoraque 75, W. R. Mace-Torim 73, W. R. Mace-Cocoraque 75, and W. R. Mace-Siete Cerros 66. The average 100 kernel weight of the five lines of the P method was different from the other three methods of selection in the crosses Kavkaz-Siete Cerros 66 and Kavkaz-Torim 73.

In Tables 14 and 15, the number of spikes per meter mean values for the eight F_5 lines representing four methods of breeding and different cycles of selection for each of the six crosses are presented.

When dealing with this complex quantitative character, a lack of consistency regarding the effect of visual selection was found in four of the six crosses under investigation. These are: Kavkaz-Siete Cerros 66, Kavkaz-Cocoraque 75, Kavkaz-Torim 73, and W. R. Mace-Cocoraque 75 (Tables 14 and 15). There were no clear differences noted between methods. Opposite results were detected for the crosses W. R. Mace-Siete Cerros 66 and W. R. Mace-Torim 73 (Table 15). In both crosses the P and MB2 methods were the highest in number of spikes per meter and different from both the B and MB1.

The kernels per spike mean values for the eight F_5 lines representing the four methods and various cycles of visual selection for

TABLE 14. SPIKES PER METER MEAN VALUES FOR THE EIGHT F_5 LINES REPRESENTING FOUR METHODS OF SELECTION WITHIN EACH OF THREE WINTER BY SPRING WHEAT CROSSES GROWN AT EL BATAN, MEXICO, 1980.

Kavkaz - 7 Cerros 66				Kavkaz - Cocoraque 75				Kavkaz - Torim 73			
Line	Method	$\bar{X}$ Spikes/Meter		Line	Method	$\bar{X}$ Spikes/Meter		Line	Method	$\bar{X}$ Spikes/Meter	
8	B	155.3	a	6	MB2	164.0	a	1	P	170.5	a
4	P	147.0	ab	5	P	162.7	a	2	P	167.7	ab
2	P	145.7	ab	2	P	149.3	ab	8	B	160.0	abc
6	MB2	144.7	ab	1	P	148.3	ab	6	MB2	147.5	abc
5	P	143.7	ab	8	B	148.0	ab	3	P	144.0	bc
7	MB1	136.3	ab	4	P	147.0	ab	5	P	143.0	bc
1	P	123.7	b	3	P	126.7	b	7	MB1	140.0	c
3	P	122.0	b	7	MB1	125.0	b	4	P	136.3	c
	$\bar{P}$	136.42			$\bar{P}$	146.80			$\bar{P}$	152.30	

Comparisons:

- Means with the same letter within a column are not significantly different by Duncan's Multiple Range Test.
- $LSD_{.05}$ = 17.7 is given for the comparison of $\bar{P}$ with B, MB1, and MB2 methods.
- $LSD_{.05}$ = 22.85 is given for the comparison of B, MB1, and MB2 methods.

TABLE 15. SPIKES PER METER MEAN VALUES FOR THE EIGHT F_5 LINES REPRESENTING FOUR METHODS OF SELECTION WITHIN EACH OF THREE WINTER BY SPRING WHEAT CROSSES GROWN AT EL BATAN, MEXICO, 1980.

Weique Red Mace - 7 Cerros 66			Weique Red Mace - Cocoraque 75			Weique Red Mace - Torim 73		
Line	Method	$\bar{X}$ Spikes/Meter	Line	Method	X Spikes/Meter	Line	Method	$\bar{X}$ Spikes/Meter
2	P	176.3 a	3	P	144.7 a	6	MB2	149.0 a
4	P	170.3 ab	2	P	141.3 a	2	P	140.3 ab
8	B	149.7 bc	7	MB1	141.3 a	1	P	137.7 ab
1	P	143.0 c	6	MB2	135.7 a	5	P	130.0 ab
3	P	143.0 c	5	P	135.3 a	3	P	129.3 ab
5	P	142.7 c	4	P	133.0 a	8	B	122.0 b
7	MB1	140.0 c	8	B	130.0 a	4	P	116.0 b
6	MB2	133.7 c	1	P	120.3 a	7	MB1	114.3 b
	$\bar{P}$	155.06		$\bar{P}$	134.92		$\bar{P}$	130.66

Comparisons:

- Means with the same letter within a column are not significantly different by Duncan's Multiple Range Test.
- $LSD_{.05}$ = 17.7 is given for the comparison of $\bar{P}$ with B, MB1, and MB2 methods.
- $LSD_{.05}$ = 22.85 is given for the comparison of B, MB1, and MB2 methods.

each of the six crosses are presented in Tables 16 and 17.

Lines 5, 2, and 4 from the P method were the highest in kernels per spike in cross Kavkaz-Siete Cerros 66 (Table 16). These lines were found different from the lines of the other three methods of selection, indicating visual selection for this trait was effective in this particular cross. The effectiveness of phenotypic selection on this complex character was confirmed in the crosses Kavkaz-Torim 73 (Table 16), W. R. Mace-Siete Cerros 66, and W. R. Mace-Cocoraque 75 (Table 17). Even one cycle of visual selection resulted in a difference in number of kernels per spike when compared to the B method where only natural selection was involved.

A lack of progress through visual selection for number of kernels per spike was noted for the cross Kavkaz-Cocoraque 75 (Table 16). Lines 1 and 8 representing the P and B methods, respectively, were the highest for this character. The same effect was experienced in the cross W. R. Mace-Torim 73 (Table 17), where no differences between methods were found.

Correlation Coefficient Values for Seven Agronomic Characteristics

The correlation coefficient values for the seven agronomic characteristics studied involving eight F_5 lines derived from six winter by spring wheat crosses are presented in Table 18. In the cross Kavkaz-Siete Cerros 66, a negative association was observed between grain yield per plot and flowering date. For the cross Kavkaz-

TABLE 16. KERNELS PER SPIKE MEAN VALUES FOR THE EIGHT F_5 LINES REPRESENTING FOUR METHODS OF SELECTION WITHIN EACH OF THREE WINTER BY SPRING WHEAT CROSSES GROWN AT EL BATAN, MEXICO, 1980.

Kavkaz - 7 Cerros 66			Kavkaz - Cocoraque 75			Kavkaz - Torim 73		
Line	Method	$\bar{X}$ Kernels/Spike	Line	Method	$\bar{X}$ Kernels/Spike	Line	Method	$\bar{X}$ Kernels/Spike
5	P	49.6 a	1	P	49.9 a	3	P	44.8 a
2	P	46.8 ab	8	B	48.7 ab	7	MB1	42.8 ab
4	P	45.2 ab	5	P	44.2 bc	4	P	42.6 ab
1	P	43.3 bc	3	P	43.0 cd	5	P	42.2 ab
7	MB1	41.6 bcd	6	MB2	42.0 cde	2	P	39.8 ab
8	B	39.7 cd	2	P	41.8 cde	6	MB2	39.8 ab
6	MB2	38.2 cd	7	MB1	37.9 de	1	P	39.2 ab
3	P	36.4 d	4	P	37.4 e	8	B	38.8 b
	$\bar{P}$	44.26		$\bar{P}$	43.26		$\bar{P}$	41.72

Comparisons:

- Means with the same letter within a column are not significantly different by Duncan's Multiple Range Test.
- $LSD_{.05}$ = 3.81 is given for the comparison of $\bar{P}$ with B, MB1, and MB2 methods.
- $LSD_{.05}$ = 4.91 is given for the comparison of B, MB1, and MB2 methods.

TABLE 17. KERNELS PER SPIKE MEAN VALUES FOR THE EIGHT F_5 LINES REPRESENTING FOUR METHODS OF SELECTION WITHIN EACH OF THREE WINTER BY SPRING WHEAT CROSSES GROWN AT EL BATAN, MEXICO, 1980.

Weique Red Mace - 7 Cerros 66			Weique Red Mace - Cocoraque 75			Weique Red Mace - Torim 73		
Line	Method	$\bar{X}$ Kernels/Spike	Line	Method	$\bar{X}$ Kernels/Spike	Line	Method	$\bar{X}$ Kernels/Spike
2	P	48.5 a	5	P	47.8 a	7	MB1	46.7 a
7	MB1	47.2 a	3	P	47.7 a	3	P	45.5 a
8	B	40.5 b	2	P	45.6 ab	4	P	44.6 a
3	P	40.2 b	7	MB1	42.9 ab	2	P	44.2 a
5	P	39.7 b	4	P	41.3 b	1	P	43.6 a
6	MB2	39.5 b	8	B	41.0 b	5	P	43.6 a
4	P	35.6 bc	1	P	40.6 b	8	B	43.2 a
1	P	34.2 c	6	MB2	40.2 b	6	MB2	42.6 a
	$\bar{P}$	39.64		$\bar{P}$	44.60		$\bar{P}$	44.30

Comparisons:

- Means with the same letter within a column are not significantly different by Duncan's Multiple Range Test.

- $LSD_{.05}$ = 3.81 is given for the comparison of $\bar{P}$ with B, MB1, and MB2 methods.

- $LSD_{.05}$ = 4.91 is given for the comparison of B, MB1, and MB2 methods.

TABLE 18. CORRELATION COEFFICIENT VALUES FOR THE SEVEN AGRONOMIC CHARACTERISTICS STUDIED INVOLVING EIGHT F_5 LINES DERIVED FROM SIX WINTER BY SPRING WHEAT CROSSES, EL BATAN, MEXICO, 1980.

	Y I E L D P E R P L O T					
	Kavkaz - 7 Cerros 66	Kavkaz - Cocoraque 75	Kavkaz - Torim 73	W.R. Mace - 7 Cerros 66	W.R. Mace - Cocoraque 75	M.R. Mace- Torim 73
Plant Height	.000	-.397**	-.037	.173	.049	-.201
Flowering Date	-.288*	-.228	-.648**	-.399**	-.441**	-.546**
Maturity Date	-.208	-.316*	-.399**	-.417**	-.367*	-.626**
100 Kernel Weight	.103	.075	.254	.332*	.319*	.024
Spikes per Meter	.078	-.030	.126	-.218	-.112	.245
Kernels per Spike	.255	.008	-.033	-.224	.000	-.034

*Significant at the 5 percent probability level.

**Significant at the 1 percent probability level.

N = 48.

Cocoraque 75, negative associations were detected between yield per plot and plant height and maturity date. A negative association between yield and flowering and maturity dates were found for the cross Kavkaz-Torim 73. Within the crosses W. R. Mace-Siete Cerros 66 and W. R. Mace-Cocoraque 75, negative associations were found between yield and flowering and maturity dates, and a positive association with 100 kernel weight. Negative associations between grain yield per plot and flowering and maturity dates were found in the cross W. R. Mace-Torim 73.

It was thought that the correlation coefficients between grain yield and the yield components may be higher if only the Pedigree method was considered. Since similar results were obtained when the five lines of the Pedigree method within each cross were analyzed, these data were not included in the summary tables reported.

DISCUSSION

The main goal in plant breeding is to produce high-yielding cultivars in the most efficient manner possible in the investment of time, land, capital, and labour. Most of these expenditures are made in the selection phase of the breeding program. This becomes quite apparent when it is realized that plant breeding is based on probability. To increase the likelihood of finding the desired genotypes the breeder must achieve a compromise between the number of crosses made and the size of the resulting segregating populations within each cross evaluated. It is necessary, therefore, to develop more efficient selection methods whereby the most promising progeny can be identified earlier thus avoiding the necessity of growing unproductive materials in later generations following hybridization.

For maximum efficiency, selection should be started preferably in the F_2 generation. Although selection based on individual F_2 plants has been found to be effective for certain simply-inherited characters, it is generally ineffective for quantitatively inherited traits like grain yield (30,37). Besides the type of inheritance for specific characters, the total genetic variability available, the nature of gene action, and the environment, including a possible genotype x environmental interaction, are considered among the main factors influencing plant selection. For example, if a character is largely controlled by non-additive gene action, the breeder of self-pollinating species may be misled by selecting in early generations (F_2-F_4) since such genetic variation cannot be fixed in subsequent segregating populations in self-pollinated species. In fact, such a situation may even mask the additive genetic variation thus preventing the breeder from identifying the usable portion of the total genetic variance. There also appears to be a large genotype x environment interaction involved with quantitatively inherited traits. Therefore, for traits such as grain yield, early generation selection has not proven to be successful.

Currently, two extremes exist with regard to the type of selection methods utilized in the breeding self-fertilizing plant species. These are the Pedigree and Bulk methods. With the Pedigree system, the plant breeder visually selects individual plants within a between families from the F_2 through the F_5. The advantages of this method are (a) the ability to keep records of family lines of descent, (b) capability of pursuing genetic studies, and (c) ease in observing homogeneity within progeny rows in subsequent generations. The Pedigree system is particularly effective for qualitatively inherited traits; however, as previously noted, visual selection is not effective for quantitatively inherited traits like grain yield; therefore, a great deal of time, land, capital, and labor is spent in taking notes and propagating many poor-yielding strains in the first five segregating generations. A minimum of 400 to 1000 individual F_2 plants per cross are required to have a reasonable probability of obtaining desired segregates from a given cross. Thus, the number of crosses evaluated must be limited. Also, since wheat cultivars are solid seeded in commercial production, there is question whether or not the breeder can identify competitive genotypes under space planted conditions. The bulk method of breeding is the most economical system of obtaining homozygous lines after hybridization. It consists of planting a random sample of the population each generation, harvesting the plants in bulk, and replanting the following year. Natural selection is the only selection force acting on segregating populations. Its success as a plant breeding method is controversial due to the unpredicted direction of natural selection (7,23,25). There is also some question how much influence natural selection will have on four segregating populations (F_2-F_5). This method does offer the opportunity of evaluating many different crosses while still retaining a large number of plants per cross. Furthermore, the most competitive genotypes should surface as the populations are solid seeded (23). In actual practice, a compromise that encompasses some features of both systems is sometimes employed. A modified plant breeding procedure involving the desirable characteristics of each method would be highly beneficial to small grain breeders, especially where resources are limited as in many developing countries.

It was the objective of this study to compare two modifications of the Bulk method with the traditional Bulk and Pedigree systems for both qualitatively and quantitatively inherited traits. Therefore, the response to visual or phenotypic selection for both simple and complex traits was obtained for four different methods of selection. The four systems employed were: the Pedigree method representing three cycles of visual selection; Modified Bulk 2 involving two cycles of phenotypic selection; Modified Bulk 1 with one cycle of selection; and the classical Bulk method where only natural selection was involved.

In the Pedigree method of plant breeding, the selection of individual plants by the breeder in the early generation of a cross is mainly based on visual evaluation for overall agronomic worth. The concept of agronomic worth is strictly what the individual breeder judges it to be. Thus, such an evaluation is very subjective and will vary depending on the experience and judgment of the breeder. Allard (3) notes the importance for quick visual evaluation rather than time-consuming and precise measurements when evaluating large numbers of individuals or lines in segregating generations. Nevertheless, several investigators have pointed out that visual selection is not an accurate method for discriminating complex traits such as yield and should be used to discard only the poorest lines (6,12,22, 32). Thus, in this investigation, the effectiveness of visual selection for three simply inherited characters (plant height, flowering, and maturity dates), and four quantitative traits (100 kernel weight, spikes per meter, kernels per spike and grain yield) was undertaken.

The 3, 2, and 1 cycles of phenotypic selection represented by the Pedigree, Modified Bulk 2, and Modified Bulk 1 methods, respectively, were made in the same manner as is currently done in most breeding programs, i.e., based on the desirable agronomic phenotype of the plants as perceived by the breeder.

The eight F_5 lines resulting from the four methods originated from crossing winter and spring parents. Previous investigations have shown that by crossing these diverse gene pools (winter and spring types) greater genetic variation can be realized. However, there is some inclination that a large part of the total genetic variation is of the non-additive type and thus unavailable to the wheat breeder (11, 20,35).

Plant height, flowering, and maturity dates are generally regarded as being simply inherited and not greatly influenced by the environment. Even though these traits are not regarded as components of grain yield, they do play an important role in high rainfall and irrigated areas, or for locations where the growing season is limited by environmental stresses like drought or frost. Certainly some of these factors are important under the growing conditions observed at the experimental sites where this study was conducted. At CIANO, in the Yaqui Valley, irrigation was provided; however, the growing season from initiation of jointing to harvest is restricted to four months due to the availability of moisture. In El Batan, the second experimental site, frost limits the length of the growing season. Photoperiod response and straw strength were important criteria in selecting desirable agronomic types at both locations. Potentially high-yielding, late-maturing segregates in the Bulk population may have been penalized thus reducing the grain yield of these F_5 populations. In this study the simply inherited characters responded somewhat differently depending on the selection method employed. This result is in agreement with the findings of other authors (14,41,56). A clear superiority of the Pedigree method, however, was noted in most of the crosses for plant height and heading and maturity dates. This indicates that the Pedigree method is the best alternative for a breeder whose main goal is to isolate semidwarf and early genotypes out of segregating populations. The effectiveness of visual selection when dealing with these characters was also confirmed by the progress made with the Modified Bulk 2 and Modified Bulk 1 methods representing 2 and 1 cycles of phenotypic selection, respectively. As would be expected, greater heterogeneity was found in the populations selected by these latter two methods in comparison to the lines selected by the Pedigree method. This heterogeneity may offer an additional advantage by enabling these populations to adjust to year-to-year variation in environment. The fact that progress was made by these two modifications of the Bulk method indicates that either one could be effective for a breeder with limited resources and whose objective is to adjust either plant height and/or heading or maturity date.

When the quantitatively inherited components of yield, 100 kernel weight, spikes per meter, and number of kernels per spike are considered a different response was noted when the selection methods were compared. For these traits, even though their inheritance is complex and final expression often greatly influenced by the environment, the superiority of the Pedigree method and the effectiveness of visual selection was again noted for most of the crosses. This is in contrast to the findings reported by other investigators (8, 21,45,56). In some crosses, the Modified Bulk 1 or the Modified Bulk 2 were superior to the Bulk method, indicating and confirming that progress can be made when dealing with these traits even with one or two cycles of phenotypic selection. The two Modified Bulk methods were also equal to or better than the Pedigree method, depending on the particular cross. This suggests that phenotypic selection was effective in identifying the more promising genotypes for these components of yield; however, since one and two cycles of selection were often as good as three, further progress using visual selection with the Pedigree method would appear to be of little value.

Grain yield is considered the main objective in most breeding programs. It is influenced by many genes and is the end-product in a long chain of reactions, interactions and compensating effects. Because the expression of grain yield is very sensitive to environmental influences, it is difficult to evaluate, especially in early segregating generations. This fact is reflected in that methods of selection applied and population sizes used vary greatly in different wheat breeding programs (46). It has, in fact, resulted in a fundamental argument among breeders regarding the desired number of crosses and population size of a cross. When the four methods of selection were evaluated for this complex trait, no single method was found to be superior confirming the findings of other investigators (8,21,23, 42,45,53,56). However, because of the selection method x cross interaction, a comparison was made between the methods of selection within each particular cross. The results indicated a lack of consistency regarding the most effective method in five out of six crosses, suggesting that little or no progress can be made through visual selection for yield per se. Perhaps these results should be expected considering that grain yield is a quantitatively inherited character and the heritability estimates for yield are generally low and variable from cross to cross. All of these factors contribute to a lack of correlation between phenotype and genotype of a plant for yield. Therefore, it will be necessary to identify other factors which do respond to visual selection and, in turn, influence grain yield rather than using phenotypic selection for yield per se. Under the environmental conditions in which this study was conducted, plant height and flowering and maturity dates could be considered.

The performance of the Bulk populations in this study could have been modified by: (a) the sampling procedure for the segregating population within a cross; (b) the nature of competition resulting in genetic shifts (maturity, plant height, etc.); (3) the amount of genetic diversity between parents; and (d) the number of generations in which the population was handled as a bulk. Since, for all comparisons, the Bulk method was regarded as the check or base population within each cross, any of the above-mentioned factors could influence the performance of the bulked populations, and may be considered as possible reasons for the inconsistency regarding the best method of selection within some crosses. This inconsistency of the performance of the Bulk population between crosses clearly points out a major disadvantage of the Bulk method of breeding in that progress cannot be predictable.

The importance of winter wheats for the improvement of spring types has been stressed (2). Winter wheat germplasm can provide enhanced drought resistance, better resistance to various diseases, and genetic diversity for increased grain yield. Historically, winter and spring wheat cultivars have evolved in different evolutionary patterns forming different gene pools. This is due, in part, to the inability of spring wheats to survive sub-zero temperatures and to the vernalization and winterhardiness requirements of the winter type. Wheat breeders have emphasized crosses of either winter or spring types, however there has been concern regarding the nature of the genetic variation resulting from such crosses. It would appear that a large percentage of this variability is due to non-additive type gene action. Therefore, this would have a major effect on choice of the most effective method of handling segregating population.

The six winter x spring crosses differed for all the agronomic characters studied except number of kernels per spike. This result is perhaps due to the great amount of genetic variability present and reported in this type of crosses (11,20,35). It is interesting to note that those crosses where Kavkaz was the winter parent were consistently higher yielding under the environmental conditions of this study. Of the spring parents, Cocoraque 75 was commonly involved in the highest yielding combinations. These results are not surprising considering that both Kavkaz and Cocoraque 75 are the earliest parents of the winter and spring cultivars used in this study, respectively. Since early maturity is a major factor in developing superior cultivars for the location where the material was grown it would seem logical that these parents would be complementary for this trait. This, plus the fact that throughout the selection phase of this study emphasis was exercised in selecting for early spring types, may be the explanation for the higher yield of those combinations. A further explanation and confirmation of these results is given by the fact that consistent negative correlations were observed for grain yield with flowering and maturity dates in the other parental combinations involving these as well as other parents.

The general results of the comparison of the four methods of selection for the seven agronomic traits suggest that visual selection was effective. The most consistent improvement for the agronomic traits was made using the Pedigree method representing three cycles of visual selection. Depending on the cross and the trait, the Modified Bulk 1 or Modified Bulk 2, representing one and two cycles of selection, respectively, were shown to be as effective as the Pedigree method. All these results suggest that in a winter x spring breeding program, emphasis of visual selection for early flowering and maturity dates should be given. Certainly, where resources are limited either the Modified Bulk 1 or the Modified Bulk 2 would offer many advantages over either the Pedigree and Bulk methods. Both modifications of the Bulk method would appear to offer the most promises in taking advantage of the merits of the Pedigree and Bulk methods of breeding. By using such methods of selection as proposed in this study, the breeder could play the numbers game both in terms of the number of crosses handled and the number of plants represented in each of the segregating generations. Such an approach would provide a greater opportunity to obtain desired genotypes and also to be able to identify them in the most efficient and economical way possible.

In the final analysis, the plant breeder must decide which method of selection to follow in handling his segregating material. Even with the increasing improvements and modifications in breeding procedures, the breeder still must use his intuition and subjective judgment which are of the utmost importance for successful results of the breeding program. Breeding crop plants is a personal task requiring experience and a wealth of background information on the selected crop. Numbers of staff, available budget, land requirements, and the objectives are instrumental in deciding on a breeding method. Plant breeding is also a game of numbers and with potential yield plateaus achieved and less genetic variation available for further increases, the breeder must turn to increase population sizes and the number of crosses evaluated as well.

Any of the two modifications of the Bulk method proposed in this study would also be an advantage to an inexperienced breeder or to programs with limited resources as in many developing countries. The resulting populations from such methods due to their greater heterogeneity may well offer greater flexibility in adjusting to changes in the environment. They may also provide greater protection against plant diseases due to this genetic diversity which would be the result of the heterogeneous populations representing the new cultivars.

SUMMARY AND CONCLUSIONS

Four methods of selection representing different cycles of phenotypic selection were evaluated in six winter x spring wheat crosses. The methods were: (1) the Pedigree method with three cycles of selection; (2) the Modified Bulk 2 where two cycles of selection were practiced; (3) the Modified Bulk 1 where only one cycle of selection was exercised; and (4) the Bulk method where only natural selection was involved.

The response to various cycles of selection were measured in terms of plant height, flowering and maturity dates, 100 kernel weight, number of spikes per meter, number of kernels per spike, and grain yield.

This study was conducted over a four-year period (1976-1980) with the experimental populations being grown alternately under two different environmental conditions in Mexico.

Based on the results of this investigation, the following conclusions were drawn:

1. Differences in response to phenotypic selection based on the four methods were observed, depending on the trait and cross involved.

2. Favorable response to three cycles of phenotypic selection was observed for plant height, flowering and maturity dates.

3. Little or no progress was made after two cycles of selection for the components of yield, 100 kernel weight, spikes per meter and kernels per spike.

4. Phenotypic selection for grain yield gave inconsistent results; however, in general, superior performance of the F_5 selections obtained by the Pedigree, Modified Bulk 1, and Modified Bulk 2 were achieved when compared to the Bulk method.

5. F_5 selections representing the Bulk method may have been adversely affected due to the requirement of earliness and competition due to differential plant height within the Bulk populations.

6. A high heterogeneity within the Modified Bulk 1 and Modified Bulk 2 methods was observed. This could be an advantage of these methods when resulting populations are grown over years.

7. The six winter x spring wheat crosses differed for all the agronomic characters studied except number of kernels per spike.

8. Consistent negative correlations were observed for grain yield with flowering and maturity dates in the winter x spring crosses.

9. Kavkaz and Cocoraque 75, the two earliest winter and spring parents respectively, were most often involved in the highest yielding crosses.

10. In a winter x spring breeding program, emphasis in the use of phenotypic selection for flowering and maturity dates should be given. Any of the two modifications of the Bulk method proposed in this study may serve as alternatives due to the advantages that they offer of evaluating many different crosses while still retaining a large number of plants per cross.

BIBLIOGRAPHY

1. Adair, C. R. and J. W. Jones. 1946. Effects of environment on the characteristics of plants surviving in bulk hybrid populations of rice. J. Am. Soc. Agron. 38:708-716.

2. Akerman, A. A. and J. MacKey. 1949. Attempt to improve the yield of spring wheat. II. Crosses between spring and winter wheat. Sveriges utsadesforenings tidskr. 19:105-117.

3. Allard, R. W. 1966. Principles of plant breeding. John Wiley and Sons, New York.

4. Athwal, D. S. 1971. Semidwarf rice and wheat in global food needs. Quart. Rev. Biol. 46:1-34.

5. Atkins, R. E. 1953. Effects of selection on bulk hybrid barley populations. Agron. J. 45:311-314.

6. ________. 1964. Visual selection for grain yield in barley. Crop Sci. 4:494-497.

7. Atkins, R. E. and H. C. Murphy. 1949. Evaluation of yield potentialities of oat crosses from bulk hybrid tests. Agron. J. 41:41-45.

8. Boerma, H. R. and R. L. Cooper. 1975. Comparison of three selection procedures for yield in soybeans. Crop Sci. 15: 225-229.

9. Borlaug, N. E. 1968. Wheat breeding and its impact on world food supply. Proc. Third Int. Wheat Genet. Symp. Canberra, Australia 3:1-36.

10. Boyce, S. W., L. G. L. Copp, and O. H. Frankel. 1947. The effectiveness of selection for yield in wheat. Heredity 1:223-233.

11. Brajcich, P. 1981. Nature of inheritance, genotype-environment interaction and association of several agronomic characters in crosses of winter x spring wheats. Unpublished Ph.D. Thesis. Oregon State University Library, Corvallis, Oregon.

12. Briggs, K. G. and L. H. Shebeski. 1970. Visual selection for yielding ability of F_3 lines in a hard red spring wheat breeding program. Crop Sci. 10:400-402.

13. Casali, V. W. D. and E. C. Tigchelaar. 1975. Breeding progress in tomato with pedigree selection and single seed descent. J. Am. Soc. Hort. Sci. 100(4):364-364.

14. Casali, V. W. D. and E. C. Tigchelaar. 1975. Computer simulation studies comparing pedigree, bulk, and single seed descent selection in self-pollinated populations. J. Am. Soc. Hort. Sci. 100(4):364-367.

15. Copp, L. G. L. 1957. Bulk and pedigree methods of wheat breeding. Wheat Information Service, Biol. Lab., Kyoto University, Kyoto, Japan, No. 5:7.

16. Empig, L. T. 1975. Genetic variances in self-fertilized populations under various breeding methods. Philippine Agriculturist. 59:205-211.

17. Empig, L. T. and W. R. Fehr. 1971. Evaluation of methods for generation advance in bulk hybrid soybean populations. Crop Sci. 11:51-54.

18. Fasoulas, A. 1973. A new approach to breeding superior varieties. Dept. Gen. and Plt. Brdg. Aristotelian U. of Thessaloniki, Greece, No. 3:42.

19. Frey, K. J. 1962. Effectiveness of visual selection in oat crosses. Crop Sci. 2:102-105.

20. Grant, M. M. and H. McKenzie. 1970. Heterosis in F_1 hybrids between spring x winter wheats. Can. J. Plant Sci. 50:137-140.

21. Grignac, P., J. Poux, and A. Tomas. 1978. Comparison of different selection methods used to improve wheat varieties. Ann. Amelior. Plantes. 28(4):341-350.

22. Hanson, W. D., R. C. Leffel, and H. W. Johnson. 1962. Visual discrimination for yield among soybean phenotypes. Crop Sci. 2:93-96.

23. Harlan, H. V. 1940. A study of methods in barley breeding. U.S.D.A. Tech. Bull. 720. Washington, D.C.

24. Harlan, H. V. and M. L. Martini. 1938. The effect of natural selection in a mixture of barley varieties. Jour. Agr. Res. 57:189-199.

25. Harrington, J. B. 1940. Yielding capacity of wheat crosses as indicated by bulk hybrid test. Can. J. Res. 18:578-584.

26. Hayes, H. K., F. R. Immer, and D. C. Smith. 1955. Methods of plant breeding. 2nd ed. New York, N.Y.: McGraw Hill Book Co., Inc.

27. Jennings, P. R. and P. M. Herrera. 1968. Studies on competition in rice. II. Competition in segregating populations. Evolution 22:323-336.

28. Kaufmann, M. L. 1971. The random method of oat breeding for productivity. Can. J. Plt. Sci. 51:13-16.

29. Khalifa, M. A. and C. O. Qualset. 1974. Intergenotypic competition between tall and dwarf wheats. I. In mechanical mixtures. Crop Sci. 14:795-799.

30. Knott, D. R. 1972. Effects of selection for F_2 plant yield on subsequent generations in wheat. Can. J. Plant Sci. 52:721-726.

31. Krull, C. F., B. M. Zapata, and O. R. Lopez. 1966. Effectiveness of visual selection for yield in wheat. Rev. Inst. Columb. Agropec. 1:33-36 (abstract).

32. Kwon, S. H. and J. H. Torrie. 1964. Visual discrimination for yield in two soybean populations. Crop Sci. 4:287-290.

33. Love, H. H. 1927. A program for selecting and testing small grains in successive generations following hybridization. J. Am. Soc. Agron. 19:705-712.

34. Luedders, V. D., L. A. Duclos and A. L. Matson. 1973. Bulk, Pedigree, and early generation testing breeding methods compared in soybeans. Crop Sci. 13:363-364.

35. Mani, S. C. and M. V. Rao. 1975. Heterosis in winter x spring crosses. Ind. J. Genetics 35:330-335.

36. Matsuo, T., T. Nakazima, A. Komatzukai, and K. Sugawara. 1960. A comparison between pedigree, mass selection and bulk breeding in rice. Jap. J. Breed. 10:33-41.

37. McGinnis, R. C. and L. H. Shebeski. 1968. The reliability of single plant selection for yield in F_2. Int. Wheat Gen. Symp., Proc. 3:410-415.

38. McKenzie, R. and J. Lambert. 1961. Comparisons of F_3 lines and their related F_6 lines in two barley crosses. Crop Sci. 1:246-249.

39. McNeal, F. H., C. O. Qualset, D. E. Balridge and V. R. Stewart. 1978. Selection for yield and yield components in wheat. Crop Sci. 18:795-799.

40. Mumaw, C. R. and C. R. Weber. 1957. Competition and natural selection in soybean varietal composites. Agron. J. 49:154-160.

41. Palmer, T. P. 1952. Populations and selection studies in a Triticum cross. Heredity 6:171-185.

42. Raeber, J. G. and C. R. Weber. 1953. Effectiveness of selection for yield in soybean crosses by bulk and pedigree systems of breeding. Agron. J. 45:362-366.

43. Salmon, D. F. and E. N. Larter. 1978. Visual selection as a method for improving yield of triticale. Crop Sci. 18:427-430.

44. Salmon, D. F., E. N. Larter and J. P. Gustafson. 1978. A comparison of early generation (F_3) yield testing and pedigree selection methods in triticale. Crop Sci. 18:673-676.

45. Seitzer, J. F. and L. E. Evans. 1978. Yield gains in wheat by the pedigree method of selection and two early yield tests. Z. Pflanzenzuchtg. 80:1-10.

46. Shebeski, L. H. 1967. Wheat and breeding. In K. F. Nielsen (ed.) Proc. Canadian Centennial Wheat Symp. Modern Press, Saskatoon.

47. Snedecor, G. W. and W. G. Cochran. 1967. Statistical methods, 6th ed. Iowa State University Press, Ames, Iowa, 593 p.

48. Sneep, J. 1977. Selection for yield in early generations of self-fertilizing crops. Euphytica. 26(1):27-30.

49. Suneson, S. A. and Stevens. 1953. Studies with bulk hybrid populations of barley. U.S.D.A. Tech. Bul. 1067.

50. Taylor, L. H. 1951. Effects of natural selection in segregating generations upon bulk populations of barley. Unpublished Ph.D. Thesis. Iowa State College Library, Ames, Iowa.

51. Tee, T. S. and C. O. Qualset. 1975. Bulk populations in wheat breeding. Comparison of single seed descent and random bulk methods. Euphytica 24:393-405.

52. Thakare, R. B. and C. O. Qualset. 1978. Empirical evaluation of single plant and family selection strategies in wheat. Crop Sci. 18:115-118.

53. Torrie, J. H. 1958. A comparison of the pedigree and bulk methods of breeding soybeans. Agron. J. 50:198-200.

54. Townley, F. F., E. A. Hurd and D. S. McBean. 1973. Techniques of selection for yield in wheat. Proc. 4th International Wheat Genet. Symp. Missouri Agr. Exp. Sta., Columbia 4:605-609.

55. Van Der Kley, F. K. 1955. The efficiency of some selection methods in populations resulting from crosses between self-fertilizing plants. Euphytica 4:58-66.

56. Voigt, R. L. and C. R. Weber. 1960. Effectiveness of selection methods for yield in soybean crosses. Agron. J. 52:527-530.

APPENDIX

Appendix Table I

PEDIGREE AND DESCRIPTION OF CULTIVARS

KAVKAZ

Lutescens 314-h-147/Bezostaja 1. A hard red common winter wheat cultivar released by Russia in 1971. Large spikes, cylindrical, white and awnless. Early, tall with high yield potential, poor tillering, large seed with good milling and baking qualities.

WEIQUE RED MACE

Wheat variety/rye IB/IR substitution x Hybrid 46. A fixed line resulting from a cross made in USA of German and British germ plasm. A hard red winter wheat with cylindrical spike, white and awnless. Late maturity, semidwarf with profuse tillering, resistant to shattering and lodging.

SIETE CERROS 66

(Frontana x Kenya 58 - Newthatch/Norin 10-Baart) Gabo 55. A hard white common spring wheat cultivar released by Mexico in 1966. Mid-season maturity, semidwarf, with brown awns, oblong to clavate spike and resistant to shattering. Small to medium size kernel. Widely adapted and excellent yield potential, resistant to leaf, stem and stripe rust, but currently susceptible to all three rusts in Mexico. Poor bread-making quality.

COCORAQUE 75

II 12300//LR64/8156/Nor 67. This is a cultivar developed in 1975 by the International Maize and Wheat Improvement Center (CIMMYT) and the National Institute of Agricultural Research (INIA) in Mexico. It is a semidwarf (90 cm) with a strong stem. It is a midseason wheat (82 days to heading) with white, bearded and fusiform spikes. The kernels are small to medium in size and red in color. It is a high-yielding cultivar and resistant to stem, leaf and stripe rust under conditions observed in Mexico before 1976-77.

TORIM 73

Bluebird x Inia 66. A hard white common spring wheat cultivar released by Mexico in 1973. Midseason maturity, dwarf with white awned fusiform spike, resistant to shattering. Small to medium size kernel. High yield potential and resistant to stem rust and moderately resistant to leaf rust. Good baking qualities.

Appendix Figure 1. Procedures followed in each of the four methods of selection. P= Pedigree, MB2= Modified Bulk 2, MB1= Modified Bulk 1, and B= Bulk methods. Year indicates when a population was grown. El Batan, Mexico, 1980.