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AGRONOMIC PERFORMANCE OF MALE-STERILE AND FERTILE MAIZE GENOTYPES AT TWO PLANT POPULATIONS

PERFORMACE AGRONÔMICA DE GENÓTIPOS MACHO-ESTÉREIS E FÉRTEIS DE MILHO EM DUAS DENSIDADES DE SEMEADURA

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SUMMARY

This experiment was conducted in 1994 at Ames, Iowa, US to test whether cytoplasmic male-sterility can be used to decrease barrenness and to increase grain yield of maize at two plant populations. Four genotypes were tested: a hybrid (NK 6330) and an inbred, with sterile and fertile counterparts. Each genotype was evaluated at plant populations equivalent to 25,000 and 75,000 pl. ha-1. Hybrids produced higher grain yield than inbreds at both plant populations. Grain yield was higher at 75,000 than at 25,000 pl. ha^{-1}. No difference in grain yield, number of ears per plant, number of grains per ear, tassel length, and tassel number of branches was found between sterile and fertile counterparts of the inbred and hybrid, regardless of plant population. Fertile genotypes bore heavier tassels at anthesis than their sterile counterparts. Adequate precipitation distribution and high fertility level in the soil probably decreased competition between tassel and ears, mitigating potential yield benefits of suppressing genetically pollen production.

Key words: ***Zea mays***, *male-sterility, stress, grain yield.*

RESUMO

Este experimento foi conduzido em Ames, Iowa, US durante o ano agrícola de 1994, tendo como objetivo avaliar se a macho-esterelidade genético-citoplasmática pode ser utilizada para aumentar o rendimento de grãos de milho em diferentes populações de planta. Quatro genótipos foram utilizados: um híbrido (NK 6330) e uma linhagem, ambos em suas versões fértil e macho-estéril. Cada genótipo foi avaliado em duas densidades de semeadura, equivalentes a 25.000 e 75.000pl.ha^{-1}. Os híbridos produziram maiores rendimentos de grão do que as linhagens nas duas populações utilizadas. O rendimento de grãos por área foi maior em 75.000 do que em 25.000pl.ha^{-1}. Nenhuma diferença significativa em termos de rendimento de grãos, número de espigas por planta, número de grãos por espiga, comprimento e número de ramos do pendão, foi observada entre genótipos férteis e macho-estéreis, independentemente da população de plantas. As versões férteis apresentaram pendões mais pesados do que os genótipos macho-estéreis. A adequada distribuição da precipitação e a alta fertilidade do solo possivelmente diminuiram a competição entre o pendão e as espigas, minimizando os benefícios da supressão genética da produçao de pólen sobre o rendimento de grãos.

Palavras-chave: ***Zea mays***, *macho-esterilidade, estresse, rendimento de grãos.*

INTRODUCTION

Maize is a unique species among the economically important grasses due to its monoecious floral organization and protandrous pattern of development. The male inflorescence (tassel), which is derived from the shoot apical meristem, is differentiated first and has developmental priority over the ears, located at the tip of axillary branches (CHENG & PAREDY, 1994).

The tassel can dominate the ears and thus limit grain yield by three different mechanisms: (1) shading of the upper leaves (DUNCAN ***et al.***, 1967; HUNTER ***et al.***, 1969); (2) acting as a competitive sink (ANDERSON, 1972) and; (3) modifying the

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supply of growth regulators (specially auxins) and CO_2 acceptors (SEYEDIN *et al.*, 1980).

The degree of competition between tassel and ear development is highly related to the plant's environment. Under favorable conditions (water, light and nutrients) there is less competition between the male and female inflorescences. Under less favorable conditions, particularly in dense plantings or with drought stress, apical dominance is increased and ear development decreased. The net result of this protandrous pattern of development is an increase in barrenness and a decrease in grain yield.

A potential tool to decrease tassel dominance over the ears, and to increase maize tolerance to stresses at flowering, is male-sterility. Cytoplasmic male-sterility was used most extensively during the 50s and 60s to eliminate detasseling in the production of corn hybrid seed. The Texas male-sterile cytoplasm (TMS) was carried in female inbreds, while a nuclear gene located in the male parent restored pollen fertility of the hybrid seed.

In addition to preventing pollen production, reports of CHINWUBA *et al.* (1961), SCHWANKE (1965) and MEYER (1970), indicated that TMS affected other agronomic characteristics of single cross hybrids and seemed to reduce the detrimental effects of high plant densities on grain yield, raising the optimum stand level for maximum productivity of a genotype. A possible explanation for that behavior is that cytoplasmic male-sterile cultivars have small tassels that intercept less solar radiation, require less input of energy in their formation, and produce a lower amount of auxins.

The reports showing that male-sterility might be a way to reduce barrenness, especially under stressful conditions, generated interest in using cytoplasmic effects per se, not only to facilitate production of hybrid seeds but also to promote higher commercial grain yield. The following production system involving male-sterility was envisioned in the early 70s: the farmer would grow a blend of 95% sterile plus 5% fertile seeds of a hybrid at a population 20% higher than normal. This system would increase grain yield by 10% for the average hybrid. Moreover, it would provide the farmer a hybrid to resist stresses better than the fertile version at the lower population. However, the utilization of TMS was suddenly interrupted in 1973 due to development of the ***Helminthosporium maydis*** epidemic, which particularly affected the materials containing the T-cytoplasm. After that, hybrid seed companies substantially decreased use of cytoplasmic male-sterility in their breeding programs, and the idea of utilizing that mechanism as a tool to decrease barrenness and improve population tolerance was abandoned.

Several other sources of male-sterility have been developed since the blight of 1973. There are also a number of new technologies in various stages of development which can achieve male-sterility through non-traditional means, including chemical sprays and genetic transformation. In addition, corn hybrids have been considerably improved in the last 30 years. Hybrids developed in the 80s and 90s show a greater tolerance to barrenness than materials grown in the 60s (RUSSELL, 1991).

Given lack of information about effects of male-sterility on agronomic traits of current genotypes, this experiment was carried out to test whether genetic suppression of pollen production would increase grain yield and decrease barrenness at different plant populations.

MATERIALS AND METHODS

The study was conducted during 1994 in Ames, Iowa, US. Study site soil was a Nicollet loam (Fine-loamy, mixed, mesic Aquic Hapludoll). The experimental design was a split plot with four replications of each treatment. The main plot consisted of four different genotypes: the hybrid Northrup King (NK) 6330, in sterile and fertile versions, and the inbred used as the female parent of NK 6330, in sterile and fertile versions. The source of male-sterility was the S cytoplasm. Each genotype was evaluated at two plant populations in the split plot: 25,000 and 75,000pl. ha^{-1}. Each split plot consisted of three rows, spaced 0.75 m equidistantly. Individual plot rows were 10m long.

The experiments was hand-planted on May 3. Strings containing marks at appropriate distances were used to assure the planting pattern desired for each plant density tested in the experiment. Three seeds were dropped per hill. Two weeks after emergence, when plants were at stage V4, thinning was performed to adjust population to desired levels. Plots were also hand-hoed and wheel-hoed to control post-emergence weed competition.

Plant evaluations were performed in the central row of each split plot. Tassel dry matter was analyzed at two phenological stages, at V17 and when at least 50% of plants in fertile plots were shedding pollen. Four tassels were randomly picked for each stage. Tassels were placed in a dryer at a temperature of 65°C for 72 hours. Tassels collected during anthesis were used to determine tassel length and number of branches before they were dried.

Plant and ear insertion heights were determined at anthesis by taking five plants at random and measuring the distance from the base of the stem to the tip of the tassel and the point of insertion of the lowest fully developed ear on the stalk. The total number of leaves per plant was determined at anthesis using four plants randomly chosen. Internode length was evaluated indirectly by taking average plant height, subtracting tassel length, and dividing the result by total number of leaves produced per plant. Harvesting was performed on September 28, after leaves had senesced entirely. Ears were placed in a dryer at a temperature of 70° C, dehusked and shelled to determine grain weight, grain yield and yield components.

Daily meteorological data were collected, using an automated weather station (Campbell Scientific Corp., Logan, UT). Meteorological instrumentation was located approximately 4km from the experimental field. Values of temperature and precipitation were expressed as an average of each two-week period from May to September.

Analysis of variance was performed using the General Linear Models procedure of the Statistical Analysis System (SAS). F values for main treatment effects and their interactions were considered significant at the 0.05 level. Whenever a particular factor or interaction of factors significantly influenced a variable, means were separated using Fischer's LSD test at the 0.05 probability level, following methodology presented by LITTLE & HILLS (1978).

RESULTS

The growing season had two distinct thermal trends when compared to normal (Table 1). During the most critical period for grain yield determination (from June 28 to August 22), the mean temperature was 1.8°C lower than normal. On the other hand, from August 22 to the end of the growing season, the growing season was warmer than average. The overall precipitation was slightly below average.

Grain yield and number of ears per plant were significantly affected by cultivar and plant population. Hybrids produced higher yield per area than the inbreds (Table 2). Male-sterile cytoplasm did not promote significant increment in yield relative to fertile counterparts (Table 2). Grain yield per hectare was 67% greater at 75,000pl. ha^{-1} than at 25,000pl. ha^{-1} (Table 3). Hybrids produced more ears per plant and grains per ear than inbreds, which contributed to their higher grain yield per area (Table 2). Cytoplasmatic male sterility had no effect on those variables. All genotypes had greater number of ears per plant at the lower plant population (Table 3).

Hybrids had heavier grains than inbreds, regardless of plant population tested (Table 4). Introduction of a sterile cytoplasm did not significantly change the weight of 1,000 grains for the hybrid. Lack of viable pollen production in the inbred resulted in heavier grains, particularly at the higher plant population. The sterile version of the inbred was able to tolerate the increase in plant population without significantly decreasing the weight of 1,000 kernels, something that did not occur with its fertile counterpart.

Male sterile cytoplasm did not impact tassel dry matter at V17 (Table 5). However, fertile versions of hybrid and inbred had tassels significantly heavier at anthesis than their sterile counterparts. Tassel dry matter of the fertile inbred was 33% higher at anthesis than at V17. In the case of the sterile version, the increment was only 11%. The largest weight gain occurred with the fertile hybrid, whose tassels at anthesis were 77% heavier than at V17. The fertile hybrid also showed the largest absolute values of tassel dry matter. Cultivar average tassel dry matter was significantly lower at 75,000pl. ha^{-1} than at 25,000pl. ha^{-1} (Table 3). Averaged across plant densities, hybrids had significantly larger tassels than inbreds (Table 5). Male sterility did not affect tassel length. Hybrid plants were taller and had ears at higher positions than inbreds (Table 6). Male sterility contributed to decrease plant height for the hybrid but it did not affect this variable for the inbred. There was no significant effect of male sterility on height of ear insertion for both inbred and hybrid. Higher population density promoted increase in plant and ear insertion height of the genotypes (Table 3). The final number of expanded leaves ranged between 19.2 and 19.8, depending on the cultivar (Table 6). The fertile version of the hybrid produced more leaves than its sterile counterpart. In contrast, no effect of male sterility on the number of expanded leaves of the inbred was observed.

Hybrids had longer internodes than inbreds explaining their greater plant height (Table 6). No negative effect of male sterility on average internode length of either cultivar was noted. In fact, the opposite trend was observed for the inbred, with the sterile version having longer internodes than its fertile counterpart.

Table 1. Variation of temperature, growing degree days (GDD), heat stress hours (HS) and precipitation registered during the growing season of 1994 and the normal values (Nor) for those climatic parameters, Ames, Iowa, US.

Time of the year	Temperature		GDD[2]		HS[2]		Precipitation[2]	
	1994	Nor[3]	1994	Nor	1994	Nor	1994	Nor
	---------°C---------		---------------------number---------------------				---------mm--------	
May 3 to May 16	14.7	15.2	153	164	0.0	1.5	38	46
May 17 to May 30	19.3	17.6	237	203	2.0	4.2	6	56
May 31 to June 13	19.9	20.2	251	256	2.0	11.0	80	54
June 14 to June 27	24.2	21.7	350	288	19.0	15.4	62	60
June 28 to July 11	21.9	23.2	299	318	4.0	26.7	29	59
July 12 to July 25	22.0	23.6	299	329	10.0	29.0	22	38
July 26 to Aug. 8	20.2	22.8	256	310	2.0	22.8	52	50
Aug. 9 to Aug. 22	20.1	21.9	256	292	0.0	16.9	41	45
Aug. 23 to Sep. 5	21.6	21.2	258	276	20.0	15.3	77	46
Sep. 6 to Sep. 19	21.6	18.2	284	218	16.0	7.3	4	40
Sep. 20 to Oct. 3	16.2	15.3	117	169	3.0	2.2	59	34

[1]Values represent the daily average over the period;
[2]Values represent the total accumulated over the period;
[3]Average of a period comprehended between 1951 and 1985.

Table 2. Grain yield and components of corn inbreds and hjybrids, Ames, Iowa, US, 1994.

Cultivar	Grain yiele (kg.ha^{-1})[1]	Ears per plant - nº[2]	Grains per ear - nº[3]
Inbred Sterile	6,490*B	1.18 B	369 B
Inbred Fertile	6,162 B	1.17 B	386 B
Hybrid Sterile	12,018 A	1.26 A	581 A
Hybrid Fertile	11,942 A	1.29 A	561 A

*means of two plant populations; means followed by the same letter in the column are not significantly different by the LSD test (P=0.05);
[1]LSD means = 627 [2]LSD means = 0.09; [3]LSD means = 41;

Table 3 - Effect of plant population on agronomic traits of corn genotypes, Ames, Iowa, US, 1994.

Plant Population (pl.ha^{-1})	Grain Yield (kg.ha^{-1})[1]	Ears per plant (nº)[2]	Tassel dry matter at V17 (g)[3]	Tassel dry matter at (anthesis(g)[4]	Plant height (cm)[5]	Ear Insertion height(cm)[6]
25,000	6,846* B	1.46 A	3.54 A	4.96 A	225 B	66 B
75,000	14,461 A	0.99 B	2.96 B	4.25 B	236 A	80 A

*means of four genotypes; means followed by the same letter in the column are not significantly different by the LSD test (P=0.05)
[1]LSD means = 630; [2]LSD means = 0.08 [3]LSD means = 0.19; [4]LSD means = 4.52; [5]LSD means = 3.40; [6]LSD means = 2.20

Table 4. Effect of plant population on the weight of 1000 grains of corn inbreds and hybrids, Ames, Iowa, US 1994.

Plant Population ($Pl.ha^{-1}$)	Inbred Sterile	Inbred Fertile	Hybrid Sterile	Hybrid Fertile
		Weight of 1000 grains - g[1]		
25000	b 330* A	b 316 A	a 407 A	a 414 A
75000	c 317 A	b 297 B	a 362 B	a 363 B

* means followed by the same capital letter in the column or preceded by the same small letter in the row are not significantly different by the LSD test (P = 0.05).
[1]LSD genotype means within each level of plant density = 19; LSD plant density means within each level of genotype = 16

Table 5. Tassel traits of corn inbreds and hybrids, Ames, US, 1994.

Genotype	Tassel dry matter at V17(g)[1]	Tassel dry matter at anthesis (g)[2]	Tassel length (cm)[3]	Tassel branches (n°)[4]
Inbred Sterile	2.11*B	2.37 D	41.9 B	8.8 B
Inbred Fertile	2.13 B	3.18 C	40.9 B	8.7 B
Hybrid Sterile	4.35 A	5.13 B	46.7 A	13.1 A
Hybrid Fertile	4.38 A	7.74 A	47.2 A	12.1 A

* means followed by the same letter in the column are not significantly different by the LSD test (P=0.05).
[1]LSD means = 0.42; [2]LSD means = 0.80; [3]LSD means = 1.90; [4]LSD means = 1.80

Table 6. Plant and ear insertion height, number of leaves and internode length of corn inbreds and hybrids, Ames, Iowa, US, 1994.

Genotype	Plant Height (cm)[1]	Ear insertion height (cm)[2]	Leaves (n°)[3]	Internode length (cm)[4]
Inbred Sterile	209*C	59 B	19.2 B	9.1 B
Inbred Fertile	210 C	61 B	19.1 B	8.8 C
Hybrid Sterile	248 B	86 A	19.2 B	10.7 A
Hybrid Fertile	254 A	86 A	19.8 A	10.7 A

* means followed by the same letter in the column are not significantly different by the LSD test (P=0.05).
[1]LSD means = 4.3; [2]LSD means = 4.6; [3]LSD means = 0.4; [4]LSD means = 0.2

DISCUSSION

Contrary to the results of CHINWUBA *et al.* (1961), SCHWANKE (1965) and MEYER (1970), cytoplasmic male-sterility did not promote significant improvements in grain yield or yield components, regardless of genotype and plant density (Table 2). The work done by those authors has indicated that this mechanism might be used to reduce the size of the tassel, decreasing apical dominance and improving grain yield, particularly at high plant populations. In the present report, the male-steriles did have lower dry matter tassels at anthesis when compared to fertile counterparts (Table 5). However, this was not sufficient to promote an increase in yield, even at 75,000pl. ha^{-1}.

A combination of lack of water stress, fertile soil, and density-tolerant cultivars with small fertile tassels, probably contributed to lessen potential increments in yield that might have been promoted by cytoplasmic male-sterility. Competition between fertile tassels and developing ears is usually higher under conditions of high temperature, water deficit and low soil fertility. None of these three factors was significant during the trial.

Benefits from preventing pollen production in terms of decreasing barrenness at high plant densities have been greater for genotypes that produce large fertile tassels because there is a positive correlation between tassel size and silking delay (MOCK & BURREN, 1972; BURREN *et al.*, 1974). The values of tassel dry matter and number of branches at anthesis observed in this experiment are considerably lower than those reported by ANDERSON (1972) and MOCK & SCHUETZ (1974) for genotypes developed in the early 70s.

Considering the differences in size of the main inflorescence, a hypothesis could be drawn. Another reason for the failure of male-sterility to improve yield was the small size of the tassel of genotypes used in the experiment. Plants with small tassels require less photosynthate to develop the male inflorescence (ANDERSON, 1972), have fewer problems with apical dominance (SEYEDIN, 1980) and are potentially less yield responsive to genetic suppresion of pollen production (MEYER, 1970). Most breeding programs used to develop new inbreds and hybrids do not use tassel size per se as a criterion to select future parents (HALLAUER, personal communication - 1995). However, almost all of them emphasize the ability of the potential progenitors to withstand higher than conventional plant population without showing pronounced barrenness. Since small tassels are usually positively correlated with tolerance to high density, it is possible that many commercial hybrids have this characteristic as a side-effect of the selection process that is used during development and evaluation of inbreds.

One of the most consistent effects of male-sterility is a reduction in plant height (MEYER, 1970). This was observed only in the hybrid (Table 6). The smaller tassels and lack of fertile pollen production in male-steriles may have reduced the amount of IAA produced by the shoot apex. The reduction in the amount of auxin being produced in the growing point may have promoted less cell elongation, which would result in an irregular shortening of the upper internodes of the stalk (SARVELA & GROGAN, 1965). The fertile version of the hybrid had heavier tassels at anthesis in comparison to its sterile counterpart, which may have contributed to the increase in plant height (Tables 5 and 6). However, no significant influence of male-sterility in decreasing internode length was observed (Table 6). The apparent contradiction between the impacts of male-sterility on plant height and internode length may be explained by the way the second variable was estimated. No direct measurement of individual internode length was made. As SARVELA and GROGAN (1965) pointed out, the smaller plant height of male-stelile genotypes arises from the non-sequential shortening of specific internodes probably caused by a temporary block of the plant hormones regulating cell elongation or cell division.

CONCLUSION

Cytoplasmic male-sterility did not increase maize grain yield, regardless of genotype or plant population. Male-sterile genotypes produced heavier tassels, higher weight of 1,000 grains and taller plants than their fertile counterparts. No difference was found between fertile and male-sterile counterparts in terms of number of grains per ear, tassel lenght and number of branches.

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