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COMBINING ABILITY OF SILAGE MAIZE EAR LENGTH

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Abstract: The aim of the present study was to evaluate the following parameters of silage maize ear length: variability of inbred lines and their diallel hybrids, superior-parent heterosis and general and special combining abilities. According to obtained results of the two-year study, it can be concluded that variability of this trait is significantly affected by a genotype and a genotype x year interaction. As expected, hybrids had greater average values of ear length than inbreds due to the depression of this trait that occurs in inbreds during inbreeding. The highest average value of heterosis for ear length was detected in the hybrid ZPLB 402 x ZPL B406 (62.3% and 48.8% in 1997 and 1998, respectively).

The estimation of combining abilities was done on the basis of diallel hybrids after the method established by Griffing, 1956a (method II, mathematical model I). The analysis of variance of combining ability for ear length indicated highly significant positive values of GCA and SCA for the observed trait in both years of investigation. Ear length inheritance was more affected by non-additive genes (dominance and epistasis) as indicated by the GCA to SCA ratio that was smaller than unity. The inbreds ZPLB 401 and ZPLB 406 had high GCA effects, while the hybrid combinations ZPLB 401 x ZPLB 403, ZPLB 401 x ZPLB 402, ZPLB 401 x ZPLB 406 and ZPLB 403 x ZPLB 406 had high SCA effects in both investigation years. These hybrid combinations include both parents with high GCA effects or one parent with low GCA effects. Furthermore, there are combinations ZPLB 403 x ZPLB 405 and ZPLB 404 x ZPLB 405 with significant SCA effects that include parents with low GCA effects. This is probably a result of the additive type (additive x additive) of interaction between parents.

Key word: Ear length, heterosis, combining abilities, GCA, SCA, silage maize.

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Introduction

A proper evaluation of combining abilities of genotypes can be made on the basis of intercrossing. Heterosis as hybrid vigour of the F_1 generation in relation to parents is maximally used in maize production. However, heterosis is not a frequent phenomenon, and a case that the progeny is more superior in all traits than the superior parent is even rarer. Therefore, in order to develop a hybrid, it is necessary to recognise combining abilities of parents prior to their crossing. Consequently, the estimation of combining abilities, done according to crosses, is a very important stage in developing highly productive maize hybrids. A good combining ability implies the capacity of a genotype to produce superior progenies when crossed with another genotype. Combining abilities are classified into two groups: general combining ability (GCA) and special combining ability (SCA). GCA and SCA were initially presented by Sprague and Tatum, 1942, according to whom GCA was used to indicate an average performance of the inbreds in the hybrid combinations, while SCA was used to point out cases in which performed combinations had been better or worse than expected according to average performances of inbreds included into such combinations. Griffing, 1956a, b, Sprague and Tatum, 1942, Falconer, 1960, Lonquist and Gardner, 1961, Borojević, 1981, determined that GCA was a result of an additive genetic variance, while SCA was a result of a non-additive genetic variance, i.e. of dominance and epistasis.

Diallel cross techniques are the most reliable method for analysing combining abilities. There are several methods to evaluate combining abilities: method proposed by Hayman, 1954a, b, and modified by Jones, 1965, and the analysis used by Griffing, 1956a. The diallel cross techniques for the analysis of GCA proposed by Griffing, 1956a, encompass four experimental methods and two mathematical analyses: Method 1 (encompasses parents, F_1 hybrids and reciprocal crosses), Method 2 (encompasses parents and F_1 hybrids without reciprocal crosses), Method 3 (includes F_1 hybrids and reciprocal crosses), Method 4 (includes F_1 hybrids without reciprocal crosses), Model 1 (fixed model implies that parents are not a random sample of a certain population) and Model 2 (i.e. a random model that implies that parents are a sample of a population analysed on the basis of a diallel cross). Methods used by Griffing, 1956a, point out to significance of GCA and SCA of inbreds indicating additive and dominant gene effects.

Singh and Gupta, 1969, Kraljević-Balalić, 1974, reported that high positive values for SCA were often obtained by crosses of a parent with high GCA and a parent with low GCA. Similar results were obtained by Pajić, 1984, Babić, 1993, Todorović, 1995. Moreover, parents with low GCA can produce positive and high values of SCA. Borojević, 1963, established that parents with good GCA could produce potential inbreds in later generations and that high values of combining abilities were in many cases related to a heterosis phenomenon.

The analysis of combining abilities of the heterozygous genetic material (populations and varieties) showed that GCA was more important than SCA, i.e. that additive gene effects were more important for inheritance of grain yield and its components. This was also confirmed by results of other authors, Obilana et al., 1979, Lamkey and Hallauer, 1984, Vančetović, 1992, Delić, 1993.

Pajić, 1984, Todorović, 1995, studied combining abilities of ear length in diallel series of hybrids and determined very significant values of GCA and SCA, as well as greater effects of dominant genes (GCA/SCA<1) for the observed trait.

Vattikonda and Hunter, 1983, determined that the most grain yielding hybrid had a silage yield lower by 10% than the record yielding silage maize. These results point out that there are justifiable reasons for a specific selection programme on silage maize. The genetic background of traits important for the increase of yield and quality of silage maize has not been significantly studied yet in comparison to studies on inheritance of grain yield and its components, Barriere et al., 1988, Dhillon et al., 1990.

The existence of a difference between GCA and SCA for ear length in maize inbred lines was a starting point in this study.

Material and Methods

Six inbred lines of silage maize of the FAO maturity group 400 within the ZP collection (ZPLB 401, ZPLB 402, ZPLB 403, ZPLB 404, ZPLB 405, ZPLB 406) and 15 hybrids derived by diallel crosses of inbred lines were used in this study. A comparative field trial with inbreds and hybrids was set up according to the randomised complete-block design with four replications at Zemun Polje in 1997 and 1998. Each genotype was sown in one row per replication with the density of 71,400 plants ha^{-1}. The elementary plot size was 2.8 m^2. Statistical processing of obtained results was done for each year due to a high significance of effects of a year, genotype and their interaction on ear length of silage maize. The following biometrical parameters were estimated: means, standard deviation, coefficient of variation and superior-parent heterosis. The analysis of combing abilities was performed after Griffing, 1956a, Method 2, mathematical model I, without reciprocal crosses according to the following model:

Source of variance	d.f.	Sum of squares	Mean squares	Expected mean squares
GCA	p-1	Sg	Mg	$\sigma^2 + (p+2)(\frac{1}{(p-1)}\Sigma gi^2$
SCA	P(p-1)/2	Ss	Ms	$\sigma^2 + \frac{2}{p(p-1)}\frac{\Sigma\Sigma}{i \le j}S_{ij^2}$
Error	M	Se	Me	σ^2

Results and Discussion

Obtained results of the two-factorial analysis of variance show very significant values of mean squares of genotypes and the year x genotype interaction (YxG) (Table 1).

T a b. 1. - Mean squares of ANOVA for ear length

Sources of variance	df	Ear length
Year (Y)	1	0.17
Genotype (G)	20	75.85**
Y x G	20	2.08**
Error	126	0.68

*,** significant at the probability level of 0.01

The greatest ear length in both years of investigations was recorded in the inbred line ZPLB 404 (16.45 and 16.42 cm in 1997 and 1998, respectively). The shortest ear length (12.47 and 12.35 cm) in 1997 and 1998 was detected in the inbred ZPLB 406 and ZPLB 405, respectively (Table 2). The highest average value for this trait in 1997 was expressed by the hybrid ZPLB 405 x ZPLB 406 (22.19 cm), and in 1998 by the hybrid combination ZPLB 401 x ZPLB 406 (22.65 cm). The lowest average value of the ear length was recorded in both years in the hybrid ZPLB 402 x ZPLB 403 (12.39 cm in 1997 and 12.92 cm in 1998, Table 2).

The coefficient of variation for inbreds ranged from 0.80% (ZPLB403) to 4.44% (ZPLB405) in 1997 and from 2.70% (ZPLB404) to 8.40% (ZPLB406) in 1998. The corresponding values for hybrids ranged from 1.71% (ZPLB401 x ZPLB40t) to 6.35% (ZPLB403 x ZPLB406), and from 0.53% (ZPLB405 x ZPLB406) to 8.54% (ZPLB403 x ZPLB405).

The majority of hybrid combinations expressed highly significantly positive values of heterosis in both years, except the hybrids ZPLB 402 x ZPLB 404 and ZPLB 403 x ZPLB 404 that had positive, but not significant values of heterosis in both investigation years, as well as F_1 generation of ZPLB 401 x ZPLB 404 in 1997 (Table 2). The hybrid combinations ZPLB404 x ZPLB405 (1997) and ZPLB403 x ZPLB405 and ZPLB 404 x ZPLB 406 (1998) had significant positive values of heterosis, while the hybrid ZPLB402 x ZPLB403 had negative heterosis in both years. The maximum positive value of heterosis was recorded in the hybrid combination ZPLB 402 x ZPLB 406 (62.3% in 1997 and 48.8% in 1998), while the combination ZPLB 403 x ZPLB 404 had the lowest positive heterosis (5.1% in 1997 and 2.0% in 1998, Table 2).

The analysis of variance of combining ability shows that there are highly significantly positive values of GCA and SCA in both years of investigation. It indicates the fact that the ear length is affected by additive and non-additive gene effects with the prevalence of non-additive gene effects in inheritance of this trait which is indicated by the GCA to SCA ratio lower than unity (GCA/SCA=0.72 in 1997 and GCA/SCA=0.77 in 1998, Table 3).

T a b. 2. - Mean values ($\overline{X}$), standard deviations (σ), coefficients of variation (CV%) and heterosis for ear length (%)

Genotype	$\overline{X}$		σ		CV (%)		Heterosis (%)	
	1997	1998	1997	1998	1997	1998	1997	1998
ZPLB401	15.36	16.05	0.321	0.450	2.09	2.80		
ZPLB402	12.55	13.10	0.318	0.505	2.54	3.85		
ZPLB403	14.32	14.70	0.114	0.636	0.80	4.33		
ZPLB404	16.45	16.42	0.528	0.444	3.21	2.70		
ZPLB405	14.26	12.35	0.633	0.536	4.44	4.34		
ZPLB406	12.47	14.25	0.195	1.197	1.57	8.40		
ZPLB401xZPLB402	20.32	19.72	0.782	0.753	3.85	3.82	32.3**	22.9**
ZPLB401xZPLB403	20.72	19.60	0.537	0.644	2.59	3.29	34.9**	22.1**
ZPLB401xZPLB404	18.44	19.77	0.635	0.228	3.44	1.15	12.1	20.4**
ZPLB401xZPLB405	20.52	19.77	0.351	0.858	1.71	4.34	33.6**	23.2**
ZPLB401xZPLB406	20.89	22.65	0.452	0.610	2.16	2.69	36.0**	41.1**
ZPLB402xZPLB403	12.39	12.92	0.755	0.779	6.10	6.03	-13.5	-12.1
ZPLB402xZPLB404	17.44	17.00	0.325	0.374	1.86	2.20	6.0	3.5
ZPLB402xZPLB405	18.32	18.57	0.682	0.580	3.72	3.12	28.5**	41.8**
ZPLB402xZPLB406	20.37	21.20	0.938	0.930	4.61	4.39	62.3**	48.8**
ZPLB403xZPLB404	17.29	16.75	0.433	0.403	2.51	2.41	5.1	2.0
ZPLB403xZPLB405	20.50	19.40	0.611	1.657	2.98	8.54	43.1**	32.0*
ZPLB403xZPLB406	20.47	21.40	1.300	1.034	6.35	4.83	42.9**	45.6**
ZPLB404xZPLB405	19.11	19.42	0.927	0.286	4.85	1.47	16.2*	18.3**
ZPLB404xZPLB406	20.64	20.70	0.542	1.525	2.63	7.37	25.4**	26.0*
ZPLB405xZPLB406	22.19	20.62	0.664	0.109	2.99	0.53	55.6**	44.7**

*, ** significant at the probability levels of 0.05 and 0.01

According to the analysis of GCA values, it is observable that inbreds ZPLB 401 and ZPLB 406 expressed positive very significant high values in both years of investigation, while remaining inbreds, except the inbred ZPLB 406 in 1998, expressed negative GCA values (Table 4).

Statistically very significant, i.e. significant and positive values of SCA for ear length in the F_1 generation were recorded for the majority of the hybrid combinations except for ZPLB402 x ZPLB403 and ZPLB403 x ZPLB404 that were characterised by negative values in both years of investigations, while the combination ZPLB402 x ZPLB404 expressed a negative value only in 1997 (Table 5).

Grain yield is an important and a complex trait consisting of a greater number of components of quantitative nature with a polygenic base. Ear length is one of these components. The ear length is an elementary quantitative trait that directly affects the grain yield; it is a varietal property and varies under effects of the environments. Leng, 1954, points out that the ear length is an essential component that affects grain yield. As a quantitative trait it varies under effects of genetic factors and interactions of genetic factor x growing conditions. Relatively high values of coefficients of variants obtained for this trait lead to a conclusion that the variability of the ear length is conditioned by effects of genetic factors and environmental factors in both years of investigation (Table 2). Hybrids and inbreds had higher values of coefficients of variations in 1998 (Table 2).

T a b. 3. - ANOVA for combining ability of ear length

Sources of variance	df	Mean square	
		1997	1998
GCA	5	144.544**	7.549**
SCA	15	200.413**	10.087**
E	60	3.904	0.194
GCA/SCA		0.72	0.77

** - significant at the probability level of 0.01

Heterosis was estimated in relation to mid-parent heterosis and was named relative and absolute heterosis after F i s h e r (1978). High heterosis usually occurs when effects of non-additive genes are higher, especially in case of superdominance, as in this study. Negative heterosis in relation to a parent with greater ear length was detected only in ZPLB402 x ZPLB403 (Table 2) in both years. Considering GCA a parameter of the additive genetic variance, and SCA of non-additive genetic variance, G r i f f i n g, 1956b, F a l c o n e r, 1960, point out that the ear length in the two-year study is affected by a non-additive (dominance and epistasis) gene effects as it is confirmed by the GCA/SCA ratio lower than unity (Table3). Greater importance of SCA than GCA effects in the expression of this trait was also confirmed by studies carried out by P a j i ć, 1984 and T o d o r o v i ć, 1995. Inbreds with good GCA are of a great significance in the maize breeding programme for development of both new, more yielding hybrids and new synthetic populations. The highest value of SCA in 1997, i.e. 1998 was detected in the hybrid combination ZPLB 401 x ZPLB 403, i.e. the hybrid ZPLB 402 x ZPLB 406, respectively (Table 5). In both cases a population with high GCA effects and a population with low GCA effects participated in hybridisation. This is in accordance with the results obtained by S i n g h and G u p t a, 1969. Crosses with a high SCA value usually include a parent with a high GCA and a parent with a low GCA value. This means that GCA of a certain inbred is related only to an actual combination and that it does not have to be an inferior combiner for a certain trait in the combination with another inbred.

T a b. 4. - General combining abilities for ear length of parents

Parents	GCA		Rank		SE	
	1997	1998	1997	1998	1997	1998
ZPLB401	5.406**	1.021**	1	2	0.988	0.220
ZPLB402	-4.219	-1.229	6	6		
ZPLB403	-2.813	-0.751	5	5		
ZPLB404	-1.406	0.130	3	3		
ZPLB405	-2.281	-0.373	4	4		
ZPLB406	5.313**	1.202**	2	1		

$LSD_{0.05}$ = 1.976 and $LSD_{0.01}$ = 2.628 in 1997. and $LSD_{0.05}$ = 0.440 and $LSD_{0.01}$ = 0.585 in 1998

Inbreds ZPLB 401 and ZPLB 406 having highly significant positive GCA effects in both investigation years (Table 4) can be used as good combiners in maize breeding programmes related to a greater ear length. The hybrid combinations ZPLB 401 x ZPLB 403 for 1997 and ZPLB 402 x ZPLB 406 for 1998 (Table 5) confirm the fact established by Kraljević-Balalić, 1974, that high SCA effects have crosses that include a parent with high GCA and a parent with a low GCA value. A highly positive SCA for ear length was recorded in the hybrid combination ZPLB 404 x ZPLB 405 that was developed by crossing of inbred lines with negative GCA effect for 1997. The hybrid ZPLB 404 x ZPLB 405 included inbred lines that had extremely low GCA values in both investigation years (Table 4). This is probably a result of the additive genes x additive genes interaction. This indicates that obtained estimation of GCA of maize inbred lines relates only to an actual hybrid combination. The hybrid combinations ZPLB 403 x ZPLB 404 (1997) and ZPLB 402 x ZPLB 403 (1998) had the lowest SCA value and were developed by crossing of parents with negative GCA values.

T a b. 5. - Specific combining abilities for ear length of hybrid combinations

Parents		ZPLB 402	ZPLB 403	ZPLB 404	ZPLB 405	ZPLB 406	SE
ZPLB401	1997	13.991**	15.835**	2.429	1.554	8.460**	2.420
	1998	2.011**	1.408*	0.701	1.204*	2.504**	0.539
ZPLB402	1997		-0.040	-3.696	0.679	13.835**	
	1998		-3.017	0.176	2.254**	3.304**	
ZPLB403	1997			-8.353	7.522**	13.929**	
	1998			-0.552	2.576**	3.026**	
ZPLB404	1997				12.116**	13.022**	
	1998				1.745**	1.445**	
ZPLB405	1997					1.147**	
	1998					1.873**	

$LSD_{0.05}$ = 4.840 and $LSD_{0.01}$ = 6.437 in 1997, and $LSD_{0.05}$ = 1.078 and $LSD_{0.01}$ = 1.434 in 1998.

Conclusion

According to obtained results of the two-year investigation it can be concluded that the analysis of variance for ear length show highly significant differences among observed genotypes, as well as a significant influence of the year x genotype interaction. As expected, hybrids had higher average values for ear length than inbreds due to the depression of this trait that occurs in inbreds during inbreeding. The highest average heterosis for ear length was recorded in the hybrid ZPLB 402 x ZPLB 406 (62.3% in 1997 and 48.8% in 1998). The analysis of variance of combining abilities show highly significantly positive values of GCA and SCA for observed trait in both years of investigations. The non-additive gene effect has a more significant role in inheritance of ear length as confirmed by the

GCA to SCA ratio lower than unity. Inbreds ZPLB 401 and ZPLB 406 were the best general combiners in both years of investigations, and hybrid combinations ZPLB 401 x ZPLB 403, ZPLB 401 x ZPLB 402, ZPLB 401 x ZPLB 406 and ZPLB 403 x ZPLB 406 had significant SCA effects in both years of investigations. This include both parents with high or one parent with high and the other parent with low GCA. Also, there are hybrid combinations such as ZPLB 403 x ZPLB 405 and ZPLB 404 x ZPLB 405 that had significant SCA effects in both years of investigations, and included parents with low GCA effects. This is probably a consequence of additive type (additive x additive) of interaction between parents.

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KOMBINACIONE SPOSOBNOSTI DUŽINE KLIPA SILAŽNOG KUKURUZA

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Rezime

Cilj ovog istraživanja je bio da se za dužinu klipa silažnog kukuruza procene: varijabilnost šest inbred linija i njihovih dialelnih hibrida, heterozis u odnosu na boljeg roditelja i opšte i posebne kombinacione sposobnosti u dialelnom ukrštanju po metodi Griffing-a, 1956, (metod II, matematički model I). Na osnovu dobijenih rezultata dvogodišnjeg istraživanja može se zaključiti da na varijabilnost ove osobine značajno utiču genotip, i interakcija genotipa i godine. Hibridi su u odnosu na linije ispoljili veće prosečne vrednosti za dužinu klipa što je i očekivano obzirom da pri inbridingu dolazi do depresije ovih osobina kod linija. Najviša prosečna vrednost heterozisa za dužinu klipa je utvrđena za hibrid ZPLB402 x ZPLB406 (62,3% (1997) i 48,8% (1998)).

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Analiza varijanse kombinacionih sposobnosti za dužinu klipa je pokazala da postoje visoko značajne pozitivne vrednosti OKS i PKS za ovu ispitivanu osobinu u obe godine ispitivanja. Za nasleđivanje dužine klipa utvrđen je veći značaj neaditivnih gena (dominacije i epistaze) što pokazuje odnos OKS/PKS koji je bio manji od jedinice. Najbolji opšti kombinatori su u obe godine ispitivanja bile linije ZPLB401 i ZPLB406, a hibridne kombinacije ZPLB401 x ZPLB403, ZPLB401 x ZPLB402, ZPLB401 x ZPLB406 i ZPLB403 x ZPLB406 su sa značajnim efektima PKS u obe godine ispitivanja. One uključuju oba roditelja sa dobrim OKS ili jednog roditelja sa dobrim OKS i drugog sa lošijim OKS. Takođe imamo i hibridne kombinacije ZPLB403 x ZPLB405 i ZPLB404 x ZPLB405 koje su u obe godine ispitivanja imale značane efekte PKS, a uključuju roditelje sa lošim OKS vrednostima. Ovo je verovatno posledica delovanja aditivnog tipa (aditivni x aditivni) interakcije među roditeljima.

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