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Estimation of Heterosis and Combining Ability in Oats (*Avena sativa* L.) for Green Fodder Yield and Attributing Traits using Line X Tester Design

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ABSTRACT

Forty F_1 hybrids which were obtained by crossing eight lines and five testers selected from oat germplasm available at Forage Research farm, PAU, Ludhiana were evaluated along with parents in RBD during Rabi 2016-17. Analysis revealed significant gca and sca mean squares for most of the traits, however non-additive gene action was found to be more predominant as variances due to sca were higher than gca variances. Among female parents OS-403 showed significant positive gca effects for green fodder yield, number of leaves, number of tillers, stem girth and number of leaves on main shoot. The male parent OL-125 was best general combiner for green fodder yield whereas OL-1760 was good general combiner for green fodder yield, number of leaves, leaf length, number of tillers, flag leaf length and number of leaves on main shoot. The best specific combinations were OS-403 x OL-125, OL-1842 x OL-9,OS-403 x OL-9, Kent x OL-1892, OL-1869 x OL-9 and OS-403 x OL-1760 for different traits. Highest significant and positive heterosis for green fodder yield (1702.1%) was shown by F_1 OS-403 x OL-125 followed by OS-403 x OL-1760.

Key words: *Oat, Line x tester, Combining ability, SCA, GCA.*

INTRODUCTION

Oat (*Avena sativa* L.) is the most important cereal fodder crop belongs to family poaceae grown during Rabi season in many parts of the country including North Western, Central and extending upto the parts of Eastern India. Oat (*Avena sativa* L.) ranks sixth in cereal production globally following wheat, maize, rice, barley and sorghum[1]. In respect to animal feeding purposes, high contents of protein, carbohydrates, lipids and lower fiber contents are required[9]. In self- pollinated crops like oat, combining ability is mostly used by plant breeders to select desirable parental genotypes to produce the larger progeny of new combinations through their hybridization. Knowledge on the mechanisms that control the main traits of agronomic interest of a species is fundamental for genetic improvement and can be acquired through methodologies of line x tester mating design as the one developed by Griffing[7].

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The line x tester analysis method can be used to estimate general and specific combining abilities in both self and cross-pollinated plants[10]. Line x tester analysis provides for the detection of appropriate parents and crosses superior in terms of the investigated characters so application of the analysis has been widely used by plant breeders for selection in early generations[2,11,13]. Based on the combining ability analysis of different characters, dominance gene action is the result of higher sca values and higher gca effects indicate a greater role of additive gene effects. If sca and gca values are not significant, epistatic gene effects may play an important role in genetic of characters[14].

In autogamous plants, the heterosis manifested in the F_1 generation is reduced by 50% in each selfing generation since reduction occurs in the number of heterozygous plants in the same proportion[12]. With the mean values of F_1 and the calculated heterosis, it is therefore possible to foresee/predict the population means in future generations. According to Cruz *et al*[4]., the best hybrid combinations are those with the most favorable estimates for the sca effects that have at least one parent with the most favorable GCA effect for the target trait. According to Cruz and Vencovsky[3], the best hybrid is result of a cross between parents (a) selected based on gca and parent (b), whose frequency of favorable alleles is superior to the mean population frequency and considerably divergent from parent (a). Crosses of two parents with high general ability do however not necessarily generate the best hybrid.

MATERIALS AND METHODS

The experiment material consisted of thirteen genetically diverse genotypes being maintained at Punjab Agricultural University (PAU), Ludhiana, India. Of these thirteen genotypes selected, eight genotypes viz; OL-10, Kent, OL-1842, OL-1866, OL-1869, OL-1766-1, OS-403 and OS-405 were used as female parent and five genotypes viz; OL-125, OL-9, UPO-212, OL-1892 and OL-1760 were used as male parent. The selected genotypes were crossed in Line x Tester design[10] during *Rabi* 2015-16 to obtain 40 F_1 crosses. The trial comprising of 40 F_1s, 13 parents and one commercial check OL-10, was conducted during *Rabi* 2016-17 at the experimental field of Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana. All the entries were evaluated in a randomized block design with three replications. The material was grown in two rows of 5 m length with row to row spacing of 25 cm. Recommended package of practices to raise a good crop was followed. Observations were recorded on five random plants selected from each entry on 11 quantitative variables viz; number of leaves, leaf width (cm), leaf length (cm), internode length (cm), number of tillers per plant, stem girth (cm), flag leaf length (cm), flag leaf width (cm), plant height (cm), number of leaves on main tiller and green fodder yield (g/plot). Genotype means were used for the analysis of variance. The combining ability analysis was carried out for different traits following procedure laid out by Kempthorne[10]. Heterosis was computed as percentage increase or decrease over commercial check.

RESULTS AND DISCUSSION

The analysis of variance for combining ability for different characters is presented in Table 1. The variance among hybrids was partitioned in to different components corresponding to the combining ability of females, males and their interaction. Analysis revealed significant gca and sca mean squares for most of the traits, however non-additive gene action was found to be more predominant for all the traits under evaluation as variances due to sca were higher than gca variances. Hence, these traits can be exploited through heterosis breeding for enhancing the green fodder yield in oat. Variances for hybrids and due to female x male interaction were significant for all the traits except for stem girth. Variances due to only females were significant for all the traits except internode length whereas variances due to only males were significant for all the traits under study.

Further perusal of the data about gca values of parents (Table 2) revealed that all the parents (both male and female) involved in the study were good general combiner for most of the traits under study except for flag leaf length for which only three male parents were good combiner. OS-403 was found to be the best general combiner for green fodder yield amongst all the parents. It was also found to have significant positive GCA values for other traits viz; number of leaves, number of tillers, stem girth and number of leaves on main tiller. Besides OS-403, only two parents OL-125 and OL-1760 showed positive and significant gca values for green fodder yield and rest all of the parents exhibited significant and negative gca values for this trait. Another peculiar observation was made about the OS-403 that the traits for which it had positive and significant gca values, very few parents were found to be good combiner for those traits like for number of leaves per plant, number of leaves on main tiller, number of tillers and stem girth only four parent was found to be good general combiner. For other important traits contributing towards green fodder yield like plant height, genotypes OL-10 and OL-125 were the best general combiner female and male parent respectively. For number of leaves per plant only three parents viz; OL-1869, OS-403 and OL-1760 had significant and positive gca values and except OL-1892 rest all parents showed significant and negative values of gca for this trait. Genotype KENT showed high value of significant and positive gca for leaf length. For leaf width five parents viz; OL-9, OL-125, OS-405, OL-1866, OL-1869 showed significant and positive values of gca for this trait. KENT and OL-1869 was the best general combiner for internode length and number of tillers respectively.

The sca effects of the crosses for green fodder yield and other component traits were presented in Table 3. Perusal of the data revealed that, of the forty crosses generated and evaluated, twenty-six crosses had significant and positive sca effects. Hybrid OS-403 x OL-125 recorded highest sca effect for green fodder yield closely followed by OS-403 x OL-9. OS-403 x OL-125 also showed positive and significant sca values for six other traits viz; number of leaves per plant, leaf length, number of tillers, flag leaf length, plant height and number of leaves on main tiller. Further perusal of the data exhibited that the best specific combinations were the F_1 hybrids viz; OS-403 x OL-125 for number of leaves per plant, OL-1842 x OL-9 for leaf length, OS-403 x OL-9 for leaf width, Kent x OL-1892 for internode length, OL-1869 x OL-9 for number of tillers, OS-403 x OL-1760 for stem girth, OL-1842 x OL-9 for flag leaf length and plant height,OS-403 x OL-9 for flag leaf width and OL-1869 x OL-1892 for number of leaves on main tiller. Some of these crosses were related with gca effects of their parents and found having at least one parent with high or average gca effects for the particular trait. Results authenticated that high x low and low x high general combiners were responsible for the manifestation of the desirable sca effect coupled with remarkable mean performance. Similar results were also obtained by Hathcock and McDaniel[8], Stuthman and Stucker[15] and Pixley *et al*[11]. Such combinations may result into appearance of transgressive segregants. However, some of the best specific combinations were obtained from parents having low and even negative gca effects, means that some desirable sca effects could be administered by low gca parents. Such poor combining parents are highly responsible to heterozygosity due to non-additive gene effect.

Mean performance and heterotic values of 40 F_1 hybrids for green fodder yield and related traits revealed that majority of the F_1 hybrids produced higher values as compared to parental cultivars (Table 4). Also heterosis generally was greater for green fodder yield than for yield components which could be expected since green fodder yield is the product of these component traits. Yield increase does not necessarily result from changes in yield components, but yield change must be accompanied by a change in one or more of the yield components[5,6]. Highest significant and positive heterosis for green fodder yield (1702.1%) was shown by F_1 OS-403 x OL-125 followed by OS-403 x OL-1760 (1356.3%). The results revealed that, of the forty crosses evaluated, twenty-one showed positive and significant heterosis for green fodder yield with heterosis values ranged between 5.4 to 1702.1% while as many as eight hybrids exhibited negative and significant heterosis for this trait. For traits viz; leaf length and flag leaf length none of the hybrid exhibited significant and negative heterosis. Correspondingly for trait viz; number of leaves on main tiller, only four hybrids exhibited the positive and significant heterosis and rests all hybrids showed significant and negative or no heterosis at all. Stuthman and Stucker[15] and Pixley *et al*[11]., also recorded positive and significant heterosis for above mentioned traits thus corroborated our results.

Table 1: Analysis of variance for combining ability for different characters

Source of variation	df	No. of leaves/plant	Leaf length (cm)	Leaf width (cm)	Internode length (cm)	No. of tillers	Stem girth (cm)	Flag leaf length (cm)	Flag leaf Width (cm)	Plant height (cm)	No. of leaves on main tiller	Green fodder yield (g/plot)
Hybrids	39	1182.06**	105.87**	0.78**	43.49**	22.02**	0.07	95.08**	0.82**	542.27**	3.23**	3335343.00**
Females(F)	7	3210.83**	168.88**	1.47**	0.45	25.79**	0.07**	157.2**	1.29**	509.28**	4.67**	5029205.00**
Males(M)	4	1309.28**	74.47**	0.98**	39.39**	17.81**	0.09**	55.09**	0.98**	400.24**	3.50**	2093762.00**
F X M	28	1067.76**	80.58**	0.77**	41.65**	19.52**	0.03	79.86**	0.73**	433.85**	0.83**	2615853.00**
Error	104	17.11	3.10	0.01	1.30	0.66	0.003	3.31	0.01	6.71	0.03	445.48
σ^2_f		154.20	6.15	0.04	-0.62	0.13	0.001	5.29	0.03	7.49	0.32	234223.50
σ^2_m		15.89	-0.92	0.01	-0.59	-0.02	0.001	-0.82	0.01	-1.52	0.02	-14670.46
$\sigma^2_{f\,x\,m}$		269.61	27.82	0.24	14.43	6.02	0.011	24.84	0.24	139.04	0.25	838471.40
V_A		69.09	1.79	0.02	-0.60	0.03	0.002	1.50	0.02	1.94	0.14	81057.98
V_D		407.79	31.42	0.29	13.22	6.09	0.016	27.90	0.28	142.93	0.54	1000587.00

*, ** are level of significance at 5 % and 1% respectively.

Table 2: Estimates of specific combining ability of the hybrids for various characters

S.N.	Hybrids	No. of leaves/ plant	Leaf length (cm)	Leaf width (cm)	Internode length (cm)	No. of tillers	Stem girth (cm)	Flag leaf length (cm)	Flag leaf width (cm)	Plant height (cm)	No. of leaves/main tiller	Green fodder yield (g/plot)
1	OL-10 x OL-125	-8.44**	-0.99	-0.11	3.40**	-0.08**	-0.33	-0.24	-0.11	-6.40**	0.14	-285.41
2	OL-10XUPO-O9-2	6.85	1.24	-0.36**	-1.14**	-1.50	-0.19**	1.40	-0.38**	5.39**	0.12**	311.62
3	OL-10 X UPO-212	11.85**	-2.02	-0.10	-3.85**	1.20**	-0.01	0.10	-0.27**	-1.38	-0.25*	600.37
4	OL-10 X OL-1892	-10.44**	1.02**	0.39**	1.73	-3.58**	0.11**	1.44	0.34**	-2.34	-0.20	389.75
5	OL-10 X OL-1760	11.18	-3.90**	0.06*	0.99	0.12*	0.04*	-9.76**	0.16	3.74**	-0.09	-257.33
6	Kent X OL-125	9.09**	-1.52**	-0.55**	3.00**	1.28**	0.05	-1.71	-0.69**	-4.77**	0.03	-202.08
7	Kent X OL-9	10.72**	1.03*	-0.14*	-4.67**	1.99**	0.01	0.18	-0.34*	8.22**	0.24**	122.29
8	Kent X UPO-212	-16.95**	1.99*	0.35*	-6.25**	1.14	0.14**	0.90	0.16	1.01	-0.12	471.04
9	Kent X OL-1892	-13.91**	-1.85	0.11**	10.65**	-2.98**	-0.05**	0.53	0.21**	-11.94**	-.0.07	318.75
10	Kent X OL-1760	-6.95	-0.19	0.66**	1.12	-0.87*	-0.03	0.03	0.39**	1.57	-0.30**	-280.00
11	OL-1842 X OL-125	-13.98**	-7.32**	-0.35**	-9.40**	-3.95**	-0.06	6.18**	-0.46**	-17.37**	0.08	-322.41
12	OL-1842 X OL-9	-5.95	10.89**	0.46**	0.05	-1.70**	0.12**	9.44**	0.42**	19.62**	0.87**	401.95
13	OL-1842 X UPO-212	9.05**	4.31	0.52**	3.01**	2.00*	0.13**	1.44	0.25**	-7.91**	-0.12	354.04

14	OL-1842 X OL-1892	14.09**	1.35**	-0.09*	3.26**	2.21**	-0.08*	7.40**	-0.65**	4.09**	-.0.04	210.08
15	OL-1842 X OL-1760	-7.62	-4.23**	-0.18**	3.81**	0.88	-0.06**	1.65	-0.27**	-2.12	-0.38**	-313.66
16	OL-1866 X OL-125	-6.11**	-3.78**	-0.09*	1.13	-0.81*	-0.15**	-2.58**	-0.03	-4.17**	0.01	-400.08
17	OL-1866 X OL-9	9.84**	-3.24**	-0.27**	4.59**	1.39**	-0.06	-0.95	-0.15	-6.64**	0.24**	504.29
18	OL-1866 X UPO-212	6.52	2.50**	-0.01	-1.45**	0.87	-0.01	0.70	-0.27	3.81*	-0.16*	481.37
19	OL-1866 X OL-1892	4.12*	2.55**	0.82**	1.46**	-2.31	0.05**	3.00*	0.39**	12.19**	0.21*	249.08
20	OL-1866 X OL-1760	-7.48**	1.97	0.05	-2.74**	-0.44	0.04	0.73	-0.10	-6.39**	-0.25**	-284.66
21	OL-1869 X OL-125	-15.51**	1.88	0.29**	3.80**	-4.88*	0.10**	0.37	0.23**	10.95**	-0.28**	-201.08
22	OL-1869 X OL-9	10.11**	-1.08	-0.19**	6.59**	3.70**	0.07**	-2.35	-0.80**	13.62**	-0.34**	309.95
23	OL-1869 X UPO-212	-28.55**	9.51**	0.05**	1.48**	-1.12**	-0.04	4.97**	0.18**	-10.58**	-1.79**	222.04
24	OL-1869 X OL-1892	27.49**	-4.45**	-0.52**	-4.20**	0.68	-0.14**	-5.19**	-0.67**	-11.54**	0.87**	159.75
25	OL-1869 X OL-1760	-5.55**	0.30	-0.86**	-6.07**	-2.07**	-0.11	0.43	-0.81**	-4.45**	0.04	-310.66
26	OL-1766-1 X OL-125	13.76**	6.68**	0.09	0.46	2.05**	-0.21	2.21**	0.42	9.09**	-0.11	-359.08
27	OL-1766-1 X OL-9	14.72**	-0.11	0.01*	-1.44**	1.00**	-0.16*	-1.15	0.13	-9.57**	0.17	476.95
28	OL-1766-1 X UPO-212	-0.62	4.30	-0.44**	1.48**	-3.79*	-0.12*	1.17*	-0.54**	-6.45**	-1.32**	270.70
29	OL-1766-1 X OL-1892	-10.24**	-3.98**	0.65*	1.73*	-1.24**	0.04**	-0.19	0.29**	10.25**	-0.24**	261.75
30	OL-1766-1 X OL-1760	-6.62**	-2.00**	0.42**	-1.64**	-0.70	0.09	-5.03**	0.58**	-9.32**	0.50**	-240.33
31	OS-403 X OL-125	29.42**	5.21**	-0.80**	-0.20	2.91**	-0.02**	6.21**	-0.49**	4.09**	0.28**	2988.58
32	OS-403 X OL-9	-22.95**	0.13	1.34**	1.59**	-4.50**	0.11**	1.50	1.15*	0.75	-0.42**	2822.45
33	OS-403 X UPO-212	-3.61	-0.52	-0.39**	6.21*	-2.79**	-0.14**	-1.49	-0.16**	10.88**	0.29**	2300.89
34	OS-403 X OL-1892	-20.24**	-5.05**	-0.66**	-3.53**	-1.91**	-0.09**	-7.53**	-0.19**	-2.74**	-0.84**	2234.78
35	OS-403 X OL-1760	21.38**	6.37**	-0.48**	-1.07	2.29**	0.24**	4.30**	-0.39**	-1.99	-0.09	202.33
36	OS-405 X OL-125	-9.64**	2.75**	0.11**	0.13**	-1.61**	0.17**	1.88**	0.53**	-0.50	-0.11	-329.41
37	OS-405 X OL-9	-26.35**	-7.71**	-0.46**	-1.74**	-3.03**	-0.16**	-2.15**	-0.74**	-20.50**	-0.72**	100.62
38	OS -405 x UPO-212	27.31**	-8.96**	-0.30*	-2.45	0.67**	0.06**	-6.82**	0.06	1.61	0.57**	320.37
39	OS -405 X OL-1892	11.02**	3.41**	0.48**	-1.53**	2.55**	0.19**	5.80**	0.81**	16.32**	-1.24**	1493.08
40	OS-405 X OL-1760	6.65	3.50**	-0.43**	1.59**	-0.47	0.14**	3.30**	-0.16	11.07**	0.50**	-185.66
	SE	2.10	0.85	0.05	0.20	0.34	0.13	0.88	0.06	1.25	0.09	10.11

* , ** are level of significance at 5 % and 1% respectively.

Table 3: Estimates of General combining ability of the parents for various characters

Parents	No. of leaves	Leaf length (cm)	Leaf width (cm)	Internode length	No. of tillers	Stem girth (cm)	Flag leaf length (cm)	Flag leaf width (cm)	Plant height (cm)	No. of leaves/main tiller	Green fodder yield (g/plot)
Females											
OL-10	-26.93**	2.86**	-0.10**	-1.19**	-1.77**	-0.05**	2.72	-0.16*	6.43**	-0.41**	-422.25**
Kent	-3.80**	5.72**	0.04	2.54**	0.50*	-0.08**	4.92	0.14	2.36**	-0.28**	-392.92**
OL-1842	-6.80**	-5.08**	-0.34**	-1.72**	0.20	-0.06**	-3.28	-0.30**	-1.04	-0.38**	-287.58**
OL-1866	-1.27*	-1.68	0.22**	1.08**	0.07	-0.01	-2.21	0.58**	4.89**	-0.31**	-384.92**
OL-1869	14.80**	2.09**	0.13**	-1.26**	3.13**	0.06**	1.19	0.22**	-9.38**	0.19**	-222.25**
OL-1766-1	-9.47**	0.96*	-0.32*	1.41**	-1.67**	-0.11**	3.99	-0.05	-6.51**	-0.28**	-164.25**
OS-403	13.20**	-2.08**	-0.36**	-0.92**	0.67**	0.10**	-4.68	-0.33**	-3.17**	1.13**	1858.08**
OS-405	-2.73**	-4.21**	0.46**	0.08	-0.13**	0.11**	-1.68	0.47**	-5.57**	-1.18**	-183.92**
SE_F	1.05	1.43	0.24	0.28	1.20	0.32	0.34	0.31	0.63	0.05	5.06
SE_d	1.59	0.64	0.37	0.42	1.00	0.73	0.67	0.05	0.95	0.07	7.64
Males											
OL-125	-16.49**	-0.15**	0.24**	0.01	-0.42**	-0.02*	-0.48	0.22**	6.44**	-0.08*	707.42**
OL-9	-6.08**	1.74**	0.36**	1.88**	-0.90**	0.01	1.56**	0.14**	2.14**	-0.28**	-213.63**
UPO-212	-1.22	0.22	-0.22**	-0.42*	0.23	-0.06**	0.22	-0.06**	-3.00**	0.33**	-319.04**
OL-1892	0.84	-2.05**	-0.11	-0.33	-0.18	0.08**	-2.40**	-0.18**	-2.13**	0.04	-401.75**
OL-1760	2.55**	1.33**	-0.65**	-1.13**	1.30**	0.01	1.10**	-0.12**	-1.88**	0.49**	487.00**
SE_M	0.79	0.32	0.18	0.21	0.25	0.01	0.33	0.23	0.47	0.04	3.82
SE_d	1.26	0.50	0.19	0.34	0.22	0.04	0.43	0.02	0.65	0.06	6.04

*, ** are level of significance at 5 % and 1% respectively.

Table 4: Estimates of Commercial heterosis over check (OL-10) expressed in percentage for different characters

S no.	Hybrids	No. of leaves	Leaf length (cm)	Leaf width (cm)	Internode length (cm)	No. of tillers	Stem girth (cm)	Flag leaf length (cm)	Flag leaf width (cm)	Plant height (cm)	No. of leaves/ main tiller	Green fodder yield (g/plot)
1	OL-10 x OL-125	-30.1**	60.0**	4.0	10.0	-20.7**	-17.0**	49.6**	5.3	20.7**	-16.7**	-34.1**
2	OL-10XUPO-O9-2	-23.2**	65.0**	-9.01**	-16.7**	-10.0**	-21.5**	33.9**	-4.7	10.4**	-15.7**	-17.7**
3	OL-10 X UPO-212	4.9	55.0**	-10.5**	-20.2**	2.2	-20.6**	56.4**	-10.5**	3.4**	-16.0**	-4.9
4	OL-10 X OL-1892	-18.2**	70.0**	6.9*	-8.5*	-26.4**	7.4	47.7**	7.9	6.3**	-16.5**	-17.8**
5	OL-10 X OL-1760	9.6	56.0**	-16.3**	-20.7**	3.2	-3.9	46.8**	-9.3**	14.1**	-15.7**	7.4
6	Kent X OL-125	5.6	52.0**	-19.5**	11.8**	5.2	-6.8	44.1**	-19.5**	7.9**	-12.4**	-16.7**
7	Kent X OL-9	6.1	65.0**	4.6	-6.5*	9.7	-6.0	55.3**	2.3	16.9**	-15.3**	15.8**
8	Kent X UPO-212	-11.0**	69.0**	7.0	-14.9**	2.2	-3.9	46.4**	4.0	4.3	-17.7**	-22.6**
9	Kent X OL-1892	-26.4*	41.0**	6.6	28.7**	-12.3**	-9.4	49.0**	3.6	-6.7**	-14.6**	-5.4

10	Kent X OL-1760	13.3	33.0**	4.4	9.6	4.4	-10.4	42.4**	4.3	2.8	-15.1**	-66.2**
11	OL-1842 X OL-125	-20.0**	-19.0	-9.6**	-45.5**	-30.7**	-8.4	-11.4*	-26.7**	-22.8**	-16.3**	-58.9**
12	OL-1842 X OL-9	-25.6**	50.0**	20.9*	-4.8	-14.6**	10.1	44.5**	6.7	20.3**	-16.5**	7.4
13	OL-1842 X UPO-212	11.1	56.0**	0.0	3.2	6.7	-4.2	29.9**	6.6	-4.6*	-14.7**	59.8**
14	OL-1842 X OL-1892	20.7**	48.0**	-30.2**	6.0	11.0**	-3.2	30.9**	-36.6**	2.8*	-16.7**	60.3**
15	OL-1842 X OL-1760	12.8*	29.0**	-18.2**	-4.8	26.1**	-20.1**	61.4**	-11.0**	-4.8*	-12.7**	-6.1
16	OL-1866 X OL-125	-11.9*	26.0**	6.9*	7.0	-40.3**	-11.4	50.9**	7.7	10.7**	-16.4**	7.9
17	OL-1866 X OL-9	7.6	43.0**	6.9*	14.4**	6.2	-3.2	30.1**	5.9	8.4	-17.7**	38.7**
18	OL-1866 X UPO-212	4.0	44.0**	0.0	-26.3**	4.2	-9.4	45.1**	-3.4	19.3**	-13.7**	86.1**
19	OL-1866 X OL-1892	16.0*	59.0**	11.6**	4.8	-6.4	16.3**	46.3**	7.9	20.7**	-10.1	50.2**
20	OL-1866 X OL-1760	4.3	52.0**	-2.3	-18.0**	7.4	3.7	32.9**	-10.5**	5.5	-16.0**	70.0**
21	OL-1869 X OL-125	35.4*	67.0**	36.1**	-3.2	5.0	14.3**	53.8**	30.1**	16.0**	-12.1**	55.3**
22	OL-1869 X OL-9	40.2**	57.0**	6.9*	17.0**	26.0**	16.3**	44.7**	3.4	7.9**	-14.7**	45.3**
23	OL-1869 X UPO-212	5.3	74.0**	17.1**	-4.8	3.0	2.4	31.5**	20.4**	-15.2**	-15.9**	33.1**
24	OL-1869 X OL-1892	40.3**	77.0**	-19.6**	-27.9**	12.3**	-1.2	42.3**	-21.9**	-10.1**	-14.7**	16.7**
25	OL-1869 X OL-1760	60.0**	60.0**	-27.2**	-19.0**	1.7	5.5	23.5**	-16.6**	-21.1**	11.0	15.1**
26	OL-1766-1 X OL-125	4.5	65.0**	4.6	7.2	4.2	-4.8	57.3**	4.4	13.4**	-12.3**	-5.4
27	OL-1766-1 X OL-9	4.0	55.0**	8.0**	5.6	7.0	-4.4	40.7**	6.7	-14.6**	-16.1**	19.7**
28	OL-1766-1 X UPO-212	-9.1	55.0**	-29.9**	8.9	-23.1**	-10.6**	35.3**	-20.6**	-12.7**	-16.4**	-8.4
29	OL-1766-1 X OL-1892	-29.1**	35.0**	7.0	4.8	-20.2**	13.7**	26.3**	5.0	16.9**	-15.7**	49.8*
30	OL-1766-1 X OL-1760	9.0	46.0**	2.3	-11.7**	-4.2	1.4	37.4**	1.1	-14.3**	9.0	8.9
31	OS-403 X OL-125	73.2**	54.0**	-13.9**	-19.1*	11.2**	4.4	50.6**	-27.8**	6.1**	16.7**	1702.1**
32	OS-403 X OL-9	4.4	47.0**	27.5**	25.9**	-37.8**	20.0**	25.1**	30.5**	1.8	2.0	15.8*
33	OS-403 X UPO-212	90.2**	46.0**	-35.6**	-5.3	-14.6**	-19.4	32.0**	-29.6**	6.1**	16.3**	5.4
34	OS-403 X OL-1892	4.6	8.0	-20.9**	-30.3**	-19.1**	15.7**	-4.9	-20.9**	-16.6**	0.0	-20.1
35	OS-403 X OL-1760	38.3**	50.0**	-38.7**	-19.9**	30.3**	28.0**	32.9**	-18.7**	-20.0**	16.7**	1356.3**
36	OS-405 X OL-125	-20.0**	53.0**	27.9**	4.8	-37.7**	20.9**	40.7**	29.1**	2.9	-21.7**	43.1**
37	OS-405 X OL-9	-59.9**	21.0**	3.0	-7.5*	-21.0**	-3.2	18.8**	-3.4	-20.8**	-15.3**	-20.1**
38	OS-405 x UPO-212	32.3*	6.0	11.3**	-16.5*	4.2	34.3**	3.6	28.4**	-3.6	1.9	40.4**
39	OS-405 X OL-1892	12.7**	44.0**	35.9**	-13.3**	31.0*	25.8**	40.9**	2.7	4.9	-16.1**	60.5**
40	OS-405 X OL-1760	22.3*	36.0**	6.6	3.6	-5.4	0.9	34.7**	6.1	5.7	2.5	72.5**
	SEm±	4.4	2.7	1.9	2.8	2.6	2.3	2.4	2.9	2.1	2.0	47.0

** = significant at 5 level, * = significant at 1 level

CONCLUSION

The heterotic and combining ability analysis revealed that the genotype OS-403 had significant desirable gca values for five traits and was associated with five crosses that exhibited highest sca values. Likewise, OS-403 displayed maximum value of heterosis for three traits including green fodder yield. Another genotype OL-9 had significant desirable gca values for six traits and was associated with six crosses that exhibited highest sca values. OL-9 exhibited maximum value of heterosis for three traits.

Henceforth, the two genotypes OS-403 and OL-9 can be used as potential parents for combining desirable traits as well as enhancing the green fodder yield through heterosis breeding in future oat improvement programmes.

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