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Shivaji Kallappa Duradundi
PhD, Scholar, Department of Vegetable Science, UHS, Bagalkot, Karnataka, India

VD Gasti
Professor and Head, Department of Vegetable Science, Kittur Rani Chennamma College of Horticulture, Gokak, Karnataka, India

Ravindra Mulge
Dean PGS, UHS Bagalkot, Karnataka, India

MG Kerutagi
Dean, Kittur Rani Chennamma College of Horticulture, Gokak, Karnataka, India

Deelip Kumar A Masuthi
Assistant Professor of Seed Science and Technology, Kittur Rani Chennamma College of Horticulture, Gokak, Karnataka, India

Corresponding Author:
Shivaji Kallappa Duradundi
PhD, Scholar, Department of Vegetable Science, UHS, Bagalkot, Karnataka, India

Combining ability studies in muskmelon (*Cucumis melo* L) for quantitative and qualitative traits

Shivaji Kallappa Duradundi, VD Gasti, Ravindra Mulge, MG Kerutagi and Deelip Kumar A Masuthi

Abstract
An investigation was undertaken to study the combining ability in muskmelon (*Cucumis melo* L.) for quantitative and qualitative traits, during 2016-2017 at department of vegetable science, KRC College of Horticulture, Arabhavi. Combining ability analysis was conducted to understand the nature of gene action of quantitative traits and to identify promising parents for breeding Programme in muskmelon. The ten lines and three testers were sown and crossed in a line X tester mating system to obtain 30 F_1 hybrid combinations. Among the lines KM-1, KM-2 and KM-10 were the best general combiner for fruit yield per hectare and most of the quantitative traits. The crosses like KM-2 x PS, KM-1 x DK and KM-3 x PS exhibited significant scan effects for fruit yield per hectare and most of the other traits.

Keywords: GCA, SCA, Line X Tester

Introduction

Muskmelon (*Cucumis melo* L.) (2n=24) belongs to the family cucurbitaceous. Edible melons belong to either *Cucumis melo* var. *reticulatus* or *Cucumis melo* var. *cantaloupensis.* Plants are either monoecism or andromonoecious annuals with long trailing vines with shallow lobed round leaves. There is considerable variation in fruit size and shape. External appearance may be smooth with netted, the skin colour may be white, green and yellow. Yellowish brown or speckles yellow or orange with green or yellow background. Fruits of some cultivars crack when ripe. Upon ripening, fruits soften and fruity aromatic essence are formed in the fruit.

Muskmelon is used as dessert fruit and fruit juice has cooling effect. At greener stage, it is used as cooked vegetable. The fruit juice is nutritive and acts as demulcent and diuretic drink. Juice is also acts as remedy for skin diseases, tan freckles and dyspepsia. The seeds are edible and its kernel is rich in oil (40-44%). This oil is useful in overcoming the problems like painful discharge and suppression of urine. The roots of melon have purgative and vomit causing properties. Fruits are good source of vitamins and minerals and relatively low in protein. The yellow and orange fleshed melons contain β-carotene and particularly cantaloupes are high in provitamin A (4200 IU/100g). Melons are also rich in vitamin C (26mg/100g edible portion). For every 100g edible portion, melons provide 26 to 17 calories energy, 0.3g protein, 32mg calcium, 1.4mg iron and 14 mg phosphorus (Chakrabarti, 2011) [4].

In breeding, the development of hybrids for high yield, the breeder is often faced with the problem of selecting parents and crosses. Combining ability analysis is one of the powerful tools available, which gives an estimate of combining ability effect and aids in selecting desirable parents and crosses for further exploitation. The common approach of selecting parents on the basis of *per se* performance does not necessarily lead to fruitful results. Selection of the best parents for hybridization has to be based on complete genetic information. Knowledge of combining ability estimates gives information about the genetic architecture of the parents. With this aim in view, the present investigation was undertaken to identify the best combiners among the existing germplasm. General and specific combing ability for quantitative characters influencing yield and its components is very helpful in selecting parents for production of superior hybrids. Several biometrical methods are available for studying the combining ability, heterosis and gene action. The line x tester (l x t) analysis is one of the most used methods to test the large number of lines for combing ability. With these backdrops, an effort to exploit heterosis in muskmelon was made in the present investigation through line x tester mating design with the objective of analysis of combining ability for quantitative and qualitative traits.

Materials and Methods

The experiment on heterosis and combining ability studies in muskmelon (*Cucumis melo* L.) was conducted in the fields of Vegetable Science unit of Kittur Rani Channamma College of Horticulture, Arabhavi, Belagavi District (Karnataka). Seeds of lines and testers were sown during the month of June 2016 for attempting crosses in line x tester fashion. Sowing was done on 2.00m apart ridges at a spacing of 0.90m between plants for easy movement. All the recommended cultivation practices were followed to raise a good crop (as per the package of practices of horticultural crops of University of Horticultural Sciences, Bagalkot (Anon., 2014) [1]. A total of 30 hybrids were developed by crossing 10 female parents (lines) with each of three male parents (testers). Flower buds of male and female parents were selected on the previous evening prior to the day of their opening. The selected flower buds of male parents were covered with butter paper bags to avoid contamination of pollens by other parents. Similarly flower buds of female parents were emasculated and covered with butter paper bag to avoid outcrossing. Pollination was carried out on the next day morning between 5.30 am and 8.00 am by using pollens of desired male parents. After pollination, the female flower buds were again covered with butter paper bags to avoid contamination and tagged with the details of male parent and date of pollination. Simultaneously, the male and female parents were selfed by bagging the flower buds with butter paper bags prior to the day of flower opening. Crossed and selfed fruits were harvested separately at full maturity stage. The seeds were hand extracted and preserved in butter paper bags labelled with the details of cross or entry number. The mean of all the replications for each parents, hybrids and check for each of the characters was computed and used in analysis of combining ability. Replication means of various characters of parents and hybrids were subjected to line x tester (*l* x t) with randomised block design analysis (Kempthorne, 1957) [10].

Table 1: General combining ability effects of parents for growth, earliness, yield and yield parameters in muskmelon.

SI. No.	Lines	Vine length at 90 DAS	Number of leaves on 60 DAS	Number of branches at 60 DAS	Days to first flowering	Days to first female flowering	Node to first female flower	Days to first harvest	Sex ratio	No. of fruiting branches per vine	No. of fruits per vine	Average fruit weight	Fruit yield per vine	Fruit yield per plot	Fruit yield per hectare
1	KM-1	13.81**	16.82**	1.01**	-3.06**	-6.11**	-1.02**	-5.69**	-1.75**	2.38**	0.61**	134.15**	0.68**	6.81**	3.78**
2	KM-2	12.28**	18.69**	0.81**	-1.99**	-4.21**	-1.32**	-6.49**	-0.72*	2.08**	0.44*	20.96**	0.33*	3.32*	1.85*
3	KM-3	-4.72**	2.19	0.15	1.27*	-1.68*	-0.32	-1.32	0.05	-0.18	-0.19	-12.20**	0.04	0.36	0.20
4	KM-4	-4.34**	-4.84**	0.05	-0.36	-1.78*	0.32	4.61**	0.31	-0.32	-0.26	41.21**	-0.16	-1.61	-0.89
5	KM-5	-1.39	-30.71**	-0.59**	0.07	9.39**	0.15	2.78**	1.60**	-0.78	-0.19	22.28**	0.00	-0.01	-0.01
6	KM-6	-13.85**	-5.91**	-0.92**	3.11**	7.39**	1.18**	5.38**	1.21**	-2.12**	-0.76**	-37.29**	-0.35*	-3.51*	-1.95*
7	KM-7	-11.53**	-14.88**	-0.79**	2.11**	3.45**	0.62**	1.15	0.74*	-1.08	-0.19	-117.32**	-0.68**	-6.79**	-3.77**
8	KM-8	1.21	1.62	0.25	-1.16*	-3.35**	-0.12	-1.19	-0.72*	0.62	0.34	14.52**	0.15	1.51	0.84
9	KM-9	-20.17**	-13.58**	-1.32**	2.81**	2.89**	1.42**	6.51**	1.27**	-2.98**	-0.59**	-176.66**	-0.78**	-7.76**	-4.31**
10	KM-10	18.26**	22.59**	1.15**	-2.79**	-5.98**	-0.92**	-5.75**	-1.98**	2.38**	0.81**	110.36**	0.77**	7.69**	4.27**
	SEm±	0.668	0.882	0.122	0.362	0.523	0.136	0.651	0.231	0.396	0.144	2.553	0.112	1.114	0.619
	CD at 5%	1.93	2.55	0.35	1.05	1.51	0.39	1.88	0.67	1.14	0.42	7.39	0.32	3.22	1.79
	CD at 1%	2.60	3.44	0.47	1.41	2.04	0.53	2.53	0.90	1.54	0.56	9.96	0.43	4.34	2.41
	Testers														
1	PS	-5.95**	-3.07**	-0.39**	-0.81*	-1.82**	-0.12	-1.67**	-0.59**	0.66*	0.29*	-25.43**	0.14	1.41	0.79
2	HM	-4.83**	-6.28**	-0.36**	0.39	1.46**	-0.05	1.25*	0.29	-0.52	-0.22	-2.84	-0.16	-1.59	-0.89
3	DK	-1.12*	-3.21**	-0.04	0.42	0.35	0.17	0.42	0.30	-0.15	-0.08	-22.58**	0.02	0.18	0.10
	SEm±	0.366	0.483	0.066	0.198	0.286	0.074	0.356	0.127	0.217	0.079	1.400	0.061	0.610	0.339
	CD at 5%	1.06	1.40	0.19	0.57	0.83	0.22	1.03	0.37	0.63	0.23	4.05	0.18	1.76	0.98
	CD at 1%	1.43	1.88	0.26	0.77	1.12	0.29	1.39	0.49	0.85	0.31	5.46	0.24	2.38	1.32

* And **indicate significance of values at $p = 0.05$ and $p = 0.01$, respectively. DAS: Days after sowing and PS: Punjab Sunheri HM: Hara Madhu DK: Durga Kranti

Table 2: Specific combining ability effects of crosses for growth and earliness parameters in muskmelon

Sl. No.	Crosses	Vine length at 90 DAS	Number of leaves on 60 DAS	Number of branches at 60 DAS	Days to first flowering	Days to first female flowering	Node to first female flower	Days to first harvest	Sex ratio
1.	KM-1 × PS	-17.89**	-11.80**	-0.79*	1.81*	3.68**	0.89*	4.44**	1.44*
2.	KM-1 × HM	2.71	-0.75	0.16	-1.96*	-2.40	-0.28	-2.08	-0.26
3.	KM-1 × DK	15.18**	12.56**	0.64*	-0.42	-1.29	-0.60	-2.35	-1.18*
4.	KM-2 × PS	18.80**	14.13**	1.21**	-1.39	-4.02**	-0.21	-4.76**	-1.92**
5.	KM-2 × HM	-8.04**	-8.92**	-0.64*	1.24	2.40	0.12	1.42	0.82
6.	KM-2 × DK	-10.76**	-3.21	-0.56	0.71	1.61	0.10	3.35*	0.76
7.	KM-3 × PS	16.31**	20.33**	1.67**	-3.32**	-4.75**	-1.21**	-6.73**	-1.58**
8.	KM-3 × HM	0.81	-2.62	-0.18	0.28	0.17	-0.28	-0.75	0.31
9.	KM-3 × DK	-17.12**	-17.71**	-1.50**	3.05**	4.58**	1.50**	7.48**	1.61**
10.	KM-4 × PS	3.02	6.06**	0.07	-1.49	0.45	-0.05	-2.96	-0.38
11.	KM-4 × HM	-7.96**	-1.79	-1.28**	3.51**	5.17**	1.58**	2.72	1.32*
12.	KM-4 × DK	4.94**	-4.28	1.20**	-2.02*	-5.62**	-1.54**	0.25	-0.93
13.	KM-5 × PS	-7.02**	-7.27**	0.01	0.28	-8.82**	0.42	1.77	-0.32
14.	KM-5 × HM	5.40**	4.28	-0.04	-2.32*	3.60**	-0.55	1.55	-0.43
.15.	KM-5 × DK	1.63	2.99	0.04	2.05*	5.21**	0.13	-3.32*	0.74
16.	KM-6 × PS	14.81**	8.53**	0.84**	-5.46**	-7.72**	-1.31**	-3.33*	-1.64**

17.	KM-6 × HM	-2.97	-1.72	-0.21	2.44**	3.10*	0.42	2.65	0.23
18.	KM-6 × DK	-11.84**	-6.81**	-0.63*	3.01**	4.61**	0.90*	0.68	1.41*
19.	KM-7 × PS	3.48*	5.80*	0.01	4.84**	11.52**	-0.35	3.00	0.25
20.	KM-7 × HM	-0.20	-12.75**	0.56	-2.56**	-6.66**	-0.22	-2.82	-0.64
21.	KM-7 × DK	-3.29	6.94**	-0.56	-2.29*	-4.85**	0.56	-0.19	0.40
22.	KM-8 × PS	-7.68**	-10.40**	-1.43**	2.91**	5.52**	1.39**	3.54*	2.33**
23.	KM-8 × HM	5.03**	6.15**	0.82**	-1.59	-3.16*	-0.48	-2.48	-1.15*
24.	KM-8 × DK	2.65	4.26	0.60*	-1.32	-2.35	-0.90*	-1.05	-1.17*
25.	KM-9 × PS	-17.04**	-22.40**	-1.06**	2.44**	2.78*	0.25	3.74**	1.20*
26.	KM-9 × HM	-5.25**	9.95**	0.09	0.24	0.50	-0.02	1.52	0.35
27.	KM-9 × DK	22.29**	12.46**	0.97**	-2.69**	-3.29*	-0.24	-5.25**	-1.56**
28.	KM-10 × PS	-6.80**	-2.97	-0.53	-0.06	1.35	0.19	1.30	0.63
29.	KM-10 × HM	10.48**	8.18**	0.72*	0.14	-2.73*	-0.28	-1.72	-0.54
30.	KM-10 × DK	-3.68*	-5.21*	-0.20	-0.09	1.38	0.10	0.41	-0.08
	SEm±	1.157	1.528	0.210	0.627	0.905	0.235	1.127	0.400
	CD at 5%	3.35	4.42	0.61	1.81	2.62	0.68	3.26	1.15
	CD at 1%	4.51	5.96	0.82	2.44	3.53	0.92	4.39	1.56

* And ** indicate significance of values at $p = 0.05$ and $p = 0.01$, respectively. DAS: Days after sowing and PS: Punjab Sunheri HM: Hara Madhu DK: Durga Kranti

Table 3: Specific combining ability effects of crosses for yield and yield parameters in muskmelon.

Sl. No.	Crosses	Number of fruiting branches per vine	Number of fruits per vine	Average fruit weight	Fruit yield per vine	Fruit yield per plot	Fruit yield per hectare
1	KM-1 × PS	-1.96	-0.83*	-95.57**	-0.39	-3.91	-2.17
2	KM-1 × HM	0.22	0.28	122.21**	0.05	0.54	0.30
3	KM-1 × DK	1.75	0.54	-26.64**	0.58*	5.62*	3.21*
4	KM-2 × PS	1.94	0.74*	28.59**	0.67*	6.72*	3.73*
5	KM-2 × HM	-0.08	-0.35	-39.16**	-0.15	-1.47	-0.82
6	KM-2 × DK	-1.85	-0.39	10.57	-0.53	-5.25	-2.91
7	KM-3 × PS	2.70**	0.97**	143.36**	0.73*	7.29*	4.05*
8	KM-3 × HM	-0.22	0.48	67.44**	-0.08	-0.76	-0.42
9	KM-3 × DK	-2.49*	-1.46**	-210.80**	-0.65*	-6.53*	-3.63*
10	KM-4 × PS	0.04	0.64	62.31**	0.20	2.01	1.11
11	KM-4 × HM	-1.98*	-0.85*	-149.26**	-0.46	-4.59	-2.55
12	KM-4 × DK	1.95	0.21	86.94**	0.26	2.59	1.44
13	KM-5 × PS	-0.40	-0.63	157.41**	-0.32	-3.15	-1.75
14	KM-5 × HM	2.38*	0.88*	-265.37**	0.25	2.46	1.37
15	KM-5 × DK	-1.99*	-0.26	107.96**	0.07	0.69	0.38
16	KM-6 × PS	1.84	0.84*	149.34**	0.60*	6.01*	3.34*
17	KM-6 × HM	-0.08	-0.55	-106.78**	-0.17	-1.74	-0.97
18	KM-6 × DK	-1.75	-0.29	-42.56**	-0.43	-4.27	-2.37
19	KM-7 × PS	0.30	-0.23	-201.39**	-0.34	-3.36	-1.87
20	KM-7 × HM	-1.72	-0.12	256.12**	-0.09	-0.91	-0.50
21	KM-7 × DK	1.41	0.34	-54.73**	0.43	4.27	2.37
22	KM-8 × PS	-2.20*	-0.66	-266.00**	-0.99**	-9.86**	-5.48**
23	KM-8 × HM	1.38	0.25	132.72**	0.51	5.14	2.86
24	KM-8 × DK	0.81	0.41	133.28**	0.47	4.72	2.62
25	KM-9 × PS	-1.90	-0.63	47.78**	-0.03	-0.30	-0.16
26	KM-9 × HM	-0.52	-0.32	-16.39*	-0.09	-0.94	-0.52
27	KM-9 × DK	2.41*	0.94*	-31.39**	0.12	1.24	0.69
28	KM-10 × PS	-0.36	-0.23	-25.85**	-0.15	-1.45	-0.81
29	KM-10 × HM	0.62	0.28	-1.53	0.23	2.26	1.26
30	KM-10 × DK	-0.25	-0.06	27.37**	-0.08	-0.82	-0.45
	SEm±	0.686	0.250	4.426	0.192	1.929	1.072
	CD at 5%	1.98	0.72	12.80	0.56	5.58	3.10
	CD at 1%	2.67	0.97	17.25	0.75	7.52	4.18

* And ** indicate significance of values at $p = 0.05$ and $p = 0.01$, respectively. DAS: Days after sowing and PS: Punjab Sunheri HM: Hara Madhu, DK: Durga Kranti

Table 4: General combining ability effects of parents for quality parameters in muskmelon

SI. No.	Lines	Fruit shape index	Flesh thickness	Rind thickness	Cavity length	Cavity breadth	Total soluble solids	Total sugars	β-carotene content
1	KM-1	0.26**	0.31**	-0.05*	0.56*	0.05	-0.37	0.04	198.66**
2	KM-2	0.02	0.04	-0.06**	0.43	0.54*	2.47**	1.67**	-0.77
3	KM-3	0.08	-0.21*	-0.01	-0.54*	-0.60*	0.98**	0.89**	-22.91**
4	KM-4	-0.01	0.18	0.00	-0.34	0.52*	1.44**	0.85**	-30.38**
5	KM-5	0.12*	0.44**	-0.06**	0.40	0.51*	0.57	-1.01**	-81.91**

6	KM-6	-0.07	-0.42**	0.03	-0.39	-1.27**	1.20**	0.72**	65.08**
7	KM-7	-0.09*	-0.10	0.08**	-0.07	0.15	-1.36**	-1.11**	-158.27**
8	KM-8	-0.16**	-0.04	0.04	-0.06	0.69**	-1.79**	-1.18**	-28.90**
9	KM-9	-0.19**	-0.44**	0.04	0.03	-0.03	-2.75**	-2.01**	-56.89**
10	KM-10	0.06	0.24*	-0.02	-0.02	-0.56*	-0.40	-0.87**	116.29**
	SEm±	0.033	0.074	0.016	0.185	0.170	0.226	0.170	3.626
	CD at 5%	0.09	0.21	0.05	0.53	0.49	0.65	0.49	10.49
	CD at 1%	0.13	0.29	0.06	0.72	0.66	0.88	0.66	14.13
	Testers								
1	PS	0.01	0.12	-0.01	-0.03	0.17	0.27	0.20	43.38**
2	HM	-0.01	-0.04	0.02	0.33*	0.06	-0.40*	-0.16	-13.15**
3	DK	0.00	-0.08	-0.01	-0.30*	-0.23	0.13	-0.04	-30.23**
	SEm±	0.018	0.040	0.009	0.101	0.093	0.124	0.093	1.987
	CD at 5%	0.05	0.13	0.03	0.29	0.27	0.36	0.27	5.74
	CD at 1%	0.07	0.16	0.04	0.39	0.36	0.48	0.36	7.74

* And ** indicate significance of values at $p = 0.05$ and $p = 0.01$, respectively. DAS: Days after sowing and PS: Punjab Sunheri HM: Hara Madhu, DK: Durga Kranti

Table 5: Specific combining ability effects of crosses for quality parameters in muskmelon.

Sl. No.	Crosses	Fruit shape index	Flesh thickness	Rind thickness	Cavity length	Cavity breadth	Total soluble solids	Total sugars	β-carotene content
1	KM-1 × PS	-0.30**	-0.68**	0.04	-1.06*	0.10	-0.47	-0.21	190.08**
2.	KM-1 × HM	0.19*	0.08	0.01	0.55	-0.92*	2.03**	1.12*	14.54
3.	KM-1 × DK	0.11	0.60**	-0.05	0.50	0.82	-1.56**	-0.91*	7.94
4.	KM-2 × PS	-0.12	0.87**	-0.06	-0.81	-0.40	1.08	1.45**	-22.48*
5.	KM-2 × HM	0.07	-0.63**	0.05	-0.06	-0.16	-0.87	-0.16	-107.17**
6.	KM-2 × DK	0.05	-0.24	0.01	0.87	0.56	-0.21	-1.45**	-82.91**
7.	KM-3 × PS	-0.09	0.87**	-0.10	1.12*	1.73**	2.33**	1.61**	65.49**
8.	KM-3 × HM	0.02	0.00	0.00	0.18	-0.42	-2.29**	-1.60**	-9.71
9.	KM-3 × DK	0.06	-0.87**	0.10	-1.31**	-0.68	-0.04	0.15	-55.78**
10.	KM-4 × PS	0.10	-0.16	-0.02	-0.89	-1.01*	-0.87	-1.03*	-9.14
11.	KM-4 × HM	-0.21*	-0.71**	0.07	-0.44	-0.06	-0.58	-0.14	105.52**
12.	KM-4 × DK	0.11	0.87**	-0.05	1.33**	1.08*	1.45*	1.17**	-96.38**
13.	KM-5 × PS	0.20*	-0.14	0.09*	-0.10	0.37	-1.32*	-1.06*	45.85**
14.	KM-5 × HM	-0.20*	-0.04	-0.02	-0.49	0.20	0.16	0.39	16.57
.15.	KM-5 × DK	0.00	0.18	-0.07	0.59	-0.57	1.16*	0.67	-62.42**
16.	KM-6 × PS	0.36**	0.23	0.04	1.94**	0.28	-1.55**	-1.44**	40.65**
17.	KM-6 × HM	-0.17*	-0.12	-0.04	-0.14	0.40	2.05**	1.65**	-46.24**
18.	KM-6 × DK	-0.19*	-0.11	-0.01	-1.81**	-1.31**	-0.50	-0.21	5.59
19.	KM-7 × PS	-0.13	-0.85**	0.00	-1.66**	-1.65**	2.64**	2.32**	-78.62**
20.	KM-7 × HM	0.17*	0.58**	0.06	1.03*	0.87*	-2.01**	-1.92**	16.43
21.	KM-7 × DK	-0.03	0.28	-0.06	0.63	0.77	-0.63	-0.40	62.18**
22.	KM-8 × PS	-0.10	-1.19**	0.03	0.08	-0.20	-1.11	-0.26	-0.46
23.	KM-8 × HM	0.04	0.90**	-0.13**	-0.03	0.39	1.47*	0.73	111.09**
24.	KM-8 × DK	0.06	0.29	0.10*	-0.05	-0.20	-0.37	-0.47	-110.63**
25.	KM-9 × PS	0.01	0.62**	0.05	1.18*	0.87*	-1.37*	-1.36**	-140.73**
26.	KM-9 × HM	0.03	-0.04	-0.08*	0.17	0.47	1.36*	0.60**	-56.75**
27.	KM-9 × DK	-0.05	-0.59**	0.03	-1.34**	-1.34**	0.01	0.76	197.48**
28.	KM-10 × PS	0.07	0.43*	-0.06	0.19	-0.10	0.65	-0.01	-90.64**
29.	KM-10 × HM	0.05	0.00	0.08*	-0.77	-0.76	-1.33*	-0.67	-44.28**
30.	KM-10 × DK	-0.12	-0.43*	-0.01	0.58	0.87*	0.69	0.69	134.92**
	SEm±	0.056	0.128	0.028	0.319	0.295	0.391	0.294	6.280
	CD at 5%	0.16	0.37	0.08	0.92	0.85	1.13	0.85	18.16
	CD at 1%	0.22	0.50	0.11	1.24	1.15	1.52	1.15	24.48

* And ** indicate significance of values at $p = 0.05$ and $p = 0.01$, respectively. DAS: Days after sowing PS: Punjab Sunheri HM: Hara Madhu DK: Durga Kranti

Results and Discussions

The analysis of variance for genotypes showed significant differences for all the characters. The estimates of mean sum of squares due to parents showed significant differences for all the characters except for days to first harvest, sex ratio and rind thickness indicating the presence of sufficient variability among the parents studied. The magnitude of variance due to *SCA* was greater than *GCA* for all the characters and *GCA: SCA* less than unity also confirmed the preponderance of non-additive gene action for all the traits. This result is expected as muskmelon as cross pollinated crop thus exhibiting predominance of dominance genetic variance in comparison to additive component. These results are in same line with those obtained by Bayoumy *et al.* (2014) [3] in melon.

The estimates of *GCA* effects of each parents are presented in Table 1 and 4. Among the three testers, no one tester showed significant and positive *GCA* effects for fruit yield per vine, the three lines exhibited positive and significant GCA effects and highest was observed in the line KM-10 (0.77) followed by KM-1 (0.68) and KM-2 (0.33). The parent KM-10 was found to be good general combiner for number of fruits per vine and estimated fruit yield per hectare these results are in agreement with Vashisht *et al.*, 2010 [14] and Bayoumy *et al.*, 2014 [3].

Among the lines KM-1 (-6.11) and among the testers PS (-1.82) exhibited highest negative and significant *GCA* effects for days to first female flower appearance. Highest significant *GCA* effects for days to first harvest was observed in the parent KM-2 (-6.49) among the lines and among the testers, observed in the PS (-1.67). The parents *viz.,* KM-1, KM-2, KM-3 and PS exhibited the significant and negative *GCA* effects for both days to first female flower appearance and days to first harvest so, these parents may be used in breeding programme for earliness. These results are in agreement with Vashisht *et al.*, 2010 [14] and Bayoumy *et al.*, 2014 [3].

For vine length at 90 DAS, three lines showed positive and significant GCA effects. The highest GCA effects was observed in the line KM-10 (18.26) followed by KM-1 (13.81) and KM-2 (12.28), none of the testers exhibited positive and significant GCA effects. The female parents KM-10 (22.59), KM-2 (18.69) and KM-1 (16.82) had positive significant *gca* effects for number of leaves at 60 DAS and none of the testers showed significant positive gca effects and for number of branches at 60 DAS, three lines had significantly positive gca effects. Maximum positive GCA effects was observed in the line KM-10 (1.15) followed by KM-1 (1.01) and KM-2 (0.81). Among the testers no one tester showed significant positive GCA effects. The average fruit weight in the line KM-1 (134.15) exhibited maximum and significant *GCA* effects. The parents KM-1, KM-2 and KM-10 exhibited significant *GCA* effects for the most of the traits. Due to predominant role of non-additive gene action for yield and its components, it is difficult to bring together desirable genes by pedigree method. In this situation formation of central gene pool by bringing together the multiple parents having the good *GCA* effects suggested by Jensen (1970) [8] might prove to be useful.

The crosses having desired significant specific combining effects are presented in Table 2, 3 and 5. Out of 30 crosses, four crosses exhibited positively significant *sca* effects for fruit yield per vine. Highest and significantly positive sca effects was observed in the cross KM-3 x PS (0.73) followed by KM-2 x PS (0.67) and KM-6 x PS (0.60). Maximum positive and significant sca effects was found in the cross KM-9 x DK (22.29) followed by KM-2 x PS (18.80) and KM-3 x PS (16.31). For vine length at 90 DAS. The highest positive and significant sca effects were exhibited by the cross KM-3 x PS (20.33) followed by KM-2 x PS (14.13) and KM-1 x DK (12.56) for number of leaves per vine at 60 DAS. Number of branches was maximum and significant *sca* effects were exhibited by KM-3 x PS (1.67) followed by KM-2 x PS (1.21) and KM-4 x DK (1.20). Days to first female flower appearance, in the cross KM-5 x PS (-8.82) followed by KM-6 x PS (-7.72) and KM-7 x HM (-6.66) exhibited negative and significant *sca* effects. Among the crosses, four crosses exhibited significant and negative sca effects and maximum being observed in the cross KM-4 x DK (-1.54) followed by KM-6 x PS (-1.31) and KM-3 x PS (-1.21) for node to first female flowering. The highest negative and significant sca effects was observed in the cross KM-3 x PS (-6.73) followed by KM-9 x DK (-5.25) and KM-2 x PS (-4.76) for days to first harvest. These results are in agreement with Dhaliwal and Lal, 1996 [5] and Vashisht *et al.*, 2010 [14]. A comparison of the *sca* effects of the crosses and *GCA* effects of the parents involved indicated that most of the cases *gca* effects were reflected in the *sca* effects of the cross combination.

The cross KM-2 x PS (-1.92) followed by KM-6 x PS (-1.64) and KM-3 x PS (-1.58) exhibited significant in desirable direction (negative) for sex ratio. The highest and significantly positive sca effects was observed in the cross KM-8 x HM (0.90) followed by KM-2 x PS (0.87) and KM-3 x PS (0.87) and KM-4 x DK (0.87) and KM-9 x PS (0.62) for flesh thickness. The cross KM-8 x HM (-0.13) followed by KM-9 x HM (-0.08) exhibited significant in desirable direction (negative) for rind thickness. Out of 30 crosses, eight crosses exhibited significant and positive sca effects. Highest and significantly positive sca effects was observed in the cross KM-7 x PS (2.64) followed by KM-3 x PS (2.33) and KM-6 x HM (2.05) for total soluble solids. The highest and significantly positive sca effects was observed in the cross KM-7 x PS (2.32) followed by KM-6 x HM (1.65) and KM-3 x PS (1.61) for total sugars. Among 30 crosses, nine crosses exhibited significant and positive sca effects. Highest and significantly positive sca effects was observed in the cross KM-9 x DK (197.48) followed by KM-1 x PS (190.08) and KM-10 x DK (134.92). For β-carotene content. The crosses KM-2 x PS, KM-1 x DK and KM-3 x PS were the superior hybrids selected for yield since, these crosses exhibited significant sca effects for yield per hectare.

The crosses involving parents with good general combining ability effects can be exploited effectively by conventional breeding procedure like pedigree method. However the crosses one good combiner and other average or poor combiner could produce desirable transgressive segregators if additive genetic system was operative in good combining parents and epistatic effects also act in the same direction.

For exploitation of heterosis, the information on GCA should be supplemented with sca and hybrid performance. Heterosis in F1 indicates operation of non-additive gene effects, but it cannot give any idea about the relative magnitude of non-additive (dominance + epistasis) and additive gene action. Hence, analysis of combining ability is one of the potential tools for identifying prospective parents to develop commercial F1 hybrids (Griffing, 1956) [6]. General and specific combining ability effects and variances obtained from a set of F1's would enable a breeder to select desirable parents and crosses for each of the quantitative characters. General combining ability effects of parents and sca effects of crosses were significant for the characters studied. From the present investigation, it is evident that GCA or sca effects in parents or crosses were in desirable direction for some characters and in undesirable direction for some other traits. Therefore it is important to ascertain the status of parent or hybrid with respect to combining ability effects over a number of component characters (Arunachalam and Bandopadhay, 1979) [2].

Comprehensive assessment of parents by considering gca effects of 22 characters has resulted into identification of lines, *viz*., KM-1, KM-2, KM-8 and KM-10 as good combiners over all characters and lines, viz., KM-4, KM-5, KM-6, KM-7 and KM-9 were identified as poor combiners over all characters and KM-3 was identified as average combiners over all the characters among the lines. Among the testers PS was identified as average combiner over all characters, HM and DK were identified as poor combiners over all characters.

Ratio of general combining ability variance (GCA) to specific combining ability variance (SCA) is an indication of predominance of additive or non-additive genetic variance. GCA to SCA ratio was very low for the average fruit weight (Dhaliwal and Lal, 1996, Munshi and Verma, 1999, Vashisht *et al*., 2010 and Bayoumy *et al*., 2014) [3, 5, 13, 14], flesh thickness (More and Seshadri, 1980, Kalloo *et al.*, 1990, Dhaliwal and Lal, 1996, Munshi and Verma, 1999, Vashisht *et al*., 2010 and Bayoumy *et al*., 2014) [3, 5, 9, 13, 14] and cavity length (Vashisht *et al*., 2010) [14] indicating preponderance of non-additive gene action and hence these traits can be improved through recurrent selection for specific combining ability or heterosis breeding. Non-additive component of genetic variance was higher than additive component for vine length (Gurav *et al*., 2000 and Bayoumy *et al*., 2014) [3, 7], number of branches (Gurav *et al*., 2000 and Bayoumy *et al*., 2014) [3, 7], sex ratio (Vashisht *et al*., 2010) [14], fruit yield per vine (More and Seshadri, 1980, Kalloo *et al.*, 1990, Dhaliwal and Lal, 1996, Munshi and Verma, 1999, Vashisht *et al.*, 2010 and Bayoumy *et al.*, 2014) [3, 5, 9, 13, 14], fruit yield per plot (More and Seshadri, 1980, Kalloo *et al.*, 1990, Dhaliwal and Lal, 1996, Munshi and Verma, 1999, Vashisht *et al.*, 2010 and Bayoumy *et al.*, 2014) [3, 5, 9, 13, 14], fruit yield per hectare (More and Seshadri, 1980, Kalloo *et al.*, 1990, Dhaliwal and Lal, 1996, Munshi and Verma, 1999, Vashisht *et al.*, 2010 and Bayoumy *et al.*, 2014) [3, 5, 9, 13, 14], days to first flowering (Dhaliwal and Lal, 1996 and Bayoumy *et al.*, 2014) [3, 5], days to first female flowering (Dhaliwal and Lal, 1996, Vashisht *et al.*, 2010 and Bayoumy *et al.*, 2014) [3, 5, 14], number of nodes up to first female flowering (Dhaliwal and Lal, 1996 and Vashisht *et al.*, 2010) [5, 14], number of fruiting branches per vine (Vashisht *et al*., 2010) [14], number of fruits per vine (Dhaliwal and Lal, 1996, Munshi and Verma, 1999 and Bayoumy *et al.*, 2014) [3, 5, 13, 14], fruit shape index (Vashisht *et al.*, 2010) [14], rind thickness (Vashisht *et al.*, 2010) [14], cavity breadth (Vashisht *et al.*, 2010) [14], total soluble solids (Munshi and Verma, 1999 and Vashisht *et al.* 2010) [13, 14], total sugars (Bayoumy *et al.*, 2014) [3], and β-carotene content (Bayoumy *et al.*, 2014) [3]. Hence, these characters can be improved through recurrent selection schemes.

There is great scope for heterosis breeding in order to exploit the non-additive genetic variance observed for yield and yield components. Non additive component of genetic variance was slightly higher than additive components for number of leaves at 60 DAS and days to first harvest (More and Seshadri, 1980, Kesavan and More, 1991, Dhaliwal and Lal, 1996 and Bayoumy *et al.*, 2014) [3, 5, 11]. Hence, direct selection or recurrent selection schemes can be employed for improvement of these traits.

Conclusions

The importance of combining ability analysis was to understand the nature of gene action of quantitative traits and to identify promising parents for breeding programmer. In the present study, the parents KM-1, KM-2 and KM-10 are the good general combiners for yield per hectare and can be used in identifying superior new heterosis combinations and the crosses KM-2 x PS, KM-1 x DK and KM-3 x PS were the superior hybrids selected for yield since, these crosses exhibited significant sca effects for yield per hectare. In this study, the predominance of non-additive gene action for most of the traits, suggested that heterosis breeding might be useful for improvement of these traits in muskmelon.

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