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Breeding potential of maize composite Isanão VF1 in small spacing in the second growing season

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ABSTRACT - *The purpose of this study was to verify the breeding potential of the maize composite Isanão VF1 in the second growing season. One hundred and fifty half-sib progenies were evaluated at spacing of 0.45 m, densities of 57,778 and 80,000 plants ha*$^{-1}$*, in a randomized block design with three replications. Gains of 16.0 and 19.2% were estimated for grain yield, 11.1 and 10.5% for prolificacy and 12.3 and 12.9% for ear height, respectively, at 57,778 and 80,000 plants ha*$^{-1}$*. The heritabilities for plant height, ear height and grain yield were 65.2 and 61.3%, 64.3 and 66.9% and 53.5 and 63.3%, respectively, confirming the potential for breeding at both densities. The absence of progeny by density interaction indicates that no further selection programs are necessary. The occurrence of segregation for modifier genes for height suggests stabilizing selection based on ear height.*

Key words: plant arrangement, sowing density, genetic variation, genetic parameters.

INTRODUCTION

In maize, intraspecific competition is intensive and morphological changes promoted in the species over the last years, such as reduction of the height, leaf insertion angle, life cycle and increased speed of water loss in ears during plant senescence require a revision of crop establishment and management procedures. Spacing, plant density and even aspects related to nutrition or soil fertilization, must be reconsidered to adjust conditions for grain yield optimization (Silva et al. 2006).

A higher population density is a possibility of maximizing light interception (Sangoi and Silva 2006). However, the ideal number of plants per hectare is variable, since maize grain yield depends on the degree of intra-specific competition, determined by the plant density (Silva et al. 1999). Slight alterations in plant populations can affect the grain yield significantly (Silva et al. 2006). Another form of increasing light interception is to reduce row spacing (Argenta et al. 2001a), which is more effective for shorter cultivars. At a wider spacing it will take a long time until the spaces between rows become overgrown and cultivars are often unable to shade the entire area; strong competition may occur within rows while between them water, light and nutrients are wasted.

Morphological differences among cultivars induce different responses when plant population and spacing are changed. The competition among plants of very tall cultivars with horizontal leaves is greater

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and yields drop at high densities (Oliveira 1993). An equidistant plant distribution is an ideal condition for a maximum exploitation of the genetic potential of each cultivar.

Relative frequent evaluations of cultivars in different spacing and populations have been carried out in Brazil (Mundstock 1978, Arriel et al. 1993, Endres and Teixeira 1997, Argenta et al. 2001a, Argenta et al. 2001b, Resende et al. 2003, Penariol et al. 2003, Paulo and Andrade 2003, Marchão et al. 2005). However, studies on the genetic variability and breeding potential in base populations (Paterniani et al. 2004) under said conditions are less frequent.

This paper addresses the quantification of genetic variation in the maize population Isanão VF1 to verify the breeding potential in the second growing season.

MATERIAL AND METHODS

A dwarf mutant with erect leaves was identified in the S_4 generation of Composite Flintisa lines (normal height). Due to the interesting plant architecture for a possible use at reduced spacing and high population density as well as resistance to most of the main leaf diseases, the mutation was reincorporated in the original population by crossing, selfing and recombination of the dwarf plants, which gave rise to composite Isanão VF1. Of this composite 150 half-sib progenies were separated and evaluated in the second growing season of 2004, spaced at 0.45 m, at densities of 57,778 and 80,000 plants ha^{-1}, in no-till system, in Selvíria, state of Mato Grosso do Sul, Brazil (lat 20° 22' S, long 51° 22' W, alt 335 m asl). The climate is classified as AW type (Köppen's climate classification system), with a mean annual temperature of 25 °C, mean annual precipitation of 1330 mm and mean relative humidity of 66% (Hernandez et al. 1995). The soil is a typical clayey dystrophic Red Latosol (Embrapa 1999).

The experiments were arranged in randomized complete block design with three replications, and 50 progenies representing each maize population. The hybrids AGN 34A11 and AGN 3050 were included in all experiments as controls. Plots consisted of two 5m rows, with 26 plants for a population of 57,778 plants ha^{-1} and 36 plants for a population of 80,000 plants ha^{-1}. Twice the number of necessary seed was distributed at sowing and plants were thinned in the phase of five developed leaves. As proposed by Cantarella et al. (1996), 300 kg ha^{-1} of the locally prepared fertilizer formula 9.2-16.7-15 was applied in the sowing moment. In the stages of four and seven fully expanded leaves 200 kg ha^{-1} of the fertilizer mixture 20-00-20 and 100 kg ha^{-1} urea was applied as sidedressing, respectively.

The following traits were evaluated: plant height (mean of 10 plants per plot); ear height (mean of 10 plants per plot); % of lodged and broken plants; prolificacy; and grain yield corrected to 13% of moisture and an ideal stand of 26 plants at a density of 57,778 ha^{-1} and 36 plants at a density of 80,000 plants ha^{-1}, by the analysis of covariance between grain yield and stand.

Analyses of variance and covariance were carried out for each experiment and the mean squares and mean products of progenies and of the experimental error were grouped for each population (Table 1). Joint analyses of variance and covariance were performed as well, involving the two populations and joint groups (Table 2), according to the criterion of homogeneity of the residual mean squares, considering the progenies as random and density as fixed.

Based on the group and joint group analyses of variance and covariance (Tables 1 and 2), and using the software Genes (Cruz 2005), according to the scheme of variance components for mixed models (Vencovsky and Barriga 1992), the following parameters were estimated: environmental variance; progeny genetic variance; coefficient of genetic variation; additive genetic variance; variation index; progeny by density variance of interaction; mean phenotypic variance; heritability coefficient at the mean progeny level; expected progress with 20% selection intensity among progenies; environmental covariance; progenies genetic covariance; additive genetic covariance; mean phenotypic covariance; coefficients of additive genetic correlation; and phenotypic correlation coefficients among traits. The path analysis proposed by Wright (1921) and described by Li (1975) was performed to assess direct and indirect effects of the traits plant height, ear height, lodged and broken plants, and prolificacy (independent variables) on grain yield (principal variable).

RESULTS AND DISCUSSION

The means for plant height, ear height and grain yield (120.50 cm, 55.18 cm and 1.12 kg plot^{-1},

Table 1. Joint variance and covariance analyses for each population, with the respective expectations of mean squares (MS) and mean products (MP)

Sources of Variation	df	Analysis of variance		Analysis of covariance	
		MS	E(MS)	MP	E(MP)
Blocks/E	e(r-1)	MSB	—	MPB	—
Experiments (E)	e-1	MSE	—	MPE	—
Progenies (P)/E	e(p-1)	MSP	$\sigma_e^2 + r\sigma_p^2$	MPP	$COV_e + rCOV_p$
Controls (C)	c-1	MSC	$\sigma_e^2 + r\phi_C$	MPC	$COV_e + r\varphi_C$
(P vs C)/E	e	MSPvsC	$\sigma_e^2 + r\phi_{PvsC}$	MPPvsC	$COV_e + r\varphi_{PvsC}$
C x E	(c-1)(e-1)	MSCE	$\sigma_e^2 + r\phi_{CxE}$	MPCE	$COV_e + r\varphi_{CxE}$
Mean error	e(r-1)(p+c-1)	MSR	σ_e^2	MPR	COV_e
Total	er(p+c)-1	—	—	—	—

respectively) at the density of 57,778 plants ha^{-1} were higher than at 80,000 plants ha^{-1} (113.92 cm, 52.62 cm and 1.01 kg plot^{-1}) (Table 3). The tendency of increases in plant and ear height in dense maize populations of normal height, due to the greater competition for light, (Sangoi et al. 2002, Marchão et al. 2005), was not observed in this dwarf population.

The occurrence of strong winds in the phase of grain filling affected all experiments, by increasing the mean of lodged and broken plants and the coefficient of variation, which hampers the discrimination of progenies for this trait. The rate of lodged and broken plants was higher at greater density (Table 3), as observed by Milani et al. (1999) and Marchão et al. (2005). Nevertheless Isanão VF1 exceeded the controls by 64% in the smaller population and 41.4% in the denser population. This can be explained by the differences of 76% (57,778 plants ha^{-1}) and 63% (80,000 plants ha^{-1}) between the ear height of the controls and of the dwarf population (Table 3). The higher the ears, the greater is the tendency of the plants to lodging and breaking, since the ears weigh heavier on the stalks. Although not statistically analyzed, a greater stem diameter in the dwarf population was clearly observed in the field. The importance of measuring lodged and broken plants must be emphasized, principally in experiments involving high population density. According to Almeida et al. (2000), the probability of increase of these variables in these conditions is greater, which could result in an increase of ear rot and, consequently, in yield loss.

For grain yield, the controls were 95 and 88% higher than the progeny mean, respectively, for 57,778 and 80,000 plants ha^{-1}. Nevertheless, the mean of the five best progenies was only 21% lower than the controls in both densities. Taking into consideration that lodged and broken plants cannot be harvested mechanically, the controls would be 17.6% higher than the progeny mean at the density 57,778 and 40.5% lower at 80,000 plants ha^{-1}. This also suggests the possibility that progenies superior to controls could be developed, with a view to high technology plantations. The greater resistance to lodging and breaking may be exploited in lines derived from this dwarf population in the future.

As expected the density of 57,778 plants ha^{-1} was more prolific (0.82 ears per plant) than the density of 80,000 plants ha^{-1} (0.65 ears per plant) (Table 3), since dense populations tend to produce a greater number of sterile plants. The mean prolificacy values were low, which may be result of smaller plants being suffocated by larger ones, due to segregation for modifier genes for height, normally observed in recently formed dwarf populations (Paterniani and Rissi 1976). Araújo et al. (2005) observed a mean prolificacy of 1.19 in the CMS-39 population of normal height in a row spacing of 0.50m and a density of 50,000 plants ha^{-1}.

In the joint group analysis (Table 4) the means for plant and ear height were respectively, 117.35 and 53.96 cm, considered normal in the regional conditions and for dwarf progenies. The prolificacy and grain yield means were low, compared with those found in the literature, in the first as well as the second growing season (Tozetti et al. 1995, Ferreira et al. 1999). These results can be explained by the heavy stress provoked by plant lodging and breaking in the period of grain filling, causing the plants to spend great quantities of energy in an attempt to recover the normal position

Table 2. Joint group analyses of variance and covariance, with the respective expectations of the mean squares and mean products

		Analysis of variance		Analysis of covariance	
Sources of Variation	**df**	**MS**	**E(MS)**	**MP**	**E(MP)**
Blocks/D/E	de(r-1)	MSB	———	MPB	———
Experiments (E)	e-1	MSE	———	MPE	———
Densities (D)	d-1	MSD	$\sigma_e^2 + r(^{rd}/_{d-1})\sigma_{pd}^2 + p\sigma_b^2 + pr\phi_d$	MPD	$COVe + r[rd/(d-1)]COV_{pd} + pCOV_b + pr\varphi_d$
D x E	(d-1)(e-1)	MSDE	———	MPDE	
Progenies/E (P/E)	e(p-1)	MSP	$\sigma_e^2 + dr\sigma_p^2$	MPP	$COV_e + drCOV_p$
Controls (C)	c-1	MSC	$\sigma_e^2 + dr\phi_c$	MPC	$COV_e + dr\varphi_c$
(P vs C)/E	e	MSPvsC	$\sigma_e^2 + dr\phi_{PvsC}$	MPPvsC	$COV_e + dr\varphi_{PvsC}$
(P x D)/E	e(p-1)(d-1)	MSPD	$\sigma_e^2 + r(^{rd}/_{d-1})\sigma_{pd}^2$	MPPvsD	$COV_e + r[rd/(d-1)]COV_{pd}$
C x D	(c-1)(d-1)	MSCD	———	MPCD	———
C x E	(c-1)(e-1)	MSCE	———	MPCE	———
C x D x E	(c-1)(d-1)(e-1)	MSCDE	———	MPCDE	———
[(P vs C) x D]/E	e(d-1)	MSPvsCD	———	MPPvsCD	———
Mean error	de(p+c-1) (r-1)	MSR	σ_e^2	MPR	COV_e
Total	der(p+c)-1	——	———	——	———

Table 3. Mean squares, means and coefficients of variation of the group analyses of variance for the traits plant height (PH in cm), ear height (EH in cm), lodged and broken plants (LBP in %), prolificacy (PRO in ears per plant) and grain yield (GY in kg plot^{-1}), in the populations 57,778 and 80,000 plants ha^{-1}. Maize composite Isanão VF1, Selvíria - MS, July 2004

SV	df	PH		EH		LBP		PRO		GY	
		57,778	80,000	57,778	80,000	57,778	80,000	57,778	80,000	57,778	80,000
Blocks/E	6	531.93	1737.82	710.73	185.60	1756.16	1983.70	0.0812	0.0279	0.1239	0.1423
Experiments (E)	2	3116.52**	1168.53**	2320.80**	572.14**	59707.20**	46099.08**	0.0108	0.3072**	1.6655**	0.8766**
Progenies (P)/E	147	329.19**	288.91**	172.01**	157.32**	252.38*	252.12**	0.0528**	0.0357**	0.1724**	0.1438**
Controls (C)	1	245.68	128.00	165.01	117.55	1134.46*	102.24	0.0148	0.0066	0.4647*	0.0021
P vs C/Exp	3	9154.41**	5650.88**	10290.62**	6921.80**	4040.22**	4266.42**	0.1752**	0.5247**	6.7170**	4.6055**
C x E	2	29.43	605.54*	13.51	516.26**	1290.93**	20.32	0.0115	0.0055	1.2622**	0.0285
Mean error	306	114.58	111.88	61.39	52.13	202.275	129.58	0.0268	0.0196	0.0801	0.0527
Overall Mean	-	122.03	115.01	56.80	53.89	39.48	63.87	0.83	0.67	1.16	1.04
Progeny Mean	-	120.50	113.92	55.18	52.62	38.53	62.87	0.82	0.65	1.12	1.01
Control Mean	-	160.08	142.11	97.25	85.66	63.39	89.90	0.99	0.95	2.19	1.90
CV (%)	-	8.77	9.19	13.79	13.39	36.01	17.82	19.67	20.92	24.36	21.95

*,**- Significant at 5 and 1 % probability, by the F test

Table 4. Mean squares, means and coefficients of variation of the joint group analyses of variance for the traits plant height (PH in cm), ear height (EH in cm), lodged and broken plants (LBP in %), prolificacy (PRO in ears per plant) and grain yield (GY in kg plot^{-1}), in the populations 57,778 and 80,000 plants ha^{-1}. Maize composite Isanão VF1, Selvíria – MS, July 2004

SV	df	PH	EH	LBP	PRO	GY
Blocks/D/E	12	1062.0067	398.3261	1872.9936	0.0490	0.1097
Experiments (E)	2	3807.2606	2595.2534	35750.0198	0.1712	1.6580
Densities (D)/E	3	4383.1525*	926.2791	92554.4688**	2.2145**	1.6385**
Progenies (P)/E	147	469.7762**	264.3264**	316.6809**	0.0570**	0.2509**
Control (C)	1	226.3680	185.7569	674.2149*	0.0108	0.6037**
P vs C/E	3	13974.8246**	16790.3502**	7494.2174**	0.6313**	11.0989**
P x D/E	147	96.8507	51.2947	187.6246	0.0307	0.0633
C x D x E	2	321.5069	261.6180*	612.1961	0.0077	0.4124
(P vs C) x D/E	3	711.1683	367.2561*	794.0301*	0.0673	0.1795
Mean error	621	103.5439	56.0156	165.5196	0.0225	0.0654
Overall Mean	-	118.64	55.40	51.70	0.75	1.16
Progeny Mean	-	117.35	53.95	50.72	0.74	1.06
Control Mean	-	151.10	91.45	76.14	0.97	2.04
CV (%)	-	8.56	13.50	24.61	19.68	23.01

*, ** Significant at 5 and 1 % probability, by the F test

(Fancelli and Dourado Neto 2004). The means for lodging, plant height, ear height, prolificacy and grain yield of the same progenies, evaluated in the normal growing season, at a density of 80,000 plants ha^{-1}, were 5.0%, 149.3 cm, 67.4 cm, 1.04 ears per plant and 2.77 kg plot^{-1}, respectively.

The absence of progeny by density interaction (Table 4) indicates that the best progenies at lower density also perform best at greater density, indicating the possibility of the development of a single selection program for the two sowing densities. According to Cruz and Regazzi (2004) the presence of genotype by environment interaction, besides interfering with the recommendation of cultivars, hampers the choice of differentiating criteria for the selection of superior genotypes and the use of alternative methods to identify material with a high genetic potential.

The estimates of additive genetic variance for grain yield were similar in the two populations (0.1228 and 0.1212 kg^2 plot^{-2}) (Table 5). These values are considered low when compared with data reported in the literature (Hallauer and Miranda Filho 1988), since 50% of the genetic base of the population Isanão VF1 is originated by the S_4 line. This suggests that backcrosses with the normal population might be necessary to increase the variability. Nevertheless these genetic variances represent the greatest part of the mean phenotypic variance for grain yield, as the heritability coefficients show (53.5 and 63.3%, respectively for the densities 57,778 and 80,000 plants ha^{-1}). Ferreira et al. (1999) found a similar heritability to the one observed in the denser population.

The mean expected progress in grain yield was 16.01% for the lowest density and 19.19 % for the highest density. The values of the indices of variation (0.64 and 0.78) are also relatively high, similar to those with normal maize populations, which, according to Vencovsky and Barriga (1992), is a good indicator of successful selection.

The additive genetic variance for plant height at the density of 57,778 plants ha^{-1} (286.15 cm^2 plant^{-2}) was higher than the one found for the greater density (236.03 cm^2 plant^{-2}). These estimates exceed those found by Souza Jr. et al. (1980), Hallauer and Miranda Filho (1988) and Tozetti et al. (1995). The same tendency was observed for ear height with 147.49 and 140.25 cm^2 plant^{-2}, respectively, for the lower and higher population density, much the same as found by Geraldi and Miranda Filho (1985) at a density of 50,000 plants ha^{-1}. The heritability coefficients of over 60% for both traits are considered high in the two densities and, together with the respective expected gains and variation indices of around 0.8 (Table 5), indicate the possibility of reducing or increasing the plant height relatively easily. According to Paterniani and Rissi (1976), this genetic variability is due to modifier genes that are still

Table 5. Estimates of environmental variance, progeny variance, additive genetic variance, mean phenotypic variance, heritability based on progeny means, coefficient of genetic variation, variation index and selection progress (intensity 20%), for the traits plant height (PH), ear height (EH), lodged and broken plants (LBP), prolificacy (PRO) and grain yield (GY). Maize composite Isanão VF1, Selvíria - MS

Parameters	**Traits**									
	PH (cm)		**EH (cm)**		**LBP (%)**		**PRO (ears plant^{-1})**		**GY (kg plot^{-1})**	
	57,778	80,000	57,778	80,000	57,778	80,000	57,778	80,000	57,778	80,000
Environmental variance	114.5803	111.8875	61.3946	52.1373	202.2750	129.5831	0.0268	0.0196	0.0801	0.0527
Progeny variance	71.5385	59.0082	36.8749	35.0628	16.7027	40.8479	0.0086	0.0053	0.0307	0.0303
Additive genetic variance	286.1574	236.0328	147.4996	140.2512	66.8108	163.3916	0.0344	0.0212	0.1228	0.1212
Mean phenotypic variance	109.7319	96.3040	57.3397	52.4419	84.1277	84.0422	0.0175	0.0118	0.0574	0.0478
Heritability (%)	65.19	61.27	64.30	66.86	19.85	48.60	49.09	45.01	53.53	63.32
Coef. genetic variation	7.0186	6.7425	11.0042	11.2522	10.6064	10.1656	11.2423	11.1205	15.6583	17.2143
Variation index (CVg/CVe)	0.8001	0.7331	0.7977	0.8399	0.2945	0.5704	0.5714	0.5314	0.6425	0.7843
Selection progress (unid.)	9.5595	8.4169	6.8166	6.7775	2.5490	6.2371	0.0909	0.0682	0.1793	0.1938
Selection progress (%)	7.93	7.38	12.35	12.88	6.61	9.92	11.08	10.4924	16.0151	19.1942

segregating in the population. Therefore, mass selection against high plants may be sufficient to standardize the population for the dwarf phenotype. There is also the possibility of standardizing the population at an intermediate height, without loosing the beneficial stem traits the dwarf genotype confers to maize plants. The expected gain for plant height was lower than for ear height at both densities (Table 5), suggesting that stabilizing selection to standardize height may be based on the second trait.

The coefficients of genotypic correlation of grain yield with plant and ear height were positive and relatively high (0.5271 and 0.5447) (Table 6). This can be a result of the segregation for modifier genes, increasing the intrapopulation competition. However, these correlations are also common in populations of normal height (Lordêlo and Miranda Filho 1981, Lemos et al. 1992). Nevertheless, the path analysis (Table 7) indicates that the direct effect of ear and plant height on grain yield is low (0.27 and 0.12 respectively). Stabilizing selection based on ear height, proposed simply to standardize the population, would therefore not affect grain yield very much. In recently formed dwarf populations it seems to be easier to break up of the initial correlation, which allows for the development of dwarf and intermediate populations with high grain yield, due to the strong effect of recessive homozygosis for the major gene. When the direct effect is small, this becomes even easier.

The high genetic correlation between prolificacy and grain yield (0.76) (Table 6) is direct (0.61) (Table 7), evidencing the important contribution of this trait to grain yield. Although the heritability of this trait is a little lower than grain yield (Table 5), it could be very useful in population improvement. The coefficient of determination of the path analysis was high (0.82), indicating that great part of the variation for grain yield is explained by the other traits, confirming the consistency of the above observations.

CONCLUSIONS

Maize composite Isanão VF1 has sufficient genetic variability for selection progress in the second growing season and in reduced spacing conditions;

The traits plant and ear height have high variability and can easily be standardized owing to the high heritability.

Table 6. Coefficients of genetic (above the diagonal) and phenotypic correlation (below the diagonal) between the traits plant height (PH), ear height (EH), lodged and broken plants (LBP), prolificacy (PRO) and grain yield (GY), according to the joint group analysis, in the maize composite Isanão VF1. Selvíria – MS

Correlation	PH	EH	LBP	PRO	GY
PH	———	0.9155	0.8042	0.0514	0.5271
EH	0.9050	———	1.0017	0.0569	0.5447
LBP	0.1892	0.2783	———	0.9341	1.0586
PRO	0.0659	0.0613	0.2980	———	0.7594
GY	0.4648	0.4631	0.2849	0.6582	———

Table 7. Estimates of the direct and indirect effects of the traits plant height (PH), ear height (EH), lodged and broken plants (LBP) and prolificacy (PRO) on grain yield (GY), obtained by the path analysis, according to the joint group analysis, of the maize Composite Isanão VF1. Selvíria-MS

Effects	Direct effect	Indirect effect
PH (total correlation = 0.5271)		
direct on GY	0.2721	-
indirect via EH	-	0.1134
indirect via LBP	-	0.1100
indirect via PRO	-	0.0313
EH (total correlation = 0.5447)		
direct on GY	0.1239	-
indirect via PH	-	0.2491
indirect via LBP	-	0.1368
indirect via PRO	-	0.0347
LBP (total correlation = 1.0500)		
direct on GY	0.1368	-
indirect via PH	-	0.2189
indirect via EH	-	0.1239
indirect via PRO	-	0.5702
PRO (total correlation = 0.7594)		
direct on GY	0.6105	-
indirect via PH	-	0.0139
indirect via EH	-	0.0070
indirect via LBP	-	0.1278
Coef. of determination	0.8183	

Potencial do composto Isanão VF1 de milho para melhoramento em espaçamento reduzido na segunda safra

RESUMO - *O objetivo foi verificar o potencial de melhoramento do composto Isanão VF1 na segunda safra (safrinha). Foram avaliadas 150 progênies de meios irmãos, no espaçamento 0,45 m e nas densidades 57.778 e 80.000 plantas ha^{-1} em delineamento em blocos casualizados com três repetições. Foram estimados ganhos de 16,0 e 19,2% para rendimento, 11,1 e 10,5% para prolificidade e 12,3 e 12,9% para altura de espigas, respectivamente para 57.778 e 80.000 plantas ha^{-1}. As herdabilidades para altura de plantas, altura de espigas e o rendimento foram de 65,2 e 61,3%, 64,3 e 66,9% e 53,5 e 63,3%, indicando potencial para melhoramento tanto em baixa quanto em alta densidade de semeadura. A ausência de interação progênies x densidades indica que não há necessidade de programas de seleção distintos. A ocorrência de segregação para* *genes modificadores para altura sugere, de imediato, uma seleção estabilizadora baseada na altura de espigas.*

Palavras-chaves: arranjo de plantas, densidade de semeadura, variação genética, parâmetros genéticos.

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