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Original scientific paper

MODE OF INHERITANCE AND COMBINING ABILITY FOR PLANT HEIGHT AND HEAD DIAMETER IN SUNFLOWER (*Helianthus annuus* L.)

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The development of sunflower hybrids with high genetic potential for seed and oil yields requires information on the general combining ability (GCA) and specific combining ability (SCA) for plant height and head diameter in the F_1 generation. Used in this study were thirteen new divergent cms inbred lines (A), three Rf restorers utilized as testers, and their F_1 hybrids. The inbred A-lines, Rf-testers and F_1 hybrids differed significantly in the mean values for plant height and head diameter. The mode of inheritance for plant height was superdominance of the better parent and for head diameter it was dominance and superdominance of the better parent. Highly significant positive values of GCA for both traits were found in cms inbred line NS-G-7 and restorer line RHA-N-49. Based on the GCA values chosen were lines with the best GCA for plant height (NS-G-9, NS-G-7) originating from PRA-RUN and head diameter (NS-G-13, NS-G-12) originating from DES. The greatest highly significant positive SCA value was found in NS-G-1xRHA-N-49 for plant height and in NS-G-8xRUS-RF-OL-168 for head diameter. Non-additive genetic variance played the main role in the inheritance of both traits as confirmed by the GCA/SCA ratios in the F_1 generation, which were invariably smaller than unit. The female A lines had the highest contribution to the expression of head diameter and plant height.

Key words: combining ability, gene effect, head diameter, plant height, sunflower

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INTRODUCTION

The sunflower (*Helianthus annuus* L.) together with soybean, oil palm, oil seedrape belongs to the four most important oilseed crops in the world, and the nutritional quality of its edible oil ranks among the best vegetable oils in cultivation (ŠKORIĆ *et al*., 2008; SIDDIQI *et al*., 2012; SEMERCI *et al*., 2012). The major sunflower breeding objectives for all sunflower types should be high yields and quality of oil, proteins and other products for non-food industries and approaches to management of resistance genes, stability of sunflower resistance to certain pathogens (ŠKORIĆ *et al*., 2012). Sunflower has become the most important one due to its higher yield potential, shorter maturity duration and wider adaptability under different climatic conditions (ARSHAD *et al*., 2010; REHMAN *et al*., 2012; ONEMLI, 2012). The narrow genetic base of cultivated sunflower will be broadened by the infusion of genes from the wild species, which will provide a continued source of desirable agronomic traits. There is a global interest in the utilization of the wild sunflower species to improve cultivated sunflower (HLADNI and MIKLIČ, 2012). One of the sure ways of increasing the genetic variability of the genus *Helianthus* is the discovery of desirable genes in the wild species their incorporation into cultivated sunflower genotypes by interspecies hybridization ŠKORIĆ *et al.* (2007), HLADNI *et al*. (2009) and HLADNI *et al.* (2011). Knowing the genetics of trait inheritance, the number of genes controlling the expression of a particular trait and interdependence of morphophysiological traits with yield is of utmost importance in order for their breeding programs to be successful (ŠKORIĆ *et al*., 2012). *In sunflower breeding special attention is paid to* morphophysiological *traits which highly influence the seed yield.*

Plant height plays a major role in the creation of new SC-hybrids with a different plant model and high genetic potential for seed yield. Plant height is a very important trait because it affects the stability of the plant *i.e*., the resistance to lodging. Sunflower is normally a tall plant. Some wild types could reach 4-5 m, while cultivated ones are usually about 150-200 cm high. The height of the plants is very dependant to climatic and soil conditions and while drought or poor nutrition soil drastically reduce it, irrigating and less water stress affect the plant height very positively (KAYA *et al*., 2012). HLADNI *et al*. (2004a) studied the inheritance of planth architecture in crosses among six different inbred lines, the shortes (NS-NDF) measuring only 45-60 cm and the tallest (NS-K) being 120-140 cm in height. In the mode of inheritance of plant height in the F_1 and F_2 generation was determine superdominance, also partial dominance of the parent with a higher mean value and dominance of the parent with a higher mean value appeared. By crossing the cultivated with the wild sunflower forms partial dominance and dominance of the wild species were noticed in the inheritance of the plant height as stated by TERZIĆ *et al*. (2006). A higher contribution of nonadditive genetic variance in the inheritance of the head diameter reported by GVOZDENOVIĆ *et al*. (2005) and KARASU *et al.* (2010) while UDDIN *et. al.* (2014) found the additive component to be more significant for the inheritance of plant height.

Head diameter is a very important trait in the sunflower seed yield structure. The size of the head diameter influences the number of flowers and seeds per head which directly influence the seed yield per plant. Head size, expressed as head diameter (cm), is one of the sunflower yield components that directly influence hybrid model changes ŠKORIĆ *et al.* (2012). Sunflower head has a variable diameter, it is dependent on the genotype, enviromental factors, and interaction between these two parametars BONCIU *et al.* (2010).

In their research HLADNI *et al.* (2004a) determined superdominance and dominance of the better parent for head diameter. The result of the research done so far on the inheritance of the head diameter differs. MIJIĆ *et al*. (2008), MACHIKOWA (2011) determined a higher ratio of the additive component of the genetic variance in the inheritance of the head diameter, while PARAMESWARI *et al*. (2004) and AHMAD *et al.* (2012) determined that the nonadditive component had bigger influence than the additive one. In sunflower breeding we come across a large number of different genotypes regarding morphophysiological traits. When a breeding program begins, the choice of parents is very important for both short and long term breeding (HLADNI *et al*., 2010).

The research goal in this paper was to examine the mode inheritance, the effect of the general combining abilities (GCA) of the new divergent inbreed lines made by interspecies hybridization, also examined were the specific combining abilities (SCA) of the F_1 hybrids, gene effect, components of the genetic variance, average contribution of lines (%), testers and their interaction in the expression of the plant height and head diameter in sunflower.

MATERIALS AND METHODS

Used in the study were 13 new divergent (A) cms inbred lines, 3 Rf-restorer lines, 39 F_1 hybrids developed at the Institute of Field and Vegetable Crops in Novi Sad. Four interspecies populations, originating from three annual (*H. debilis, H. praecox runyoli, H. deserticola*) and one perennial (*H. resinosus*) wild species, were used to produce 13 new cms inbred lines (NS-G-1, NS-G-2, NS-G-3, NS-G-4, NS-G-5, NS-G-6, NS-G-7, NS-G-8, NS-G-9, NS-G-10, NS-G-11, NS-G-12, NS-G-13). Initially the plants were selected from the interspecies population RES-1, DEB-SIL-367-2, PRA-RUN-1321 and DES-1474-2, provided by Dr Gerald Seiler (USDA-ARS, Fargo ND, USA). Restorer male inbred (RHA-R-PL-2/1, RHA-N-49, RUS-RF-OL-168) with good combining abilities were used as testers in the form of fertility restorers. The F_1 hybrids had been developed by crossing each tester with each female inbred line. The trial was carried out at the the Institute's Experiment Field at Rimski Šančevi, there were three replications, and the experiment was designed according to the line x tester method. The lines and hybrids were planted manually at an optimum time on a well-prepared soil. The plots consisted of four rows with 12 plants in each. The row-to-row spacing was 70 cm and the plants were spaced at 30 cm intervals within the rows. Each trait was analyzed on a sample consisting of 30 plants (10 per replicate) taken from the middle rows in each block. Plant height (cm) and head diameter (cm) were measured at the stage of physiological maturity.

For the evaluation of the mode of inheritance the test of significance (t-test) of middle values of hybrids in relation to the parental average was applied (KRALJEVIĆ-BALALIĆ *et al*., 1991). The mean values of the inbred lines and F_1 hybrids were used to calculate the values of the combining abilities and assess the gene effects for morphophysiological traits using the line x tester method (SINGH and CHOUDHARY, 2001).

RESULTS AND DISCUSSION

Yield or productivity is an economically metric trait that is of the greatest importance for breeders. The development of sunflower hybrids with high genetic potentials for seed yield requires information on the mode of inheritance, GCA and SCA for seed yield and important morphophysiological *traits* in the F_1 generation.

Table 1. Mean values, mode of inheritance of plant height (cm) and head diameter (cm) in sunflower

	Parents and hybrids	PH cm	HD cm		Hybrids	PH cm	HD cm
1	NS-G-1 RES	93.5	22.10	29	5x14	160.3 ^{h}	24.1 ^{h}
2	NS-G-2 RES	99.0	21.79	30	5x15	161.2 ^{h}	23.6 ^{h}
3	NS-G-3 RES	104.4	21.26	31	5x16	158.5 ^{h}	23.6 ^{h}
4	NS-G-4 DEB-SIL	116.4	20.85	32	6x14	151.4 ^{h}	23.4 ^{h}
5	NS-G-5 DEB-SIL	114.2	20.18	33	6x15	157.5 ^{h}	26.2 ^{h}
6	NS-G-6 DEB-SIL	109.8	21.73	34	6x16	142.2 ^{h}	23.7 ^{h}
7	NS-G-7 PRA-RUN	111.9	21.83	35	7x14	167.3 ^{h}	24.2 ^{h}
8	NS-G-8 PRA-RUN	93.0	22.03	36	7x15	159.4 ^{h}	25.8 ^{h}
9	NS-G-9 PRA-RUN	92.7	22.28	37	7x16	161.0 ^{h}	26.1 ^{h}
10	NS-G-10 DES	79.3	22.04	38	8x14	159.8 ^{h}	24.7 ^{h}
11	NS-G-11 DES	89.6	23.05	39	8x15	159.9 ^{h}	24.9 ^{h}
12	NS-G-12 DES	90.1	21.67	40	8x16	155.5 ^{h}	22.9 $^{d+}$
13	NS-G-13 DES	73.1	21.60	41	9x14	167.5 ^{h}	23.3 ^{h}
14	RHA-R-PL-2/1	116.1	19.13	42	9x15	168.3 ^{h}	24.4 ^{h}
15	RHA-N-49	99.5	14.28	43	9x16	159.4 ^{h}	25.2 ^{h}
16	RUS-RF-OL-168	114.0	16.99	44	10x14	136.0 ^{h}	24.1 ^{h}
17	1x14	139.6 ^{h}	23.4 $^{d+}$	45	10x15	144.6 ^{h}	25.8 ^{h}
18	1x15	150.8 ^{h}	23.1 $^{d+}$	46	10x16	129.8 ^{h}	26.1 ^{h}
19	1x16	130.7 ^{h}	23.7 ^{h}	47	11x14	141.8 ^{h}	25.3 ^{h}
20	2x14	143.3 ^{h}	24.5 ^{h}	49	11x15	140.7 ^{h}	28.2 ^{h}
21	2x15	152.2 ^{h}	24.3 ^{h}	49	11x16	135.8 ^{h}	24.3 ^{h}
22	2x16	138.7 ^{h}	23.9 ^{h}	50	12x14	140.6 ^{h}	26.2 ^{h}
23	3x14	143.2 ^{h}	23.1 ^{h}	51	12x15	140.3 ^{h}	28.6 ^{h}
24	3x15	149.2 ^{h}	23.3 ^{h}	52	12x16	135.8 ^{h}	26.6 ^{h}
25	3x16	138.4 ^{h}	23.8 ^{h}	53	13x14	138.0 ^{h}	26.2 ^{h}
26	4x14	158.4 ^{h}	23.9 ^{h}	54	13x15	140.9 ^{h}	27.8 ^{h}
27	4x15	164.9 ^{h}	23.9 ^{h}	55	13x16	131.6 ^{h}	27.7 ^{h}
28	4x16	152.3 ^{h}	24.2 ^{h}				
	LSD 0.05	2.17	0.300		LSD 0.05	2.17	0.300
	LSD 0.01	3.26	0.450		LSD 0.01	3.26	0.450

(PH) plant height, (HD) head diameter

Significant differences were observed among the A lines, Rf testers and their F_1 hybrids for all the traits studied, indicating the presence of genetic differences among the genotypes concerned. Of the A-lines, NS-G-13 had the lowest (73.1 cm) and NS-G-4 the greatest plant height (116.4 cm), while in the Rf-testers RHA-N-49 was the shortest (99.5 cm) and RHA-R-PL-2/1 the tallest (116.1 cm). Among the F_1 hybrids, NS-G-10xRUS-RF-OL-168 had the lowest (129.8 cm) and NS-G-9xRHA-N-49 the greatest average plant height (168.3 cm). The head diameter means ranged from 20.2 to 23.1 cm in the A-lines, 14.3 to 19.1 cm in the testers and

22.9 to 28.6 cm in the F_1 (Tab.1). Plant height and head diameter are the most important important parameters for breeding for desirable plant architecture. That is why it is very important to be familiar with the mode of inheritance of this trait in the F_1 generation. The mode of inheritance for plant height was super dominance of the better parent and for head diameter it was dominance and super dominance of the better parent (Tab.1).

Discovering of inbred lines that posses high GCA values has great importance for the creation of new hybrids. It is very hard to combine all positive traits in one combination. The analysis of combining ability showed that the A lines and Rf testers differed significantly in GCA values. Highly significant GCA values for both traits were demonstrated by cms A-line NS-G-7 and Rf tester line RHA-N-49. Based on the GCA values chosen were lines with the best GCA for plant height (NS-G-9, NS-G-7) originating from PRA-RUN and head diameter (NS-G-13, NS-G-12) originating from DES (Tab.2).

Table 2. GCA values for plant height and head diameter in sunflower inbreds

	Parents and hybrids	PH	HD
1	NS-G-1	-8.60	-1.428
2	NS-G-2	-4.24	-0.603
3	NS-G-3	-5.35	-1.439
4	NS-G-4	9.62**	-0.858
5	NS-G-5	11.04**	-1.044
6	NS-G-6	1.43	-0.403
7	NS-G-7	13.65**	0.742**
8	NS-G-8	9.46**	-0.675
9	NS-G-9	16.79**	-0.542
10	NS-G-10	-12.15	0.464**
11	NS-G-11	-9.49	1.086**
12	NS-G-12	-10.07	2.292**
13	NS-G-13	-12.10	2.408**
14	RHA-R-PL-2/1	1.00**	-0.506
15	RHA-N-49	4.12**	0.583**
16	RUS-RF-OL-168	-5.12	-0.077
SE GCA/line		0.63	0.086
SE (GCA_i- GCA_j)/line		0.89	0.122
SE GCA/tester		0.30	0.042
SE (GCA_i – GCA_j)/tester		0.43	0.059
LSD 0.05 (1-13)		1.25	0.174
0.01		1.88	0.261
LSD 0.05 (14-16)		0.29	0.084
0.01		0.44	0.126

It was to be expected that the parents with higher mean values are better general combiners, and lines with lower mean values lower general combiners which was confirmed in this research. Inbred line with the best GCA for plant height (NS-G-4) has the highest mean value for that trait while the line with the worst GCA for plant height (NS-G-13) has the lowest mean value for that trait. If the goal is the change of sunflower plant architecture, genotypes with shorter plant height (NS-G-10, NS-G-11, NS-G-12, NS-G-13) and negative GCA values, originating from interspecies population DES, are desirable in breeding programs (Tab.2). General (GCA) and specific combining abilities (SCA) are significant parameters in plant breeding, the genetic distance between parental lines is a precondition for the expression of good SCA (ŠKORIĆ *et al*., 2004; KANG *et al.* 2013). The greatest highly significant positive SCA value was found in NS-G-1xRHA-N-49 for plant height and NS-G-8xRUS-Rf-OL-168 for head diameter (Tab.3).

Table 3. SCA hybrids for plant height and head diameter in sunflower

	F_1 hybrids	PH	HD		F_1 hybrids	PH	HD
1	1x14	-1.75	0.520**	21	7x16	3.53**	0.103
2	1x15	6.30**	0.761**	22	8x14	3.53**	-0.472
3	1x16	-4.55	0.231	23	8x15	-2.59	-0.077
4	2x14	-2.44	0.409*	24	8x16	2.23*	1.684**
5	2x15	3.35**	0.845**	25	9x14	2.78*	0.895**
6	2x16	-0.91	-0.513	26	9x15	-1.59	-0.030
7	3x14	-1.41	-0.916	27	9x16	-1.19	0.391*
8	3x15	1.46	1.076**	28	10x14	-1.78	-0.284
9	3x16	-0.05	-0.524	29	10x15	3.69*	0.468**
10	4x14	-1.14	-0.747	30	10x16	-1.91	0.296
11	4x15	2.24*	-0.127	31	11x14	1.39	-0.093
12	4x16	-1.10	-0.474	32	11x15	-2.90	-0.618
13	5x14	-0.72	-0.541	33	11x16	1.51	0.604**
14	5x15	-2.93	-0.911	34	12x14	0.72	-1.179
15	5x16	3.65**	-0.478	35	12x15	-2.73	0.996**
16	6x14	0.06	-0.700	36	12x16	2.01	0.824**
17	6x15	3.02*	-0.705	37	13x14	0.17	-1.557
18	6x16	-3.08	-0.752	38	13x15	-0.04	-0.421
19	7x14	3.75**	1.131**	39	13x16	-0.13	0.571**
20	7x15	-7.29	0.312*				
SE SCA		1.09	0.150	SE SCA		1.09	0.150
$SE(S_{ij} - S_{ki})$		1.54	0.212	$SE(S_{ij} - S_{ki})$		1.54	0.212
LSD 0.05		2.17	0.300	LSD 0.05		2.17	0.300
0.01		3.26	0.450	0.01		3.26	0.450
GCA		5.59	0.178	GCA		5.59	0.178
SCA		17.96	0.570	SCA		17.96	0.570
GCA/SCA		0.31	0.312	GCA/SCA		0.31	0.312

A highly significant positive value for plant height in the F_1 generation was found in the combinations NS-G-1xRHA-N-49 which had been obtained by crossing one parent with a poor plant height GCA with another one that has a highly positive GCA for this trait (Tab.2,3). These results support those obtained by ŠKORIĆ *et al.* (2000), who determined that crosses with a good plant height SCA usually involve one parent with high and one with low GCA values. The nonadditive component of genetic variance played the main role in the inheritance of both plant height and head diameter, as shown by the analysis of variance of combining abilities and analysis of genetic variance components. This is supported by the GCA/SCA ratio for plant height (0.31) and head diameter (0.31) in the F_1 generation, which was below the value of one (Tab.3).

A higher contribution of nonadditive genetic variance has been reported by HLADNI *et al.* (2004a), PARAMESWARI *et al.* (2004), GHAFFARI *et al.* (2011), AHMAD *et al.* (2012) for the inheritance of plant height and by HLADNI *et al.* (2004b), KARASU *et al.* (2010), MEHANASUNDARAM *et al.* (2010), AHMAD *et al.* (2012), KANG *et al.* (2013), UDDIN *et al.* (2014) for the inheritance of head diameter. On the contrary GOKSOY *et al*. (2004), ORTIS *et al*. (2005), MARINKOVIĆ (2005), JAN *et al.* (2005) and KHAN *et al.* (2009) found the additive component to be more significant for the inheritance of plant height, while KAYA and ATAKISI (2004) did the same in the case of head diameter.

By studying the proportional contribution of inbred lines, testers and their crosses in the total variability breeders come to different results with the same trait. The differences in the conclusions of different authors mentioned in this work can be explained by the differences in the plant material used in their studies (HLADNI, 2010). The largest average contribution in the expression of plant height (80.3%), and head diameter (66.9%) was that of the female A-lines, while the contribution of Rf testers and line x tester interactions was less significant (Tab.4).

Table 4. Average percentage contribution of female lines and tester lines and their interactions to expression of plant height and head diameter

Average contribution	PH %	HD %
Female line	80.29	66.91
Tester line	10.96	7.86
Line x tester	8.75	25.24

According to ŠKORIĆ *et al*. 2000; GVOZDENOVIĆ *et al*. 2005; FARROKHI *et al*. 2008 the mother lines had a significant proportion in the expression of the plant height (55.8%; 83.17%; 54.9%). A higher average contribution of the interaction of Rf testers of head diameter (58.13%) was determined by GVOZDENOVIĆ *et al*. 2005.

CONCLUSION

Based on the study results, the following conclusions can be made: significant difference were found among the genotypes studied (inbreds and hybrids) in the mean values of plant height and head diameter. The mode of inheritance for plant height was super dominance of the better parent and for head diameter it was dominance and super dominance of the better parent. Based on the GCA values chosen were lines with the best GCA for plant height (NS-G-9, NS-G-7) and head diameter (NS-G-13, NS-G-12). Studying GCA in relation to the origin lines it can be observed that the lines of interspecies populations PRA-RUN are the best general combiners for plant height, lines from interspecies population DES are the best general combiners for head diameter. The worst GCA for plant height, head diameter have lines originating from interspecies population RES. The greatest highly significant positive SCA value was found in NS-G-1xRHA-N-49 for plant height and NS-G-8xRUS-RF-OL-168 for head diameter. The nonadditive components of genetic variance played the main role in the inheritance of plant height and head diameter traits. This is supported by the GCA/SCA ratio in the F_1 generation, which was below the value of one for both traits. The female A lines had the highest contributions to the expression of plant height 80.3% and head diameter 66.9%. These research can be significant for the creation of new high-yielding sunflower hybrids on the basis of interspecies hybridization.

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NAČIN NASLEĐIVANJA I KOMBINACIONE SPOSOBNOSTI ZA VISINU BILJKE I PREČNIK GLAVE SUNCOKRETA (*Helianthus annuus* L.)

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Izvod

Stvaranje novih hibrida suncokreta visokog genetskog potencijala za prinos semena i ulja zahteva posedovanje informacije o načinu nasleđivanja i kombinacionim sposobnostima visine biljke i prečnika glave u F_1 generaciji. Za ova istraživanja korišćeno je trinaest novih divergentnih (A) citoplazmatski muško sterilnih inbred linija, tri Rf-restorer linije kao testeri i njihovi F_1 hibridi. Između ispitivanih A-linija, Rf-tester linija i njihovih F_1 hibrida ustanovljene su značajne razlike u visini biljke i prečniku glave. Način nasleđivanja visine biljke bio je superdominacija roditelja veće srednje vrednosti, a prečnika glave dominacija i superdominacija roditelja veće srednje vrednosti. Visoko značajne pozitivne vrednosti OKS za oba svojstva pokazale su cms A-linija NS-G-7 i Rf tester linija RHA-N-49. Uočeno je da najbolje OKS za visinu biljke imaju linije (NS-G-9 i NS-G-7) poreklom iz populacije PRA-RUN, a za prečnik glave linije (NS-G-13, NS-G-12) poreklom iz populacije DES. Najveću visoko značajnu pozitivnu vrednost PKS za visinu biljke ispoljio je hibrid NS-G-1xRHA-N-49, a za prečnik glave hibrid NS-G-8xRUS-RF-OL-168. Neaditivna komponenta genetske varijanse imala je glavnu ulogu u nasleđivanju oba ispitivana svojstva što potvrđuje odnos OKS/PKS u F_1 generaciji koji je manji od jedinice. Najveći prosečan doprinos u ekspresiji visine biljke i prečnika glave imale su A linije majke.

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