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Effect of mass selection on the mean and genetic variance of maize cultivar AL 25

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ABSTRACT - *This study analyzed the effects of mass selection on the mean and variance of maize cultivar AL 25, using 100 half-sib progenies of an initial cycle and 100 progenies of the 11th cycle. Randomized complete blocks were used for evaluating grain yield and ear height. Individual and joint variance analyses considering the two years of experimental duration compared the mean and variance components of both cycles. A slight reduction in additive genetic variance was observed as the selection proceeded for both analyzed traits. The increase in the means of grain yield and ear height with the selection cycles was also little expressive. The mass selection cycles did not promote significant alterations in this cultivar's mean and variance.*

Key words: *Zea mays* L., crop breeding, mass selection, mean, variance.

INTRODUCTION

The methods of genetic improvement used for maize have evolved as knowledge on this cereal and on genetic-statistical methods has deepened, and as demands have emerged to meet the need of feeding populations in populous countries where maize is staple diet.

The applied improvement methods have been mass and ear-per-row selection. The information available led to the general conclusion that mass selection was only efficient to improve an introduced variety in adaptation, and not to increase the productivity (Richey 1922). On the other hand, other studies have shown that mass selection is the easiest and quickest form of improving grain productivity in certain maize populations, as it is a simple and low-cost method (Coors and Mardones 1989, Arriel et al. 1993, Carvalho et al. 1994, Liu and Peng 1994, Delgadillo et al. 1995, Zhang et al. 1995, Lopez and Biasutti 1996).

Drummond (1959) observed the alteration in the plant and ear trait means by mass selection. He considered this procedure inefficient for the increase of productivity in some populations, ascribing the inefficiency to the trait's low heritability.

Expressive increases for traits such as grain yield and ear height were obtained in populations subjected to mass selection by Rodriguez et al. (1976), Gardner (1978), Mareeck and

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Gardner (1979), and Iriarte and Márquez (1984). Coors and Mardones (1989), revising works about the effects of mass selection, concluded that significantly results have been obtained for several characters, including grain yield. However, Hallauer and Sears (1969) obtained very little progress in two maize populations with selection being conducted in one location but yield tests for evaluation of progress were conducted at three different conditions.

Richey (1922) revised the results obtained with several selection methods of improvement applied in maize and concluded that mass selection for production ensures the maintenance and not the increase of productivity. It is also known that one condition to obtain success through mass selection is the existence of genetic variability. The simplest method to estimate the components of genetic variability and the alterations entailed by the selection is the use of half-sib progenies.

According to Santos and Naspolini Filho (1986), north American studies show the existence of genetic variability after successive cycles of mass selection and the possibility of continuous gains with the use of this method, once the same does not only lead to changes in the genetic variance of the selected trait, but also in the mean, variances, and covariances.

On these grounds, the goal for the present study was set to evaluate alterations in the mean and the components of variance of half-sib progenies after 11 cycles of mass selection that developed maize cultivar AL 25.

MATERIAL AND METHODS

A total of 100 half-sib progenies of the initial cycle and 100 progenies of the 11th cycle of mass selection of the improvement program that originated maize cultivar AL 25 were used. For the ease of text comprehension, an account is given on the process of achieving cultivar AL 25 and in the following a description of the methodology of establishing and evaluating the half-sib progenies.

Thirty-five early cycle commercial hybrids, chosen for their agronomical and productivity traits, were intercrossed and recombined without selection and on isolated fields. The initial intercrosses were realized in the crop year of 1988/89 followed by three recombinations, two in the crop year 1989/90, one in summer and the other in the off-season harvest, and the third in the summer of the crop year 1990/91.

The obtained population, designated P_0, was subjected to 11 mass selection cycles twice a year, corresponding to the main season and off season crop. The population obtained at this point was called P_{11}. The intensity of selection was 5% and the traits considered during the selection process were productivity, ear height, erect plants, and a good general appearance. Selection pressure was exerted from cycle to cycle. The assays were conducted in soil with a base saturation index below 20%, verifying the plants that were actually most productive.

Initially, 100 half-sib progenies of each one of the two populations under study (P_0 and P_{11}) were obtained and sown on the Fazenda Experimental of the University Estadual Paulista – UNESP, São Manuel, State of São Paulo, in August 1998.

The evaluations were realized in the off-season when the material is commercially most demanded. When the phase of progeny establishment was concluded by the end of January 1999, the progenies were distributed among the four experiments A, B, C, and D, in randomized complete blocks with three replications.

Thus, each experiment comprised 25 half-sib progenies obtained from P_0 and 25 from P_{11}. This design was chosen to minimize the influence of experimental error since 200 treatments and four controls (single-cross hybrids) were in use, while the experimental area was relatively far-flung and probably irregular, so that a single lattice design was used. The plots held five-meter long rows spaced 0.90 m, with a useful plot of 4.5 m^2. Forty seeds were sown per plot and not thinned out, which left a mean stand of 25 plants per plot.

This process was initiated in February 1999 and the plants were harvested in July of the same crop year. The aforementioned procedure was carried out again from February 2000 to harvest in July of the same year, representing the second year of realization of the experiment. Both evaluation stages were realized in the off-season harvest cycle.

The following traits were evaluated in the half-sib progenies of cycles 0 and 11: ear height (distance in meters from the soil surface to the insertion node of the highest ear of five competitive plants within each plot, calculating the mean of the five readings), grain yield per plot (the total weight of each plot was obtained in grams by the weight of hulled ears). The grain moisture was determined and the production corrected to a moisture of 13%. The data were also adjusted to the stand mean of each experiment through the analysis of covariance, according to a methodology proposed by Vencovsky and Barriga (1992). To obtain the variances within the progenies, the weight of hulled ears was obtained individually from five competitive plants per plot.

The variances were analyzed for each experiment separately and together for the two years of evaluation. For both the individual and the joint analyses, the experimental variation coefficient (VC_e) was estimated for both traits, as well as the components of the genetic and environmental variation. Towards the end of the procedures with the analyses of variance, the coefficient of genetic variation (VC_g) was also estimated, the quotient (b), that is, VC_g/VC_e, as suggested by Vencovsky (1987). This value is extremely important in research with maize progenies. When this quotient is equal to or higher than 1.0, it indicates a very favorable situation for selection. The variance components were tested for significant differences by Bartlet's test.

RESULTS AND DISCUSSION

The mean squares of the interaction progenies x years were only significant in experiment D for grain yield in both evaluation cycles, indicating that there were no important effects of this interaction.

Table 1 shows the grain yield means at the total plot level for both populations in the two years the experiments lasted. All experiments were significant by the test F at P < 0.01 for the year variation factor. Higher values were computed in the experiments of the year 2000 than of 1999 for the general mean of grain yield per plot. These differences can be explained by the fact that the climate conditions were more favorable for a grain yield increase in 2000, owing to a greater availability of water. The progenies of cycle 11, i.e., the population generated by selection cycles for traits that result in productivity increase, showed a slight mean tendency to increase the productivity. Richey (1922) similarly observed that the mass selection cycles brought forth results that were very similar to the original population, with mean increases of little expression in productivity.

Table 1. Means of grain yield (g plot^{-1}) at the level of total plots for the progenies of the initial (C_0) and 11th (C_{11}) cycles of cultivar AL 25

Experiments	Years	Cycles	
		C_0	C_{11}
A	1999	4982.8 a B	5124.4 a B
A	2000	7494.4 b A	8308.7 a A
B	1999	5217.5 a B	5168.7 a B
B	2000	7890.6 a A	7900.9 a A
C	1999	5220.4 a B	5554.0 a B
C	2000	7357.8 a A	7360.0 a A
D	1999	4497.3 b B	4952.9 a B
D	2000	7304.2 a A	7248.7 a A
Mean yield		6245.6	6452.3

Means followed by the same lowercase letters in the lines and uppercase letters in the columns did not differ from each other in test F at P < 0.05

The range for grain yield per plot was of 6957 g plot^{-1} (757 g for the plot with the smallest value and 7714 g for the plot of greatest value) for the 100 progenies of the initial selection cycle. Regarding the values obtained for the progenies of cycle 11, the range was 6031 g plot^{-1} (455 g for the plot with the smallest value and 6486 g for the plot with the greatest production).

For the estimates of the genetic parameters in the joint analyses, the two populations were analyzed separately, but the years of realization of the experiments together for grain yield per plot (Table 2). The square means of progenies were significant by the F test at the level P < 0.05 for the experiments B, C and D for grain yield in the joint analyses.

No significant difference was detected for any of the variance components in any experiment by Bartlet's test. This shows that the values obtained for the progenies of cycle 11 did not diminish the parameter phenotypic variance within progenies, with exception of experiment A. This fact can be explained by the high values obtained for the environmental variance, influencing the referred phenotypic variance directly. The calculated values in the experiments B and C, with a decrease of the additive genetic variance in the population that underwent 11 selection cycles, are in line with the studies cited in literature. This decrease did not occur for experiment D; high values were found for the variance of the experimental error between plots - around 533.94 g plant^{-2} in 2000.

A comparison of the mean values confirmed the tendency towards a reduced additive variance after mass selection procedures, as the progeny values of the initial cycle reached values close to 688.44 g plant^{-2} and those of the 11th cycle attained 513.08 g plant^{-2}. The obtained heritability coefficients were of low magnitude for all and throughout the two-year experiments.

Table 2. Estimates of phenotypic variance within progenies ($\hat{\sigma}^2_d$), environmental variance ($\hat{\sigma}^2_e$), additive genetic variance ($\hat{\sigma}^2_a$), and coefficient of heritability ($\hat{h}^2$) for grain yield per plot based on the joint analyses in the cultivar AL 25 at the total plot level

Experiments	Years	Cycles	$\hat{\sigma}^2_d$	$\hat{\sigma}^2_e$	$\hat{\sigma}^2_a$	$\hat{h}^2$
--	1999 and 2000	C_0	3067.71	902.29	0 (*)	0
A	1999 and 2000	C_{11}	2612.98	561.67	0 (*)	0
B	1999 and 2000	C_0	2604.02	397.27	909.84	0.28
B	1999 and 2000	C_{11}	4134.25	375.39	462.88	0.10
C	1999 and 2000	C_0	2662.99	208.04	1106.56	0.35
C	1999 and 2000	C_{11}	2769.19	408.79	607.40	0.18
D	1999 and 2000	C_0	2407.95	163.41	737.36	0.27
D	1999 and 2000	C_{11}	2570.85	533.94	982.04	0.29
Estimate mean		C_0	2685.67	417.75	688.44	0.22
Estimate mean		C_{11}	3021.82	469.95	513.08	0.14

(*) value zero was assumed for the obtained negative estimate

The coefficients of genetic variation for both populations for grain yield per plot are displayed in Table 3. Since an estimate of the genetic variance between progenies in experiment A presented negative values, the genetic variation coefficient consequently resulted in value zero. For the other experiments, the estimate of this parameter was lower in cycle 11 population for the experiments B and C. Once more, the tendency was opposite to the expected, with a small increase of the coefficient of genetic variation in the population subjected to selection for experiment D. However, the mean coefficient of genetic variation resumes the tendency of a sinking genetic variation all along the selection procedures. A reduction of this variation in the progenies originated from the eleven mass selection cycles was confirmed, in spite of the small amplitude.

For grain yield, the mean coefficient of genetic variation was reduced by 15.9% during the eleven cycles of mass selection. Higher values (26%) were found in a study by Santos and Naspolini Filho (1986), who carried out three cycles of mass selection.

At the end of the determinations of the experimental and genetic variation coefficients between progenies, ratio b was estimated, which indicates the situation of the population used for selection procedures. According to the obtained results, a b of 0.024 was obtained for grain yield per plot for the progenies of the initial mass selection cycle, in other words, an unfavorable situation for selection. The values of coefficient b in cycle 0 fell short of the expected value, since the population of cycle 0 corresponds to the recombination of 35 commercial hybrids. The value of this same parameter for the cycle 11 progenies was estimated at 0.016, confirming the tendency that progenies that underwent selection cycles must present lower values.

The b ratio was too far below the required limit ($b \geq 1$) to be considered successful with this procedure for the initial selection cycle. Note that the grain yield per plot is considered to be of low heritability and therefore greatly influenced by the environmental factor. The mean values obtained for the estimates of the heritability coefficients were 0.22 for the progenies of the initial cycle and 0.14 for those subjected to the selection cycles (P_{11}) (Table 2), i.e., characterizing them as low. It is therefore very difficult to obtain success with this trait by mass selection procedure in the evaluated population. The estimated ratio b confirmed all results found in the analyses for grain yield per plot.

Table 3. Coefficients of genetic variation (VC_g) for grain yield per plot, in the progenies of the initial (C_0) and 11th (C_{11}) cycles, in the two years (1999/2000) experiment duration for cultivar AL 25

Experiments	Cycles	
	C_0	C_{11}
	CV_g %	
Experiment A	0	0
Experiment B	51.5	36.5
Experiment C	58.7	42.4
Experiment D	51.1	57.0
Mean coefficient	40.3	33.9

The mean heights of ear insertion at the level of plot means for both progenies were analyzed throughout the two experiment years (Table 4). Practically no differences between the cycles 0 and 11 were observed for the mean ear height. The maximal range between the progeny means of the cycles 0 (the smallest) and 11 (the greatest) was 4.5 centimeters in experiment B in 2000, significant by the test F. This significance was observed due to the low coefficient of experimental variation (7.93%). In some experiments, the mentioned differences between progenies were so small that they were not detected by test F. These results demonstrate the inefficiency of mass selection to diminish the ear height in cultivar AL 25.

It was observed that the progenies from the 11th selection cycle presented slightly higher mean height values, in meters per plant. The plant height was practically not reduced, on the contrary. This is explained by the fact that selection aimed at productivity increases, which generally culminates in increases in the ear insertion height, in function of the positive correlation between these traits.

Some studies that describe gains in productivity by the use of stratified mass selection also report increases in the ear height. Gardner (1978) and Mareeck and Gardner (1979) mention gains in grain productivity and increases in the mean plant height. Rodriguez et al. (1976) selected productivity indirectly, by means of mass selection for prolificacy, which led to increases in the ear height, besides the gains in productivity.

Apart from productivity increases, Iriarte and Márquez (1984) concordantly obtained significant increases in the plant and ear height for both methods, by the comparison of two improvement methods, one of which was mass selection. We underline that in all these studies the observed increases in grain yield and ear insertion height were significant, unlike the present study.

The range for ear height was 1.02 m $plot^{-1}$ (0.70 m for the plot with the smallest mean ear height and 1.72 m for the plot with the greatest mean height) for the 100 progenies of the initial selection cycle. The range value obtained for the progenies of cycle 11 was 1.01 m $plot^{-1}$ (0.70 m for the plot with the smallest

Table 4. Means of ear height (m $plant^{-1}$) at the plot mean level of the progenies of the initial (C_0) and 11th (C_{11}) cycle of cultivar AL 25

Experiments	Years	Cycles	
		C_0	C_{11}
A	1999	1.28 b A	1.32 a A
A	2000	1.11 a B	1.12 a B
B	1999	1.27 b A	1.30 a A
B	2000	1.08 b B	1.12 a B
C	1999	1.31 a A	1.32 a A
C	2000	1.02 a B	1.01 a B
D	1999	1.29 a A	1.32 a A
D	2000	0.98 a B	0.99 a B
Mean height		1.17	1.19

Means followed by the same lowercase letters in the lines and uppercase letters in the columns did not differ from each other in test F at $P < 0.05$

Table 5. Estimates of phenotypic variance within progenies ($\hat{\sigma}^2_d$), environmental variance ($\hat{\sigma}^2_e$), additive genetic variance ($\hat{\sigma}^2_a$), and coefficient of heritability ($\hat{h}^2$) for ear height based on the joint analyses of cultivar AL 25 at the plot mean level

Experiments	Years	Cycles	$\hat{\sigma}^2_d$	$\hat{\sigma}^2_e$	$\hat{\sigma}^2_a$	$\hat{h}^2$
A	1999 and 2000	C_0	0.0650	0.0100	0.0296	0.36
A	1999 and 2000	C_{11}	0.0715	0.0059	0.0572	0.62
B	1999 and 2000	C_0	0.0660	0.0089	0.0428	0.50
B	1999 and 2000	C_{11}	0.0575	0.0078	0.0716	0.86
C	1999 and 2000	C_0	0.0700	0.0068	0.0648	0.70
C	1999 and 2000	C_{11}	0.0810	0.0089	0.0376	0.38
D	1999 and 2000	C_0	0.0725	0.0085	0.0592	0.62
D	1999 and 2000	C_{11}	0.0715	0.0065	0.0212	0.25
Estimate mean		C_0	0.0680	0.0085	0.0492	0.55
Estimate mean		C_{11}	0.0700	0.0073	0.0468	0.53

and 1.71 m for the plot with the greatest mean height of insertion).

Table 5 presents the results of the joint analyses with the estimated genetic parameters for ear height (m plant^{-2}). The progenies of cycle 0 and cycle 11 were analyzed separately again, but the two years of experiment duration were now presented together. In the joint analyses, the square means of progenies were significant by the test F at $P < 0.01$ for all experiments for ear insertion height.

Except for the experiments A and C, the phenotypic variances among plants within progenies decreased for ear height in the sequence of the mass selection cycles confirming this tendency of reduction. Bearing in mind what was said about the joint analysis, we note that the tendency of a sinking additive genetic variance of the progenies, in those subjected to eleven selection cycles, was only observed in the experiments C and D in 1999 as well as in 2000. Comparing the results of the isolated analyses, we note that only some of the experiments obeyed the tendency to diminish the additive genetic variance in the proceeding of the selection cycles. This tendency can be confirmed if the mean variances for both progenies of the two different cycles are taken into consideration, where the half-sib progenies of the initial cycle presented an additive genetic variance only slightly higher than the one estimated for the cycle 11 progenies.

The results of the genetic variation coefficients for ear height for both populations are presented in Table 6. These data confirm that there was an increase in the experiments A and B in the values regarding the genetic variation coefficients when the progenies of the initial cycles and cycle 11 are compared. The opposite is true in the case of the experiments C and D, where the genetic variance among progenies decreased and, consequently, the parameter discussed in the previous table was reduced. Nevertheless, if conclusions were based on the mean genetic variation coefficients, the tendency to diminish the genetic variance among progenies would be confirmed, according to the proceeding of the mass selection. The estimated genetic variation coefficient in the initial cycle was 6.04% higher than the one of the progenies that underwent 11 mass selection cycles. This confirmed the previously explained tendency. However, the effects caused by the mass selection were of low magnitude again, for a trait little influenced by the environment and, consequently, of high heritability, as could be observed by the mean value estimates: 0.55 for the initial cycle and 0.53 for cycle 11 (Table 5).

After determining the experimental variation coefficients and the coefficient of genetic variation among progenies, ratio b was estimated for the half-sib progenies of the initial mass selection cycle, indicating the situation of the population used to proceed with selection. According to the obtained results, the ratio b of 1.05 indicated a favorable situation for selection for ear height. A value of 0.98 was estimated for the progenies of cycle 11, confirming the tendency that progenies that underwent selection cycles must present lower values. In relation to the initial population, the ratio lay higher than the required limit (b e” 1) that indicates success with this procedure, according to Vencovsky (1987). We underline that the ear height is considered highly heritable and is therefore little influenced by the environment. Despite the coefficient b value indicated a favorable situation to diminish the mean ear insertion height, it was

Table 6. Coefficients of genetic variation (CV_g) for ear height in the progenies of the initial (C_0) and 11th (C_{11}) cycles for cultivar AL 25 in the two years (1999/ 2000) of experimentation

Experiments	Cycles	
	C_0	C_{11}
	CV_g %	
Experiment A	7.22	9.82
Experiment B	8.83	11.02
Experiment C	10.95	8.32
Experiment D	10.69	6.27
Mean coefficient	9.43	8.86

observed that 11 mass selection cycles were not effective to improve this trait. The low efficiency of the mass selection for insertion ear height may be related to the fact that selection was realized in two cycles per year, corresponding to the main season and off season crop, so that the effects of the interaction genotypes x environments could have affected the selection process.

We conclude that the 11 mass selection cycles did not affect significant alterations in the mean and in the genetic variance of the maize cultivar AL 25 for grain yield and ear height.

Efeito da seleção massal na média e variância genética da cultivar AL 25 de milho

RESUMO - *Este trabalho analisou os efeitos da seleção massal sobre a média e a variância da cultivar de milho AL 25, utilizando-se 100 progênies de meios irmãos do ciclo inicial e 100 progênies do 11º ciclo. Blocos completos casualizados foram instalados para avaliação da produção de grãos e da altura de espigas. Análises de variância individuais e conjuntas, em relação aos dois anos de condução dos experimentos, compararam as médias e os componentes de variância dos dois ciclos. Observou-se ligeira redução no valor da variância genética aditiva conforme a seleção foi efetuada, para ambas as características analisadas. Ocorreu também aumento pouco expressivo nas médias de produção de grãos e de altura de espigas, com os ciclos de seleção. Os ciclos de seleção massal não promoveram alterações significativas na média e na variância desta cultivar.*

Palavras-chave: *Zea mays L.*, melhoramento genético, seleção massal, média, variância.

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