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Heterosis and combining ability for yield traits and its relationship with gene action in muskmelon (*Cucumis melo*)

KOUSHIK SAHA[1], HARSHAWARDHAN CHOUDHARY[2]*, A D MUNSHI[2] and A K SINGH[2]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

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ABSTRACT

Twenty-one F_1 hybrids were developed from seven diverse parental lines of muskmelon (*Cucumis melo* L.) from two horticultural groups, viz. *inodorous* and *cantalupensis* through half-diallel mating system and evaluated at ICAR-Indian Agricultural Research Institute, New Delhi, during 2017 and 2018. The component of variance for sca (σ^2s) was higher than gca component of variance (σ^2g) for all the characters, except average fruit weight, which indicated the importance of non-additive gene action for improvement of many traits. The predictability ratio and average degree of dominance was less than 0.5 and more than 1 for all the yield related traits, except average fruit weight, which further confirmed the predominant role of non-additive component of variance. The parent DHM-163 (P_1) was identified as good general combiner for earliness, whereas parent DCM-31 (P_4) for fruit length, average fruit weight and yield per plant. The parent Pusa Madhuras (P_5) also exhibited highest gca effects for number of fruits per plant, number of primary branches per plant, fruit diameter and negative gca effects for days to first fruit harvest. The hybrid DCM-31 × Kashi Madhu ($P_4 \times P_6$) exhibited highest heterotic value for days to first male flower anthesis, days to first female flower anthesis and days to first fruit harvest. Three crosses, DMM-159 × Pusa Madhuras ($P_3 \times P_5$), DHM-163 × Kashi Madhu ($P_1 \times P_6$) and DMM-159 × DCM-31 ($P_3 \times P_4$) were found to be best heterotic combinations for yield related traits. These promising heterotic hybrid combinations may be tested under multi-location trials to assess their potential as commercial hybrids.

Keywords: *Cantalupensis*, GCA, Heterosis, *Inodorous*, Melon, Predictability ratio, SCA

Muskmelon (*Cucumis melo* L.) is one of the most nutritive and commercially important cucurbits because of its unique musky flavour and sweet taste. It is a rich source of vitamins and minerals (Munshi and Choudhary 2014). It is considered to be one of the highly polymorphic and diverse species in Cucurbitaceae family and comprises a large number of horticultural groupings which may be a consequence of high genetic diversity in this species. Wide range of variability for yield, fruit characters and maturity are available in this crop, but very little improvement work has been done in India to exploit it, especially for hybrid development.

Muskmelon is a cross pollinated crop and andromonoecious in nature, thus exhibiting considerable amount of heterozygosity but does not suffer much from inbreeding depression. Hence, a prompt improvement can be done by assembling the genetical variability, locating the best combiners and exploiting heterosis by crossing among diverse genotypes. To date, there are only few reports on heterosis and comibining ability for yield traits in muskmelon from India (Barros *et al.* 2011, Jagpat and Musamade 2014, Shashikumar and Pitchaimuthu 2016) and most of them focused on accessions from *reticulatus* or *cantalupensis* group only. In present study, seven genetically diverse inbred lines from two groups, *inodorou*s and *cantalupensis*, were selected for heterosis and combining ability study. Heterosis is rather a function of specific cross combination, so analysis of combining ability helps in determining the feasibility of its utilization and also helps in identifying the best combiners. Therefore, this study was carried out to estimate the heterosis of different cross combinations and also general combining ability (gca) and specific combining ability (sca) of seven parents and their 21 F_1 hybrids in muskmelon.

MATERIALS AND METHODS

The study was carried out at the research farm of Division of Vegetable Science, ICAR-Indian Agricultural Research Institute, New Delhi, during the spring-summer and *kharif* season of 2017 and the spring-summer seasons of 2018. The location of research farm is at 228.61 m amsl with 28°08'N latitude and 77°12'E longitude. Seven genetically diverse inbred lines, including three commercial

[1]Indian Institute of Horticultural Research, Bangalore, Karnataka; [2]ICAR-Indian Agricultural Research Institute, New Delhi.*Corresponding author email: harshahit2001@yahoo.co.in

varieties of muskmelon from two groups, *inodorous* and *cantalupensis*, exhibiting considerable amount of variation [DHM-163 (P_1), DHM-162 (P_2), DMM-159 (P_3), DCM-31 (P_4), Pusa Madhuras (P_5), Kashi Madhu (P_6) and Hara Madhu (P_7)] were crossed in a half-diallel mating scheme during spring-summer seasons of 2017. The 21 F_1 hybrids along with seven parents were grown under polyhouse in a randomized block design with three replications during *kharif* season (August-November) of 2017 and in net house during summer season (February-June) of 2018.

The crop was sown on raised beds 1.2 m apart with 50 cm spacing between plants. All the recommended agronomic practices along with plant protection measures were followed to raise a successful crop. Manual pollination was followed for fruit set in polyhouse/net house. Five plants were randomly selected in each treatment for recording of observation. Observations on individual plant basis were recorded on 10 important quantitative characters, viz. days to first male flower anthesis, days to first female flower anthesis, node number of first female flower, days to first fruit harvest, fruit length (cm), fruit diameter (cm), average fruit weight (kg), number of fruits per plant, number of primary branches and yield per plant (kg). The combining ability analysis for different characters was carried out according to Method 2, Model 1 of Griffing 1956, where parents and F_1s were included but not the reciprocals. Relative importance of general combining ability and specific combining ability was calculated by the predictibility ratio for fixed effect model:

$$\frac{2\sigma^2 g}{2\sigma^2 g + \sigma^2 s}$$

where, $\sigma^2 g$ is the additive component of variance and $\sigma^2 s$ is the non-additive component of variance, respectively.

Heterosis was calculated in the favorable direction over mid parent (MP) and better parent (BP).

RESULTS AND DISCUSSION

Combining ability: Combining ability analysis of seven parents and their 21 hybrids showed significant gca and sca effects during 2017 and 2018 for all the yield attributes, which indicated the importance of both additive and non-additive gene action for the characters under study. The component of variance for sca ($\sigma^2 s$) was higher than gca component of variance ($\sigma^2 g$) for all the characters except average fruit weight, which indicated the importance of non-additive gene action for improvement of these characters. The predictability ratio and average degree of dominance was found to be <0.5 and >1.0 for all the characters except average fruit weight (data not presented), which also further confirmed the predominant role of non-additive component of variance and importance of heterosis breeding improvement of the yield attributing traits.

The results of general combining ability (Supplementary Table 1) from both years revealed that among the seven parental lines, the DHM-163 (P_1) from *inodorous* group showed highest negative gca effects in desirable direction for days to first male flower anthesis, days to first female flower anthesis, and node number of first female flower followed by DHM-162 (P_2) from same group. The parent DCM-31 (P_4) from *cantalupensis* group showed highest gca effect for fruit length, average fruit weight and yield per plant. The parent Pusa Madhuras (P_5) from *cantalupensis* group exhibited highest gca effects for number of fruits per plant, number of primary branches per plant and fruit diameter followed by Kashi Madhu (P_6) from same group. The parent Pusa Madhuras (P_5) also showed negative gca effects for days to first fruit harvest. The estimate of gca of a line indicates its suitability to be used as parent in combination with other lines. Our findings are in conformity with the findings of many other researcher in different Cucurbits, viz. Munshi *et al.* (2006) in cucumber, Pandey *et al.* (2010) in pumpkin and Barros *et al.* (2011) in muskmelon.

Out of 21 F_1 hybrids, number of crosses having significant sca effects for both years were observed to be 8 for days to first male flower anthesis, 5 for days to first female flower anthesis, 5 for node number of first female flower, 8 for days to first fruit harvest, 4 for fruit length, 8 for average fruit weight, 5 for number of fruits per plant, 5 for number of primary branches and 7 for total fruit yield per plant. The F_1 crosses showing highest significant sca effects for yield and its related traits in order of merit were DCM-31 × Kashi Madhu, DMM-159 × Pusa Madhuras and DHM-163 × DCM-31 for days to first male flower anthesis; DCM-31 × Kashi Madhu, DHM-162 × Pusa Madhuras and DHM-162 × Hara Madhu for days to first female flower anthesis; DHM-163 × DHM-162, DHM-163 × DMM-159 and Kashi Madhu × Hara Madhu for node number of first female flower; DCM-31 × Kashi Madhu, Pusa Madhuras × Kashi Madhu and DHM-163 × DHM-162 for days to first fruit harvest; DHM-162 × DMM-159, Pusa Madhuras × Kashi Madhu and DCM-31× Hara Madhu for fruit length; DHM-162 × Hara Madhu, DHM-163 × Kashi Madhu and DMM-159 × Pusa Madhuras for fruit diameter; DCM-31 × Hara Madhu, DHM-163 × Kashi Madhu and DCM-31 × Kashi Madhu for average fruit weight; DMM-159 × Pusa Madhuras, DMM-159 × DCM-31 and DCM-31 × Pusa Madhuras for number of fruits per plant; Kashi Madhu × Pusa Madhuras, DMM-159 × Pusa Madhuras and DMM-159 × DCM-31 for number of primary branches; DMM-159 × DCM-31, DHM-163 × Kashi Madhu and DMM-159 × Pusa Madhuras for yield per plant. In most of the cases, these hybrids showed best per se performance and also possessed desirable significant sca effects (Table 1). In most cases, high gca effects of parents resulted in high sca effects of the cross combinations. Similar findings were also reported by Munshi *et al.* (2006) in cucumber, and Shashikumar *et al.* (2011) in muskmelon.

Heterosis: The top three F_1 hybrids and their heterosis percentage are presented in Table 2. It was evident that among seven parents, DMM-163 took minimum number of days for first male flower anthesis, days to first female flower anthesis and node number of first female flower, whereas DMM-159 showed minimum number of days to first fruit harvest during both years. While, DCM-31 showed

Table 1 Ranking of best crosses for *per se* performance and desirable crosses for significant sca effects with respect to yield related traits in muskmelon during 2017 and 2018

Character	Cross	per se performance		sca effects	
		2017	2018	2017	2018
Days to first male flower anthesis	DCM-31 × Kashi Madhu	30.67	31.59	-3.49	-3.82
	DMM-159 × Pusa Madhuras	30.67	29.54	-2.12	-2.28
	DHM-163 × DCM-31	29.33	30.28	-1.79	-1.28
Days to first female flower anthesis	DCM-31 × Kashi Madhu	35.00	34.09	-2.58	-2.29
	DHM-162 × Pusa Madhuras	32.00	31.83	-2.36	-2.28
	DHM-162 × Hara Madhu	34.67	34.38	-1.99	-1.39
Node number of first female flower	DHM-163 × DHM-162	3.20	3.48	-0.83	-0.92
	DHM-163 × DMM-159	3.87	3.83	-0.78	-0.28
	Kashi Madhu × Hara Madhu	6.33	6.28	-0.67	-0.82
Days to first fruit harvest	DCM-31 × Kashi Madhu	68.67	67.83	-4.94	-4.39
	Pusa Madhuras × Kashi Madhu	69.00	68.48	-4.01	-4.93
	DHM-163 × DHM-162	71.67	72.38	-3.38	-3.29
Fruit length (cm)	DHM-162 × DMM-159	15.47	15.83	3.40	3.28
	Pusa Madhuras × Kashi Madhu	11.13	11.72	1.21	1.92
	DCM-31 × Hara Madhu	12.27	12.27	0.99	0.67
Fruit diameter (cm)	DHM-162 × Hara Madhu	12.40	12.38	1.58	1.56
	DHM-163 × Kashi Madhu	12.97	11.28	1.31	1.39
	DMM-159 × Pusa Madhuras	12.40	13.27	1.03	1.54
Average fruit weight (kg)	DCM-31 × Hara Madhu	1.16	1.28	0.24	0.38
	DHM-163 × Kashi Madhu	1.20	1.82	0.23	0.18
	DCM-31 × Kashi Madhu	1.19	1.28	0.15	0.21
Number of fruits per plant	DMM-159 × Pusa Madhuras	4.53	4.28	0.95	0.81
	DMM-159 × DCM-31	4.13	4.72	0.85	0.72
	DCM-31 × Pusa Madhuras	4.20	4.82	0.54	0.49
Number of primary branches	Kashi Madhu × Hara Madhu	7.13	7.83	1.21	1.30
	DMM-159 × Pusa Madhuras	6.93	6.72	1.10	1.48
	DMM-159 × DCM-31	6.20	6.93	0.99	0.83
Yield per plant (kg)	DMM-159 × DCM-31	4.96	4.37	1.45	1.84
	DHM-163 × Kashi Madhu	4.29	4.92	1.34	1.38
	DMM-159 × Pusa Madhuras	4.04	4.28	1.14	1.28

higher average fruit weight, fruit length and total yield per plant. Hara Madhu had highest number of fruits per plant and number of primary branches, respectively. The range of mean values in F_1 hybrids was higher than that of parents for most of the characters studied, except for traits related to earliness, where negative heterosis is desired (data not presented). In order of merit, the best three F_1 hybrids, which gave highest performance over better parent and mid parent in relation to earliness for both years includes DCM-31 × Kashi Madhu, DMM-159 × Pusa Madhuras and Kashi Madhu × Hara Madhu for days to male flower anthesis; Pusa Madhuras × Kashi Madhu, DMM-159 × DCM-31 and DCM-31 × Kashi Madhu for days to female flower anthesis, while crosses like DCM-31 × Kashi Madhu, Pusa Madhuras × Kashi Madhu and DHM-162 × Pusa Madhuras for days to first fruit harvest. The cross DCM-31 × Kashi Madhu ($P_4 \times P_6$) was most promising for earliness and both the parents of this cross are now considered in *cantalupensis* group. In accordance with the present findings, Chamnan *et al.* (2006), Jagtap and Musamade (2014), Shashikumar and Pitchaimuthu (2016) also observed earliness in different heterotic combinations in muskmelon.

The F_1 crosses showing the highest significant desirable amount of heterosis over better parent and mid parent for yield characters in order of merit were DMM-159 × DCM-31, DMM-159 × Pusa Madhuras and DCM-31 × Pusa Madhuras for number of fruits per plant; Kashi Madhu × Hara Madhu, DHM-163 × Kashi Madhu and DHM-163 × DHM-162 for average fruit weight; DHM-162 × DMM-159, Pusa Madhuras × Kashi Madhu and Kashi Madhu × Hara

Table 2 Top three F_1 hybrids and their heterosis percentage for yield related traits in muskmelon during 2017 and 2018

Character	Better parent cross	Heterosis %		Mid parent cross	Heterosis %	
		2017	2018		2017	2018
Days to first male flower anthesis	DCM-31 × Kashi Madhu	-11.54	-12.28	DCM-31 × Kashi Madhu	-15.98	-18.14
	DMM-31 × Pusa Madhuras	-8.91	-11.27	DCM-31 × Pusa Madhuras	-12.38	-10.91
	Kashi Madhu × Hara Madhu	-7.83	-6.27	DHM-163 × DCM-31	-10.20	-10.81
Days to first female flower anthesis	Pusa Madhuras × Kashi Madhu	-7.56	-8.77	DHM-162 × Pusa Madhuras	-12.73	-10.14
	DMM-159 × DCM-31	-5.56	-7.28	DCM-31 × Kashi Madhu	-11.76	-9.91
	DCM-31 × Kashi Madhu	-5.41	-5.27	Pusa Madhuras × Kashi Madhu	-10.57	-10.92
Node number of first female flower	DHM-163 × DMM-159	-34.83	-38.28	DHM-163 × DHM-162	-28.36	-24.83
	DHM-163 × Pusa Madhuras	-31.52	-29.26	DHM-163 × DMM-159	-25.16	-28.28
	DHM-163 × DHM-162	29.41	34.29	DHM-163 × Pusa Madhuras	-20.25	-18.82
Days to first fruit harvest	DCM-31 × Kashi Madhu	-12.71	15.28	DCM-31 × Kashi Madhu	-10.82	-10.17
	Pusa Madhuras × Kashi Madhu	-12.29	-10.18	Pusa Madhuras × Kashi Madhu	-10.00	-8.27
	DHM-162 × Pusa Madhuras	-10.17	-8.46	DMM-159 × DCM-31	-8.04	-8.28
Fruit length (cm)	DHM-162 × DMM-159	49.20	56.72	DHM-162 × DMM-159	49.68	48.25
	Pusa Madhuras × Kashi Madhu	16.86	13.61	Pusa Madhuras × Kashi Madhu	20.62	23.26
	Kashi Madhu × Hara Madhu	12.96	12.71	DMM-159 × Kashi Madhu	16.96	14.16
Fruit diameter (cm)	DHM-162 × Hara Madhu	23.59	20.82	DHM-162 × Hara Madhu	27.53	26.25
	DHM-163 × Kashi Madhu	15.77	18.16	DMM-159 × Pusa Madhuras	22.84	21.27
	DMM-159 × Pusa Madhuras	15.62	18.41	DHM-163 × Kashi Madhu	20.06	18.26
Average fruit weight (kg)	Kashi Madhu × Hara Madhu	33.52	35.14	DHM-163 × Kashi Madhu	53.86	52.27
	DHM-163 × Kashi Madhu	26.68	24.83	DCM-31 × Hara Madhu	53.14	50.27
	DHM-163 × DHM -162	21.02	25.27	Kashi Madhu × Hara Madhu	49.62	51.27
Number of fruits per plant	DMM-159 × DCM-31	47.62	49.38	DMM-159 × Pusa Madhuras	58.14	59.92
	DMM-159 × Pusa Madhuras	44.68	45.83	DMM-159 × DCM-31	53.09	57.92
	DCM-31 × Pusa Madhuras	39.04	38.81	DCM-31 × Pusa Madhuras	41.57	49.27
Number of primary branches	DMM-159 × Pusa Madhuras	42.47	41.18	DMM-159 × Pusa Madhuras	44.44	45.27
	Kashi Madhu × Hara Madhu	40.96	39.12	Kashi Madhu × Hara Madhu	39.87	37.27
	DMM-159 × DCM-31	30.99	33.61	DHM-163 × Pusa Madhuras	36.76	38.27
Yield per plant (kg)	DHM-163 × Kashi Madhu	112.67	114.51	DHM-163 × Kashi Madhu	113.98	117.17
	DMM-159 × Pusa Madhuras	85.04	88.51	DMM-159 × DCM -31	99.44	96.17
	DMM-159 × DCM-31	74.30	70.93	DMM-159 × Pusa Madhuras	87.41	84.72

Madhu for fruit length; DHM-162 × Hara Madhu, DHM-163 × Kashi Madhu and DMM-159 × Pusa Madhuras for fruit diameter; DMM-159 × Pusa Madhuras, Kashi Madhu × Hara Madhu and DMM-159 × DCM-31 for number of primary branches; DHM-163 × Kashi Madhu, DMM-159 × Pusa Madhuras and DMM-159 × DCM-31 for yield per plant.

Based on performance over two years, it is evident that three crosses DMM-159 × Pusa Madhuras ($P_3 \times P_5$), DHM-163 × Kashi Madhu ($P_1 \times P_6$) and DMM-159 × DCM-31 ($P_3 \times P_4$) were found to be best heterotic combinations as they exhibited significant heterosis percentage for yield contributing traits and they were the highest yielder also. The results of present investigation are in accordance with Barros *et al.* (2011), and Jagpat and Musamade (2014), who reported a moderate range of heterosis for yield in muskmelon. The range of heterosis for yield has been found very high for better parents heterosis (5.90 to 112.67%) and mid parent heterosis (11.89 to 113.98%) in present study, which might be due to selection of parents from two different horticultural groups of *inodorous* and *cantalupensis*. It also highlights the importance of diverse parent in getting the higher level of heterosis for desirable characters, including the fruit yield. The above promising heterotic hybrids for yield traits also have excellent quality and nutritional traits, hence may be tested under multi-locational trials to assess their potential as commercial hybrids.

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