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Original scientific paper

POPPING VOLUME AND GRAIN YIELD IN DIALLEL SET OF POPCORN INBRED LINES

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Popping volume and yield are traits caused by several heredity factors. It is difficult to obtain superior genotypes for both traits but it is possible to develop genotypes with good popping volume and satisfactory yield. The hybrid ZPPL2 x ZPPL5 was superior in yield, heterosis and SCA for both yield and popping volume. As inbred ZPPL4 in all combinations has a good value for popping volume could be concluded that this inbred may be used as parent in further crosses.

Analysis of variance of the combining ability indicating significant SCA effect for grain yield, and significant both GCA and SCA effects for popping volume. Therefore it can be stated that yield is influenced by non-aditive and popping volume by both additive and non-additive gene effects. Analysis of variance of genetic components for popping volume indicates that the additive as well as dominant components significantly affected the inheritance of this trait in popcorn. The objective of this study was to evalute heteorsis and combing ability for grain yield and popping volume in dialalel set of six maize inbred lines.

Key words: combining ability, heterosis,popcorn, yield

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INTRODUCTION

Grain yield and popping volume are the most important parameters of popcorn quality. Therefore, the aspiration of any breeder of this type of maize is to develop a hybrid with both high yield and popping volume. Generally, popcorn germplasm has a narrow genetic basis. Due to the higer yield and popping volume, new popcorn hybrids have almost completly replaced local varieties. SAKIN *et al*., (2005) compared yield and some quality characteristics of single-cross and three-way cross genotypes and open pollinated cultivars. They found significant differences among genotypes for yield, popping volume, and percentage of unpopped kernels. Popping volume was significantly higher in hybrid genotypes than open-pollinated cultivars whereas the percentage of unpopped kernels was 50% lower in hybrids. Popcorn is not only limited in germplasm quantity, but also is generally inferior to dent maize in yield and other agronomic traits (DOFING *et al.,* 1991; ZEIGLER and ASHMAN 1994). The most important factor affecting yield in popcorn is genotype (PAJIC 1990; PAJIC and BABIC 1991). Dent/flint germplasm could be introduced to improve grain yield and yield components through backcrossing with popcorn germplasm but due to negative correlation between popping characteristics and yield traits traditional breeding is not an efficient method to improve grain yield while maintaining popping characteristics. Higher popping volume were recorded for low- or medium-yielding cultivars whereas high-yielding cultivars had lower popping volume (PAJIC 1990).

RANGEL *et al.* (2008) evaulated 15 hybrids, resulting from circulant diallel of 10 parents, for grain yield and popping expansion. They concluded that intrapopulation breeding for poping expansion may offer superior genetic gains, but for grain yield, interpopulation breeding is required. VIANA and MATTA (2003) evaluated diallel crosses among five popcorn varieties to select parents for an intra and interpopulation breeding and determine two open-pollinated cultivars with highest potential as parents. Three popcorn inbred lines were evaluated as possible sources of favorable alleles for grain yield and popping volume improvement of an elite pop corn hybrid (BABIC *et al.,* 1996). The results obtained on utilization of the best enhancer of grain yield show serious reduction of popping volume and therefore the improvement should be done using the donor ranked the second for grain yield and the first for the popping volume.

MATERIAL AND METHOD

Six popcorn inbred lines (Table 1) were crossed to generate diallel set of progenies without reciprocal. Parent inbred lines and F_1 crosses were arranged in a randomized block design with three replicates at two locations (Zemun Polje and Pančevo). The elementary plot size was 3,5 m^2 with 57100 plants⁄ ha. The plot consisted of two 5 m long rows, 0,7 m apart. The experiment had two additional surrounding border rows.

The traits evaluated were grain yield and popping expansion. GRIFING'S method II, model I (1956), was used for the determination of combining abilities. The analysis of components of variance and heritability was done according to MATHER and JINKS (1971). Heterosis for investigated traits was estimated on the basis of the better parent, and its significance by the t-test (STEEL and TORRIE, 1960). Popping expansion (cc/g^{-1}) was measured according to Official Volume Test methods with metric weight volume tester (MWVT) instrument.

Table 1. Popcorn inbred lines and their sources

Inbreeds	Source population
ZPPL 1	ZP Syn I pc (C3)
ZPPL 2	ZP Syn II pc (C2)
ZPPL 3	(South American X Ohio Yellow) X South American
ZPPL 4	South American germplasm
ZPPL 5	South American germplasm
ZPPL 6	Supergold x Amber Pearl

RESULTS AND DISCUSSION

F_1 hybrids has statistically significant higher grain yield than inbred parents, except in case of ZPPL1 X ZPPL2 which has lower yield than parents in both location. Hybrids averaged 7,39 t/ha, with grain yields ranging from 3,80 (ZPPL1 X ZPPL2) to 11,09 t/ha (ZPPL2 X ZPPL5). Inbred parents averaged 4,46t/ha and ranged from 3,19 t/ha (ZPPL4) to 5,62 t/ha (ZPPL1), (table 2). All genotypes has higer grain yield in Zemun Polje than in Pancevo.

The analysis of variance for yield showed highly significant differences among genotypes, enviroments and genotype x enviroment interaction (table 3).

The highest heterosis for yield was detected in the combination ZPPL2 x ZPPL5 (154,13%). The lowest and negative heterosis was determined in the combination ZPPL1 x ZPPL3 (table 4). That is in accordance with results of BABIC (1993), who obtained negative heterosis for similar inbred line combinations. In an evaluation of hybrids derived from complete diallel crosses among nine parents for the trait grain yield, SCAPIM *et al*. (2002) found heterotic effect in 25 of 36 possible combinations indicating that the parents that have been used in diallel cross systems belong to distinct gene pools.

The GCA estimates were no significant for grain yield and the SCA estimates were significant for five out of 15 combinations (table 4). ZPPL3 has the lowest GCA but combination of that inbred with ZPPL1 and ZPPL2 has significant SCA value. SCA estimates exceeding GCA estimates, which are in accordance with results of PEREIRA and ARMAL (2001), and FREITAS *et al*. (2006). The hybrid ZPPL2 x ZPPL5 was superior in yield, heterosis and SCA.

Table 2. Mean value, standard deviation and coefficient of variation for grain yield

genotype	mean			σ			CV [%]
	ZP	PA	both	ZP	PA	both	
ZPPL 1	6,75±0,39	4,49±0,19	5,62±0,72	0,68	0,33	1,77	31,43
ZPPL 2	6,87±0,56	3,75±0,47	5,31±1,04	0,28	0,49	1,79	47,97
ZPPL 3	5,61±0,10	3,15±0,09	4,38±0,72	1,99	1,15	4,04	40,09
ZPPL 4	3,49±0,16	2,90±0,40	3,19±0,35	0,33	1,49	3,96	26,93
ZPPL 5	4,00±0,21	2,94±0,43	3,73±0,46	2,40	1,13	4,81	32,40
ZPPL 6	6,16±0,25	2,95±0,14	4,55±0,95	0,61	1,77	4,56	50,93
ZPPL1 x ZPPL2	5,00±0,16	2,60±0,28	3,80±0,73	0,98	0,81	2,55	47,18
ZPPL1 x ZPPL3	10,74±1,15	6,04±0,67	8,40±1,65	0,66	1,12	4,00	48,16
ZPPL1x ZPPL4	10,09±0,19	4,91±0,86	7,50±1,62	1,59	0,74	3,37	52,88
ZPPL1x ZPPL5	10,30±1,39	4,64±0,65	7,47±1,96	1,59	2,20	5,90	64,34
ZPPL1 x ZPPL6	13,38±0,35	7,51±1,02	10,44±1,86	0,99	0,87	4,57	43,64
ZPPL2 x ZPPL3	10,99±0,38	5,63±0,65	8,31±1,63	0,18	0,16	1,76	48,19
ZPPL2 x ZPPL4	8,69±0,92	4,62±0,43	6,65±1,38	0,66	1,46	3,58	50,67
ZPPL2 x ZPPL5	14,79±0,92	7,39±1,27	11,09±2,41	0,27	0,09	4,47	53,20
ZPPL2 x ZPPL6	11,49±0,57	5,30±0,50	8,40±1,87	0,86	0,41	5,58	54,42
ZPPL3 x ZPPL4	9,08±0,38	4,56±0,84	6,82±1,46	0,28	0,70	0,86	52,46
ZPPL3 x ZPPL5	9,53±0,16	3,21±0,05	6,37±1,83	1,56	1,40	3,75	70,20
ZPPL3 x ZPPL6	9,96±0,50	2,19±0,24	6,07±2,28	2,03	0,78	4,20	91,86
ZPPL4x ZPPL5	8,81±0,90	4,41±0,81	6,61±1,53	0,37	0,75	1,12	56,66
ZPPL4 x ZPPL6	8,15±1,17	3,07±0,45	5,61±1,72	1,16	1,96	4,66	74,89
ZPPL5x ZPPL6	10,24±0,67	4,49±1,13	7,37±1,90	0,43	0,24	2,32	63,31

Table 3. Analysis of variance for grain yield

Sources of variation	df	Sum of square	Mean square	F
enviroment	1	622,76	622,76	435,36**
replication	4	5,722	1,43	0,73
genotype	20	532,46	26,62	13,62**
G x E	20	114,14	26,62	2,92**
error	80	156,31	5,71	

significant at the 0,01 probability level

Table 4. Heterosis for grain yields above diagonal, SCA values below diagonal and GCA values at bottom line.

Inbred line	ZPPL 1	ZPPL 2	ZPPL 3	ZPPL 4	ZPPL 5	ZPPL 6
ZPPL 1		-32,56	49,29	33,27	32,92	85,57
ZPPL 2	-3,508**		80,00	30,54	154,13	82,40
ZPPL 3	1,604*	1,518*		77,46	96,51	48,25
ZPPL 4	1,351	0,507	1,188		107,14*	35,93
ZPPL 5	0,543	4,160**	-0,043	0,842		95,25
ZPPL 6	3,372**	1,321	-0,483	-0,303	0,669	
GCA	0,148	0,004	-0,779*	-0,136	0,382	0,380

Analysis of variance of the combining ability (table 5), indicating significant SCA effect and SCA x enviroment interaction. These results show that hybrid combination behavior is differentiated by enviroment and highlight importance of non-aditive genetic effects. With respect to grain yield, ANDRADE *et al.* (2002), SCAPIM *et al*. (2002), PEREIRA and AMARAL JÚNIOR (2001), SIMON *et al.* (2004), and MIRANDA *et al.* (2008) also demonstrated the greater importance of non-additive effects.

Table 5. Analysis of variance of combining abilities for grain yield

Sources of variation	df	Sum of square	Mean square	F
GCA	5	14,99	3,00	0,30
SCA	15	162,49	10,83	5,06**
GCA x E	5	5,92	1,18	0,55
SCA x E	15	32,13	2,14	3,29**
error	80	52,10	0,65	

GCA/SCA=0,059

Popping volume - Popping volume is one of the most important quality traits in popcorn. Popping volume for the six-entry diallel averaged 30,99 cc/g^{-1} for parents and 34,47 cc/g^{-1} for the hybrids, (table 6). All genotypes have higher value for popping volume in Zemun Polje. According to LYERLY (1942) crosses of high popping volume inbreeds tended to have high popping volumes, whereas hybrids between low popping volumes inbreeds tended to have low popping volumes. In our study the highest popping volume has combinations between two inbreeds with high popping volume value ZPPL4 x ZPPL6. However, combination of one inbred with high popping volume value ZPPL4 and inbred ZPPL2, with low, also has very high popping volume value. As inbred ZPPL4 in all combinations has a good value for popping volume could be concluded that this inbred may be used as parent in further crosses.

The coefficient of variation for popping volume and grain yield were 15,48% and 47,97%, respectively. Similar studies of popcorn cultivars carried out by SCAPIM *et al.* (2002), ANDRADE *et al.*, (2002) and CARPENTIERI-PIPOLO *et al.* (2003) obtained high CV values for these traits.

The analysis of variance for popping volume showed highly significant differences among genotypes, environments and genotype x environment interaction (table 7). Genotypes x environment interaction were significant for grain yield and popping volume. This suggests that genotypes with broad adaptation or specific adaptability to the each of the environments are needed for optimization of yield and popping volume.

Table 6. Mean value, standard deviation and coefficient of variation for popping volume

genotype	mean			σ			CV [%]
	ZP	PA	both	ZP	PA	both	
ZPPL 1	36,89±0,63	30,22±0,04	33,56±1,98	1,10	0,08	4,84	14,43
ZPPL 2	24,49±0,35	20,67±0,14	22,58±1,13	0,60	0,24	2,78	12,30
ZPPL 3	36,83±0,44	31,94±0,12	34,39±1,45	0,76	0,20	3,55	10,31
ZPPL 4	41,00±0,69	32,67±0,47	36,84±2,48	1,19	0,82	6,06	16,46
ZPPL 5	29,95±0,51	27,72±0,09	28,83±0,74	0,88	0,16	1,81	6,27
ZPPL 6	36,78±0,25	33,67±0,27	35,22±0,94	0,44	0,47	2,29	6,51
ZPPL1 X ZPPL2	32,17±1,03	27,33±0,00	29,75±1,57	1,78	0,00	3,86	12,96
ZPPL1 X ZPPL3	40,11±0,09	30,78±0,47	35,44±2,72	0,16	0,82	6,65	18,77
ZPPL1X ZPPL4	39,61±0,69	32,05±0,70	35,83±2,29	1,19	1,22	5,61	15,65
ZPPL1X ZPPL5	36,00±0,83	28,89±0,63	32,44±2,18	1,44	1,10	5,35	16,48
ZPPL1 X ZPPL6	29,34±0,68	19,61±0,32	24,47±2,86	1,18	0,55	7,00	28,60
ZPPL2 X ZPPL3	40,66±0,14	30,77±0,59	35,72±2,89	0,24	1,03	7,07	19,80
ZPPL2 X ZPPL4	40,05±0,30	38,89±0,20	39,47±0,42	0,52	0,34	1,03	2,61
ZPPL2 X ZPPL5	35,33±0,42	29,83±0,21	32,58±1,62	0,72	0,36	3,97	12,19
ZPPL2 X ZPPL6	37,28±0,33	33,94±0,28	35,61±1,01	0,57	0,48	2,47	6,94
ZPPL3 X ZPPL4	39,00±0,24	33,16±0,96	36,08±1,82	0,41	1,66	4,47	12,38
ZPPL3 X ZPPL5	36,94±0,05	28,33±0,63	32,64±2,53	0,08	1,09	6,19	18,95
ZPPL3 X ZPPL6	40,89±0,32	31,56±0,24	36,22±2,71	0,55	0,42	6,64	18,32
ZPPL4X ZPPL5	38,22±0,32	34,44±0,24	36,33±1,13	0,55	0,42	2,76	7,59
ZPPL4 X ZPPL6	41,61±0,24	37,78±0,55	39,70±1,19	0,42	0,96	2,91	7,32
ZPPL5X ZPPL6	37,28±0,16	32,33±0,57	34,81±1,49	0,28	0,98	3,65	10,47
all genotypes	36,67±0,55	30,79±0,57	33,74±1,57	4,38	4,54	5,22	15,48

Table 7. Analysis of variance for popping volume

Sources of variation	df	Sum of square	Mean square	F
enviroment	1	1095,60	1095,60	1068,04**
replication	4	4.10	1,03	1,06
genotype	20	2216,70	110,84	114,62**
G x E	20	208,16	10,41	10,76**
error	80	77,36	0,97	

Better parent heterosis for popping expansion ranged from −30,52% (ZPPL1 x ZPPL 6) to 13,01% (ZPPL2 x ZPPL5). Popping expansion of high-yielding combination ZPPL1xZPPL6 was poor at less than of both parent lines. For popping volume no significance heterosis was found in F_1 crosses, which is in accordance with results of ANDRADE *et al* (2002). Eight out of 15 F_1 hybrid combinations had negative heterosis as indicated that choice of parent which would have positive heterosis for popping volume, but in same time have a good all another agronomic trait would not be easily.

Table 8. Popping expansion heterosis above diagonal, SCA values below diagonal and GCA values at bottom line

Inbred line	ZPPL 1	ZPPL 2	ZPPL 3	ZPPL 4	ZPPL 5	ZPPL 6
ZPPL 1		-11,35	3,08	-2,71	-3,31	-30,52
ZPPL 2	-0,381		3,87	7,14	13,01	1,11
ZPPL 3	2,235**	3,042**		-2,18	-5,09	2,84
ZPPL 4	0,162	4,792**	-2,386**		-1,52	-1,52
ZPPL 5	1,528**	2,230**	-0,656	0,535		-1,24
ZPPL 6	-8,608**	3,521**	0,722	2,553**	1,390**	35,22
GCA	-1,344**	-2,253**	1,063**	3,093**	-1,162**	0,601**

The GCA estimates were significant for popping volume and the SCA estimates were significant for ten out of 15 combinations (table 8). Combination of two inbred lines, ZPPL4 and ZPPL2, one with the highest and another with the lowest GCA, had the highest SCA value and the highest popping expansion ability. LARISH and BREWBAKER (1999) identified significant GCA and SCA effects for popping expansion in the two popcorn diallel evaluated in the USA. The GCA estimates were significant for popping expansion and the sign of the estimate indicates whether the line in question is superior (+) or inferior (-) to the others. Popping expansion can be increased by the use of inbred lines ZPPL4 and

ZPPL3. FRIETAS JUNIOR *et al.* (2006) obtained combining ability of ten popcorn cultivars in a circulant partial diallel crossing and conclude that additive effects were more important than non-additive effects only for popping expansion. The predominance of genetic additive effects in popcorn for popping expansion had also been described by PEREIRA and AMARAL JÚNIOR (2001), SIMON *et al.* (2004), and MIRANDA *et al.*, 2008.

Analysis of variance of genetic components for popping volume (table 9) indicated that the additive component (D), as well as dominant components (H1 and H2) significantly affected the inheritance of popping volume in popcorn. The positive estimation of F indicated that the number of dominant alleles in the expression of popping volume was higer than the number of recesive alleles in parent involved in the diallel cross. This was confirmed by the frequency of dominant (0,759) and recessive alleles (0,241). Therefore, dominant and recessive alleles were not equally present in the parents. The ratio $H_2/4\ H_1$ (0,183) was lower than 0,25 as well as ratio Kd/Kr was higer than 1. The mean degree of dominance in the inheritance of popping volume was slighty higer than 1 and points to the presence of weak superdominance in the inheritance of popping volume. The obtained results are in accordinance with results obtained by BABIC (1994), who reported superdominance in the inheritance of popping volume.

Table 9.Components of variance for popping volume.

Component of variance	estimation
D	21,505**
H_1	24,873**
H_2	18,277**
F	16,680**
E	2,452
$H_2/4\ H_1$	0,183
u	0,759
v	0,241
$\sqrt{H_1/D}$	1,075
Kd/Kr	2,128

*** – significant at 0,01 probability level*

A midle heritability in a narrow sense (0,44), but high heritability in a border sense (0,807) was expressed for popping volume. According to ZEIGLER

(2000) heritability estimates for popping expansion have ranged from 0,62 to 0,96. This also, points to a high share of dominant variance.

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ZAPREMINA KOKIČAVOSTI I PRINOS ZRNA U DIALELNOM SETU LINIJA KOKIČARA

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I z v o d

Zapremina kokičavosti i prinos su svojstva pod uticajem nekoliko naslednih faktora. Teško je dobiti superiorne genotipove za oba svojstva ali je moguće dobiti genotip sa dobrom zapreminom kokičavosti i zadovoljavajućim prinosom. Hibrid ZPPL2 x ZPPL5 je superioran za prinos, heterozis i PKS za prinos i zapreminu kokičavosti. Kako linija ZPPL4 u svim kombinacijama ima dobre vrednosti za zapreminu kokičavosti može se zaključiti da ova linija se može koristiti kao roditelj u budućim ukrštanjima.

Analiza varijanse za kombinacionu sposobnost ukazuje na značajan PKS efekat za prinos zrna, značajan PKS i OKS efekat za zapreminu kokičavosti. Prinos je pod uticajem neaditivnih a zapremina kokičavosti i aditivnih i neaditivnih gena. Analiza varijanse genetičkih komponenti za zapreminu kokičavosti ukazuje da aditivne kao i dominatne komponente značajno utiču na nasleđivanje ovog svojstva kod kokičara.

Cilj ovih istraživanja bio je ispitivanje heteorzisa i kombinacionih sposobnosti za prinos zrna i zapreminu kokičavosti u dialelnom setu šest linija kukuruza.

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