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THE EFFECT OF CYTOPLASMIC MALE STERILITY ON YIELD STABILITY OF MAIZE INBRED LINES

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Abstract

Nowadays the production of hybrid maize seed is increasingly based on using cytoplasmic male sterility (CMS) in order to reduce costs of detasseling. Since inbred lines are unstable due to their performance, it is very important to investigate the influence of the specific type of sterility on yield stability. With the aim to analyse the effect of CMS on yield stability, seven maize inbred lines, developed at Maize Research Institute “Zemun Polje” were examined in this study. Each of these seven inbreds was investigated in five variants: with normal cytoplasm (N), with C type sterile cytoplasm (CMS-C), the fertile counterpart C (RfC), with S type sterile cytoplasm (CMS-S) and the fertile counterpart S (RfS). The yield was analysed using the method of Eberhart and Russell on the basis of the coefficient of linear regression. The inbred line ZPL-1 was the best ranked within inbreds with N, CMS-S and RfS type of germplasm. Therefore, this inbred line was most stable within the stated genotypes. On the other hand, values closest to one were detected in the inbred line ZPL-6 within the inbreds with CMS-C and RfC germplasm, so this inbred was the most stabile for those two types of cytoplasm.

Key words: maize, yield, cytoplasmic male sterility, inbred lines

Introduction

In many important field crops the CMS trait is used exclusively to produce commercial hybrid seeds. Using CMS to prevent self-fertilisation of the seed parent plant does away with the costly and labour-intensive manual or mechanical emasculation.

In a large number of investigations contradictory results have been reported with respect to differences in grain yields of CMS and normal fertile maize inbred lines and hybrids. Positive effects of CMS on grain yields were reported by Sanford (1965), Stamp (2000), Weingartner (2002) and Kaeser (2003). The absence of effect or inconsistent effects of CMS on grain yields were reported by Duvick (1958) and Everett (1960). A negative effect of CMS on grain yields was found for CMS hybrids with CMS-T cytoplasm (Stringfield, 1958), compared to the fertile counterpart, and by Noble and Russell (1963), who tested male-sterile and normal male-fertile cytoplasm.

If CMS increases the yield of inbred lines and hybrids, the generally accepted physiological explanation is the lower consumption of energy and nutrients in male-sterile tassels than in normal fertile tassels. This is advantageous for the female component of a male-sterile plant, because these stocks can be used for the development of the ear and grain filling (Kaeser et al., 2003).

Adaptability and stability of a genotype is expressed through the genotype x environment interaction. This interaction is a source of variation that includes a genotype and environmental effects. Individual consideration of these two factors does not give a real image of either a genotype or environments. Reliable results can only be obtained if the

interrelationship of these two sources of variation is included. The occurrence of intensive genotypes also increases susceptibility of genotypes to environmental conditions (Dimitrijević and Petrović, 2000).
Several models for testing adaptability and stability of yield have been developed during the last 70 years (Finlay and Wilkinson, 1963, Lin and Binns, 1988). The most widely used method for the analysis of stability was coined by Eberhart and Russell (1966). This method is based on the regression coefficient b_i and standard deviation from regression Sdi^2.
The yields of maize inbred lines with normal cytoplasm as well as their CMS and Rf variants were observed in the present study. The stability parameter b_i was used in studying yield stability of inbreds.

Materials and Methods

The following seven maize inbred lines of different origin and maturity groups (FAO 300-500) were used in this study: ZPL-1, ZPL-2, ZPL-3, ZPL-4, ZPL-5, ZPL-6 and ZPL-7.
Cytoplasmic male sterile and restorer versions of inbreds were developed by conversion of inbreds with normal cytoplasm at the Maize Research Institute, Zemun Polje.
Trials were set up according to the randomised split-plot design in three locations (Zemun Polje, Školsko dobro - a location within trial fields of the Maize Research Institute, Zemun Polje and Srbobran) in 2010 and 2011. All trials were set up under conditions of dry land farming. Sowing was always done on the optimum dates with the application of common cropping practices.
The trial encompassed three replications in five sets (blocks). Each block represented one of the type of observed inbreds:
I block – N (normal) cytoplasm, i.e. original inbred lines
II block – CMS-C inbreds
III block – RfC inbreds
IV block – CMS-S inbreds
V block – RfS inbreds .
Plots within a replication were composed of 4 rows, and each row had 12 hills at the distance of 40 cm. Sowing was done by hand with four plants per hill. The inter-row distance was 70 cm. The elementary plot size was 7.28 m^2, while sowing density amounted to 71,429 plants ha^{-1}. Thinning to two plants per hill was done in the 5-leaf stage. Plants from 10 inner hills were used for the analysis of grain yields (in order to avoid a border hill effect).
The grain yield was presented in t ha^{-1} at 14% moisture.
The parameters for grain stability were estimated using method developed by Eberhart and Russell (1966), as indicators of seed production reliability on fertile and sterile basis under various environmental conditions.

Results and Discussion

The analysis of stability parameters was done on the basis of grain yields of all seven inbreds within each block (inbred type). The regression coefficient (b_i) showed the response of a genotype to the environment. When b_i=1 average adaptability and stability of an observed genotype are uniform under both environmental conditions, favourable and unfavourable; when b_i>1 a genotype is averagely stable only under favourable environmental conditions; and when b_i<1 a genotype performance is better under poorer environmental conditions.
The values of average yields and stability parameters for inbreds with normal cytoplasm are shown in the Table 1. The highest average yields of 6.5727 t ha^{-1} and 5.3533 t ha^{-1} were recorded in the inbreds ZPL7 and ZPL2, respectively. The lowest yield of 3.7267 t ha^{-1} was achieved by the inbred ZPL4. According to the regression coefficient the inbred ZPL1 was

the most stable, while the inbred ZPL7 with the lowest yield also had the poorest value of this coefficient. Performance of inbreds ZPL6 and ZPL7 was better under favourable growing conditions, while inbreds ZPL2 and ZPL5 were more productive under somewhat unfavourable conditions.

Table 1. Yields and stability parameters of inbreds with N type of germplasm

Inbred	Yield (t ha^{-1})	Rank	b_i	Rank
ZPL1	4.498	5	1.0451	1
ZPL2	5.3533	2	0.8241	4
ZPL3	4.772	4	1.1312	3
ZPL4	3.7267	7	0.6397	7
ZPL5	4.2333	6	0.8978	2
ZPL6	4.9907	3	1.2610	6
ZPL7	6.5727	1	1.2122	5

Results obtained on average yields and stability parameters of inbreds encompassing C cytoplasm are presented in Table 2. The highest average yields of 6.5327 t ha^{-1} and 5.91 t ha^{-1} were recorded in inbreds ZPL7 and ZPL2, respectively, the same as in inbreds with N cytoplasm. On the other hand, the lowest yield (3.7267 t ha^{-1}) was detected in the inbred ZPL4. Based on stability parameters, the most stable inbred according to the values of the regression coefficient was inbred ZPL6, while the most yielding inbred was at the same time the least stable (ZPL7). The inbreds ZL1, ZPL4 and ZPL5 performed better under less favourable growing conditions. The inbred ZPL2 expressed greater adaptability under favourable growing conditions.

Table 2. Yields and stability parameters of inbreds with C type of germplasm

Inbred	Yield (t ha^{-1})	Rank	b_i	Rank
ZPL1	4.826	6	0.7838	4
ZPL2	5.91	2	1.3003	5
ZPL3	4.8407	5	1.0714	2
ZPL4	4.2633	7	0.8265	3
ZPL5	5.2027	4	0.6826	6
ZPL6	5.5453	3	0.9496	1
ZPL7	6.5327	1	1.3759	7

As for the inbreds with RfC type of germplasm (Table 3) the highest yield of 6.0883 t ha^{-1} was recorded in the inbred ZPL2, while the inbred ZPL7 ranked second with the average yield of 5.4107 t ha^{-1}. Based on the regression coefficient, the inbred ZPL6 was the most stable. According to this parameter the lowest stability was recorded in the inbred ZPL7. Under favourable growing conditions, better results were recorded in the inbreds ZPL1 and ZPL3, while the inbred ZPL5 was more adaptable to poorer conditions.

Table 3. Yields and stability parameters of inbreds with RfC type of germplasm

Inbred	Yield (t ha^{-1})	Rank	b_i	Rank
ZPL1	4.4540	5	1.6714	6
ZPL2	6.0833	1	0.0102	7
ZPL3	4.7087	4	1.5396	5
ZPL4	3.9260	7	1.0223	2
ZPL5	4.2080	6	0.6262	4
ZPL6	5.1593	3	1.0131	1
ZPL7	5.4107	2	1.1070	3

The highest yield (6.5373 t ha^{-1}) of inbreds with S type of germplasm was recorded in the inbred ZPL7 (Table 4). The inbred ZPL2 with the average yield of 5.89 t ha^{-1} ranked second. The lowest yield was again recorded in the inbred ZPL4. The inbred ZPL1 had the regression coefficient closest to unit and as such was the most stable, although it ranked next to the last by its yield. Inbreds ZPL2 and ZPL3 responded better to favourable growing conditions, while inbreds ZPL4, ZPL5, ZPL6 and ZPL7 responded better to unfavourable environmental conditions.

Table 4. Yields and stability parameters of inbreds with S type of germplasm

Inbred	Yield (t ha^{-1})	Rank	b_i	Rank
ZPL1	4.5127	6	1.0161	1
ZPL2	5.8900	2	1.5206	7
ZPL3	5.0793	4	1.2085	4
ZPL4	4.2940	7	0.8620	3
ZPL5	4.6600	5	0.7668	5
ZPL6	5.4027	3	0.7605	6
ZPL7	6.5373	1	0.8681	2

The inbred ZPL7, most yielding in previous studies, was also the most yielding inbred in the present study regarding genotypes with RfS germplasm (5.7587 t ha^{-1}, Table 5). Moreover, the inbred ZPL4 was the lowest yielding inbred in both studies, previous and present. The inbred ZPL1 was the most stable one. Inbreds ZPL3, ZPL6 and ZPL7 had values of b_i greater than one and therefore their performance was better under favourable growing conditions. Inbreds ZPL2, ZPL4 and ZPL5 were more adaptable to unfavourable environmental conditions.

Table 5. Yields and stability parameters of inbreds with RfS type of germplasm

Inbred	Yield (t ha^{-1})	Rank	bi	Rank
ZPL1	4.3930	4	0.8641	1
ZPL2	4.2667	6	0.8264	2
ZPL3	4.9253	2	1.3161	4
ZPL4	4.0847	7	0.6613	5
ZPL5	4.3060	5	0.5495	7
ZPL6	4.8960	3	1.2079	3
ZPL7	5.7587	1	1.5938	6

According to data obtained by the analysis of grain yields conducted by the method of Eberhart and Russell it can be concluded that out of seven observed inbreds the inbred ZPL7 was the most yielding for all types (blocks) except for the RfC type within where it was ranked second. Considering the grain yield, this inbred is also the most suitable for the seed production especially if it is used as a female component. On the other hand, the inbred ZPL4 had the lowest yields in all types (blocks) and therefore it can be recommended that this inbred is used as a male component. The remaining inbreds have a relatively good yield, and therefore they can be used in the maize hybrid seed production either as female or male components. Based on the regression coefficients, the inbred ZPL1 was ranked first within inbreds with N, S and RfS type of germplasm, and as such it can be considered the most stable inbred. The inbred ZPL6 had values closest to one within the inbreds of C- and RfC-type, while the inbred ZPL1 ranked fourth and sixth within C-type and RfC-type inbreds, respectively. The conclusion on which inbred has the poorest values of this parameter over different types (blocks) of inbreds cannot be drawn.

Studies by Kaeser et al. (2003) and Kaul (1988) indicate that, under high-yielding conditions CMS-S can be inferior to other CMS types with regard to the yield increase. This may be due to the fact that processes leading to pollen sterility are initiated by the CMS-S cytoplasm at a very late development stage of pollen production. The CMS-C cytoplasm interrupts pollen production at an earlier stage than does CMS-S cytoplasm, which can result in a more favourable translocation of nutrients to the ear primordia. In our research we have not observed that CMS-S inbreds are inferior comparing to inbreds with CMS-C cytoplasm. In our study, both CMS-S and CMS-C inbreds showed higher yields comparing to inbreds with normal cytoplasm and their fertile counterparts.

Conclusions

The effect of CMS on yield stability in seven maize inbred lines developed at Maize Research Institute “Zemun Polje” was observed in the present study. Each of these seven inbreds were investigated in five variants: with normal cytoplasm (N), with C type sterile cytoplasm (CMS-C), the fertile counterpart C (RfC), with S type sterile cytoplasm (CMS-S) and the fertile counterpart S (RfS). As it had been expected, it was shown that inbreds with both C and S sterile cytoplasm had higher yields comparing to normal and Rf variants. We could say that all analysed inbreds had good yield, and therefore could be used in seed production. There was no difference shown between two examined types of sterility. Based on the b_i coefficient of stability, the most stable inbred for N, CMS-S and RfS variants was ZPL1, while ZPL6 was the most stable inbred for CMS-C and RfC types of germplasm.

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