Scaling and joint scaling test for quantitative traits of generation mean analysis in sesame (*Sesamum indicum* L.)

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ABSTRACT

Gene effects for important quantitative traits of five crosses of sesame (*Sesamum indicum* L.) were estimated by partitioning the means and variances of means of six basic generations from each cross into their genetic components to assess the gene action governing the inheritance of traits. The additive, dominance and digenic non-allelic gene interactions were observed to govern most of the yield traits. The non-additive gene effects were more pronounced than additive ones for most of the traits. The A, B, C and D scales showed highly significant values for all the traits and crosses studied and departure from zero indicated the presence of epistasis. But, these tests verify only the presence of epistasis but do not provide the kind of gene action. This indicates the inadequacy of scaling and joint scaling test and presence of non allelic interactions. The next possibility is to include the effect of epistasis which can be estimated as additive x additive, additive x dominance and dominance x dominance gene effects in the inheritance of the characters.

Keywords: GMA, Joint scaling test, Scaling test, *Sesamum indicum*

Sesame (*Sesamum indicum* L.) is one of the most ancient oilseed crops known and used by man. The genus Sesamum, which belongs to the family Pedaliaceae, has about 36 species, most of which occur in tropical Africa although some wild species also occur in the Indian subcontinent (Nayar and Mehra, 1970). Both India and China are important centres of diversity of cultivated sesame.

Average yields in India are extremely low (0.25 t/ha); in China they are somewhat higher (0.67 t/ha). From an agronomic perspective, there are substantial problems associated with the crop. It is indeterminate with flowers continuing to be produced while the first pods are maturing, the pods are dehiscent and, at maturity, large numbers of seeds are lost before harvest. Production levels are extremely variable, depending on a wide range of environmental factors. A number of pests, diseases and physical factors have substantial adverse effects on yields. In India these include phyllody and resistance to seedling diseases such as downy mildew.

Once the desirable parents and F_1s are identified through combining ability and heterosis, it is necessary to test the presence of additive or dominance or epistasis effect of the genes involved in superior cross combinations. In this area scaling and joint scaling test in sesame very little work has been done in India and abroad. Hence, the present investigation was formulated to find out information on additive, dominance and epistasis effects in five promising hybrids by using scaling and joint scaling test in sesame.

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MATERIALS AND METHODS

A study was undertaken to evaluate 16 sesame cultivars (IS 1547 A, KKS-98049, PKDS-62, SI-7818, JCS-720, JCS-724, KMR-108, KMR-24, S-0018, CST 2001-5, KMS 5-396, JCS-507, IS 562 B, SI-3171, KMR-78 and TKG-22) collected from different agro morphological regions, India. These selected parents were crossed in L x T fashion to generate 60 hybrids in rainy season, 2008. These 60 crosses along with their parents and checks were evaluated in winter season, 2008-09. From the above 60 crosses based on general combining ability (*gca*), specific combining ability (*sca*) and heterosis effect five promising crosses were selected and back crosses were made and also F_1s are selfed to produce F_2 during rainy season, 2009. All the six populations (P_1, P_2, F_1, F_2, BC_1 and BC_2) were raised in randomized block design with three replications in college farm, college of agriculture, Rajendranagar, Hyderabad during rainy season, 2010.

The experiments involved the six basic generations (the P_1 and P_2 parent cultivars, the F_1 and F_2 first and second filial generations, and the BC_1 and BC_2 first and second back crosses) of five combinations of the parental cultivars, these combinations being KMR-108 x JCS-507, KKS-98049 x IS 562 B, S-0018 x SI-3171, KKS-98049 x TKG-22 and CST 2001-5 x KMS 5-396. The segregating and non-segregating parental populations were cultivated in a randomized block design with three replications at the Agricultural College farm, Rajendranagar, Hyderabad, India. We used the parents of the respective crosses as the male parent and the F_1 generation as the female parent and effected back crosses to produce the B_1 (F_1 back crossed to P_1) and B_2 (F_1 back crossed to P_2) generations and the F_1 hybrids were selfed to obtain F_2 seeds. All these generations were produced during two cropping seasons and, as such, all the six generations had to be grown together during the same cropping season. The row-length was always five meters but the number of rows varied as follows: three rows, for the non-segregating P_1, $P_2$and F_1; 40 rows for the F_2; and 20 rows for the BC_1 and BC_2 generations. Since, the non-segregating generations represent the homogeneous population while the segregating generations represent the heterogeneous population the sample size (i.e., number of plants analyzed) varied as follows: 30 plants for the P_1, P_2 and F_1 generations, 400 plants for the F_2 generations and 200 plants in the BC_1 and BC_2 generations. The recommended agronomic practices were followed to raise healthy crop. The traits assessed were days to 50% flowering, number of days to maturity, plant height (cm), number of primaries/plant, number of capsules/plant, capsule length (cm), number of seeds/capsule, weight of 1000 seeds (g), seed yield/plant (g) and oil content (%).

Scaling test: To predict genetically control of traits in the beginning only additive [d] and dominance [h] effects are assumed to be present. The means of the different generations were utilized for obtaining the various genetic effects. The data were first tested to fit in simple additive-dominance model and presence of epistasis. The adequacy of simple additive-dominance model was tested by using A, B, C and D scales their variances, standard errors and 't' test were calculated by using the following formulae.

Scales	Variances	Standard errors	't' test
Scale A= $2\overline{B}_1 - \overline{P}_1 - \overline{F}_1 = 0$	$V_A = 4V_{(B1)} + V_{(B1)} + V_{(F1)} + V_{(P1)}$	SE of A= $\sqrt{VA}$	A= A/ $\sqrt{VA}$
Scale B = $2\overline{B}_2 - \overline{P}_2 - \overline{F}_2 = 0$ = 0	$V_B = 4V_{(B2)} + V_{(F1)} + V_{(F2)}$	SE of B= $\sqrt{VB}$	B= B/ $\sqrt{VB}$
Scale C= $4\overline{F}_2 - 2\overline{F}_1 - \overline{P}_1 - \overline{P}_2 = 0$ = 0	$V_C = 16V_{(F2)} + 4V_{(F1)} + V_{(P1)} + V_{(P2)}$	SE of C= $\sqrt{VC}$	C= C/ $\sqrt{VC}$
Scale D = $2\overline{F}_2 - \overline{B}_1 - \overline{B}_2 = 0$	$V_D = 4V_{(F2)} + V_{(B1)} + V_{(B2)}$	SE of D= $\sqrt{VD}$	D= D/ $\sqrt{VD}$

Where, P_1, P_2, F_1, F_2, B_1 and B_2 are the means of different generations over replications. The variances (VA, VB, VC and VD) of the scales A, B, C and D were obtained as the square root of VA, VB, VC and VD, respectively. The significance of the deviations of the scales from zero was tested using their standard errors. The significance of the scales A, B, C and D was determined by comparing the observed and expected 't' values at 5 and 1% level of significance. When any one of the four scales was found to deviate significantly from zero the additive - dominance model was considered inadequate. In such case, the joint scale test was employed (Cavalli, 1952).

Joint scaling test: Three parameters *viz*., m, d and h defining the additive-dominance model was estimated using weighted least square (Mather and Jinks, 1982). This model provides σ^2 test for the goodness of fit of the model (Kearsey and Pooni, 1996). From these estimated parameters, the expected generation means were calculated as follows:

$P_1 = m - d$	$F_2 = m + (1/2)h$
$P_2 = m + [d]$	$B_1 = m - (1/2)d + (1/2)h$
$F_1 = m + [h]$	$B_2 = m + (1/2)d + (1/2)h$

All the yield and yield contributing traits were analyzed statistically and tested for significance. The significance of the joint scaling test was determined by the using σ^2 test and compared observed and expected 't' values at 5 and 1% level of significance. In instances where the A, B, C and D values and σ^2 test significantly deviated from zero in the joint scaling test of simple additive-dominance model, digenic interaction was assumed. Statistical analysis for scaling test, joint scaling test and σ^2 test were carried out by using advanced biometrical Indostat statistical package, Hyderabad, India.

RESULTS AND DISCUSSION

The scaling tests were applied to the data to detect the presence or absence of non-allelic interactions. The estimates of genetic parameters m, [d] and [h] were obtained for all the 11 traits in five crosses were presented in table 1.The results of the scaling tests in five hybrids showed significant values of A, B, C and D scales for all the traits under study. Majority of the hybrids coupled with traits showed deviation from zero indicated that simple additive-dominance model was inadequate. The joint scaling test were analyzed and found that mean, additive [d] and dominance [h] gene effects coupled with σ^2 test was highly significant for all the traits, and values deviated from zero.

For days to 50% flowering traits, Scale 'A' was observed to be significant for all the crosses, except cross 5 (CST 2001-5 x KMS 5-396). Scale 'B' was found significant for all the five crosses, indicating the presence of all three types of non-allelic gene interactions *viz*., additive x additive [I], additive x dominance [j] and dominance x dominance [l] for theses crosses. Scale 'C' was observed to be significant for all crosses except in cross 2 i.e., KKS-98049 x IS 562 B. The chi-square value for additive-dominance model was significant for all crosses which indicated the presence of epistasis and hence it was detected for these crosses. The three parameter model showed that the values of [d] were positively significant for cross 2, 3 and 5. Thus there was preponderance of additive gene effects for these traits. The dominance effects were negatively significant in three crosses and positively significant in one cross i.e., CST 2001-5 x KMS 5-396.For days to maturity trait, scale 'A' was found to be significant for all the crosses. Scale 'B' was non significant for cross I. Thus, all the three types of nonallelic gene interactions were present for this cross. The scale 'C' and 'D' was negatively significant for all the crosses studied, which revealed the non-allelic gene interactions. The chi-square values for additive-dominance model were significant for all crosses, this indicated the presence of epistasis. The genetic variation was sufficiently explained using joint scaling tests, which showed that the values of [d] were significant for all the crosses studied.

For plant height trait, scale 'A' was positively significant in cross 1, 4 and 5. Scale B was significant in four crosses. The scales C and D were significant in all crosses studied, which indicated the presence of non-allelic gene interactions. The additive genetic effect was positively significant in all crosses, indicating the predominance of additive gene effects for this trait. The dominance [h] gene effect was negatively significant in cross 2, 3, and 4. The chi-square values for additive-dominance model was significant in all crosses, indicating presence of epistasis for all crosses.

In case of 'capsule length' trait, the scale 'A' was found to be non-significant for all the crosses except cross 5 (CST 2001-5 x KMS 5-396). The scale 'B' was found to be non significant for all five crosses. The scale 'C' was found significant for cross 2 and 4. Thus, it signifies the presence of non-allelic gene interactions. The chi-square values for capsule length were found to be significant for all the crosses. For this cross, the three parameter model was considered adequate as epistasis was observed to be absent and only predominant role of dominance gene action was found to be governing inheritance of this trait as shown by significant expression of [h]. The trait, capsules per plant, scale 'A' and 'B' was found to be significant for all crosses. indicating the preponderance of all the three types of non-allelic gene interactions. The scale 'C' was found significant for all the crosses except cross 1. The chi-square values for additive-dominance model were significant for all crosses, this indicated the presence of epistasis. The mean and additive gene effects was significant and positive in all crosses for number of capsules/plant.

Scale 'A' was negatively significant in all crosses for the trait 1000 seed weight. Negatively significant in cross 1, 2 and 3. The scale C was significant in all five crosses, indicating the presence of non-allelic gene interactions. The σ^2 values were significant for all the crosses. The additive and dominance gene effects were negatively significant coupled with significant values of mean.

Seed yield/plant trait, the scale 'A' for this trait was non-significant for cross 1 and rest of the crosses were significant. The values of scale 'B' differed significantly from zero for all crosses. The significance of scales 'A' and 'B' revealed the presence of all three types of non-allelic gene interactions for yield/plant. The scale 'C' was significant for all crosses. The chi-square values for this trait were significant for all the crosses. Thus, the presence of epistasis was confirmed for these crosses. The [d] type of gene effects were significant which signifies that their inheritance was under the control of additive gene effects.

In case of 'oil content' trait, scales A, B and C scales were significant which indicated the presence of epistasis. The additive and dominance gene effects were significant in all the crosses, respectively. The σ^2 values were significant for five crosses studied coupled with significant values of mean. Number of effective primaries/plant showed positive and significant in A, B, C and D scales, mean, additive, dominance gene effects in five crosses. In number of seeds/capsule trait, scales C and D, additive and dominance effect were negatively significant coupled with significant values of mean and σ^2 test showed significance difference in all the crosses, which showed the presence of epistasis.

In the present investigation sig values of A, B, C and D scales , mean , [d] , [h], gene effect and σ^2 test showed that additive and dominance effect are not adequate to predict the performance of F_2, B_1 and B_2 generations and thus do not represent the true properties of genes controlling these traits. When any one of the four scales and [d], [h] and σ^2 test are found to deviate significantly from zero the simple additive dominance model was inadequate for determining the gene action and indicated the role of non-allelic interaction (epistasis). Report on combining ability and heterosis study in indigenous sesame lines showed that the magnitude of *sca* variance was greater than *gca* for all the 11 characters which indicates predominance of non-additive gene action (Sumathi and Muralidharan, 2008; Toprope, 2008). Further, it is confirmed by the ratio of *gca* variance component to total variance which was less than unity for all the traits studied (Table 2).

Table 1 Scaling and joint scaling tests for 11 traits in sesame

Hybrid	Scaling test				Joint scaling test			
	A	B	C	D	m	(d)	(h)	x^2
				Days to 50% flowering				
KMR-108 x JCS-507	-2.00** ± 0.27	-0.67*± 0.31	8.00**± 0.43	5.33 ** ± 0.13	40.14** ±0.10	-3.66** ± 0.08	0.29 ± 0.20 NS	1861.71**
KKS-98049 x IS 562 B	1.00* ± 0.41	-4.00** ± 0.49	-0.33 ± 0.78 NS	1.33** ± 0.20	40.44** ± 0.14	0.63** ± 0.10	-3.06** ± 0.29	135.96**
S-0018 x SI-3171	1.66**± 0.315	-0.66** ± 0.32	-2.33 **± 0.571	-1.66** ± 0.173	38.91** ± 0.10	1.66** ± 0.08	-2.93** ± 0.21	118.84**
KKS-98049 x TKG-22	1.00 * ± 0.41	3.00 ** ± 0.37	-18.67 ** ± 0.82	-11.33 ** ± 0.22	40.06** ± 0.11	-1.04** ± 0.07	-1.59** ± 0.22	2741.65**
CST 2001-5 x KMS 5-396	0.00± 0.27 NS	-1.67** ± 0.41	-7.00** ± 0.62	-2.67** ± 0.15	38.74**± 0.11	1.92** ± 0.07	0.59** ± 0.22	329.79**
				Days to maturity				
KMR-108 x JCS-507	-3.00** ± 0.35	-0.67± 0.44 NS	-4.33**± 0.62	-0.33 *± 0.13	95.70** ± 0.15	1.99** ± 0.09	-1.91** ± 0.30	86.15**
KKS-98049 x IS 562 B	0.67 *± 0.32	-1.00**± 0.27	-5.67**± 0.54	-2.67**± 0.17	96.67** ± 0.08	-3.34** ± 0.07	-3.66**± 0.17	269.50**
S-0018 x SI-3171	-2.66** ± 0.384	4.33 **± 0.30	-7.00**± 0.62	-4.33**± 0.17	94.68** ± 0.11	0.58** ± 0.08	1.74** ± 0.21	1354.93**
KKS-98049 x TKG-22	4.33**± 0.27	2.00**± 0.27	-3.00**± 0.54	-4.67**± 0.15	94.77** ± 0.08	-0.50** ± 0.06	1.82** ± 0.18	1074.48**
CST 2001-5 x KMS 5-396	3.67 **± 0.33	3.33 **± 0.33	3.00 **± 0.60	-2.00 **± 0.15	94.44**± 0.13	0.63** ± 0.06	0.44 ± 0.06	289.54**
				Plant height (cm)				
KMR-108 x JCS-507	9.48 **± 2.08	-8.78 **± 1.74	20.19 **± 2.47	9-74*± 0.86	139.75** ±0.61	5.70** ±0.58	0.12 ±1.21	292.94**
KKS-98049 x IS 562 B	1.55 ± 2.03 NS	0.001 ± 1.65 NS	14.28 **± 3.24	6.37**± 1.12	143.93** ±0.59	3.74** ±0.49	-6.06** ±1.18	38.83**
S-0018 x SI-3171	3.11± 1.65NS	15.08**± 1.36	-47.57**± 2.10	-32.88**± 0.84	131.45** ± 0.49	2.20 ** ± 0.47	-13.10 **± 0.93	1782.60**
KKS-98049 x TKG-22	29.13**± 2.00	8.73**± 1.50	8.62**± 2.42	-14.62**±0.92	136.10** ± 0.54	16.10** ± 0.50	-7.86** ± 1.05	313.24**
CST 2001-5 x KMS 5-396	22.83 **± 1.81	-6.30**± 1.62	-35.19**±2.96	-25.86**± 0.75	132.54** ± 0.60	6.66** ± 0.41	-2.25± 1.21NS	1566.12**
				No. of effective primaries/plant				
KMR-108 x JCS-507	-1.47**± 0.32	1.33**± 0.23	5.33**± 0.45	2.73 **± 0.11	7.06** ± 0.10	-0.81** ± 0.07	2.64** ± 0.20	648.40**
KKS-98049 x IS 562 B	1.03**± 0.22	1.30**± 0.18	3.53**± 0.29	0.60 **± 0.10	7.48** ± 0.06	0.02 ± 0.05NS	1.98** ± 0.13	177.72**
S-0018 x SI-3171	1.53**± 0.15	-0.56**± 0.13	0.50*± 0.23	-0.23**± 0.06	7.11** ± 0.05	0.56 ** ± 0.04	2.30 ** ± 0.10	193.95**
KKS-98049 x TKG-22	0.77**± 0.12	-0.40*± 0.18	2.50**± 2.26	1.07**± 0.06	6.95** ± 0.06	0.54** ± 0.03	0.80** ± 0.11	366.71**
CST 2001-5 x KMS 5-396	1.67**± 0.12	0.20 ± 0.11 NS	0.80 **± 0.18	-0.53 **± 0.07	8.32** ± 0.03	0.36** ± 0.03	-1.89** ± 0.07	283.34**

Table 1 (Contd....)

Hybrid	Scaling test				Joint scaling test			
	A	B	C	D	m	(d)	(h)	x^2
				No. of effective capsules/plant				
KMR-108 x JCS-507	-29.50*± 11.57	13.00**± 2.61	8.50± 12.19 NS	12.50 **± 1.02	63.11** ± 0.25	-5.75** ± 0.19	-5.76** ± 0.48	131.33**
KKS-98049 x IS 562 B	7.10 **± 2.69	-31.57**± 2.56	86.93**± 5.14	55.70**± 1.08	94.98** ± 0.77	2.38** ± 0.43	23.13** ± 1.58	3061.55**
S-0018 x SI-3171	14.43**± 2.64	30.43**± 1.96	28.40**± 3.76	-8.23**± 0.91	109.54** ± 0.78	-18.38** ± 0.55	30.31** ± 1.56	259.66**
KKS-98049 x TKG-22	64.93**± 2.11	42.33**± 2.32	68.27**± 3.27	-19.50**± 0.91	114.27**±0.76	-14.10** ± 0.55	6.83** ± 1.47	1167.43**
CST 2001-5 x KMS 5-396	57.30**± 2.57	13.90** ± 1.76	20.60 **± 3.53	-25.30**± 1.07	104.01**± 0.60	7.99** ± 0.57	2.51* ± 1.18	825.00**
				Capsule length (cm)				
KMR-108 x JCS-507	0.08± 0.04 NS	-0.03± 0.04 NS	0.10± 0.07 NS	0.03*± 0.01	2.35** ±0.01	-0.01**± 0.00	0.23** ±0.02	15.03**
KKS-98049 x IS 562 B	0.06 ± 0.04 NS	-0.02 ± 0.08 NS	-0.56** ± 0.10	-0.30 **± 0.01	2.75** ±0.01	-0.20** ±0.00	-0.44** ±0.02	556.48**
S-0018 x SI-3171	-0.00± 0.11NS	-0.14± 0.08NS	0.35± 0.18NS	0.25**± 0.28	2.64** ±0.01	0.00 ±0.01	-0.02 ±0.03	86.92**
KKS-98049 x TKG-22	0.03± 0.04 NS	0.08± 0.06NS	-0.23** ± 0.07	-0.17**± 0.03	2.63**± 0.00	-0.07** ±0.01	-0.12**± 0.01	78.67**
CST 2001-5 x KMS 5-396	-0.18*± 0.08	-0.12 ±0.10NS	-0.09 ± 0.17NS	0.10**± 0.02	2.71** ±0.01	0.01± 0.01	-0.26**± 0.03	25.19**
				No. of seeds/capsule				
KMR-108 x JCS-507	-0.42± 0.90 NS	6.67**± 0.61	2.70 *± 1.14	-1.78** ± 0.29	63.11**± 0.24	-5.74**± 0.19	-5.75** ±0.47	131.32**
KKS-98049 x IS 562 B	-1.56 ± 1.09 NS	3.65 **± 1.31	-18.55**± 1.25	-10.32 **± 0.76	57.84** ± 0.29	-2.42** ± 0.31	-13.75** ± 0.55	345.93**
S-0018 x SI-3171	7.96**± 1.18	-7.62 **± 0.96	-20.27 **± 1.88	-10.30**± 0.47	67.32** ± 0.40	12.61** ± 0.24	-10.28** ± 0.79	689.53**
KKS-98049 x TKG-22	3.96**± 1.01	2.05 ± 1.07NS	-35.99**± 1.91	-20.10**± 0.58	64.86** ± 0.35	-7.38** ± 0.26	-7.44** ± 0.71	1313.35**
CST 2001-5 x KMS 5-396	0.42± 0.69 NS	-13.24 **± 1.02	-19.64**± 1.44	-3.41**± 0.41	64.83**± 0.30	3.64** ± 0.22	-5.07** ± 0.58	355.74**
				1000 seed weight				
KMR-108 x JCS-507	-0.19**± 0.03	-0.21**± 0.03	0.41**± 0.06	0.40**± 0.01	2.46** ±0.01	-0.02** ± 0.005	0.06**± 0.02	1084.09**
KKS-98049 x IS 562 B	-0.13**± 0.14	-0.26**± 0.07	-0.37**± 0.08	0.01± 0.02 NS	2.65**± 0.01	0.01 ±0.01	-0.25** ± 0.02	31.94**
S-0018 x SI-3171	-0.61**± 0.05	-0.03± 0.06NS	-0.30**± 0.09	0.17**± 0.02	2.70** ±0.02	-0.17**± 0.00	-0.29**± 0.03	212.61**
KKS-98049 x TKG-22	0.38**± 0.03	0.06± 0.04 NS	-0.48**±0.05	-0.46**± 0.02	2.75**±0.01	-0.08** ± 0.01	-0.26** ± 0.02	407.05**
CST 2001-5 x KMS 5-396	-0.30**± 0.06	-0.50**± 0.07	1.59**± 0.15	1.20**± 0.05	2.75** ± 0.02	0.20** ± 0.01	0.48** ± 0.03	684.34 **

Table 1 (Contd...)

Hybrid	Scaling test				Joint scaling test			
	A	B	C	D	m	(d)	(h)	x^2
				Oil content (%)				
KMR-108 x JCS-507	2.80**± 0.12	0.77**± 0.11	-1.37**± 0.20	-2.47**± 0.06	43.73** ± 0.03	1.49** ± 0.03	-2.84** ± 0.07	1324.16**
KKS-98049 x IS 562 B	3.07 **± 0.16	2.57 **± 0.13	5.70 **± 0.21	0.03 ± 0.07 NS	39.76** ± 0.05	5.40** ± 0.04	1.40** ± 0.09	773.78 **
S-0018 x SI-3171	0.50**± 0.13	1.50**± 0.14	2.47**± 0.23	0.23**± 0.05	43.64** ± 0.04	-5.27** ± 0.03	-0.86** ± 0.08	170.43**
KKS-98049 x TKG-22	0.67**± 0.11	2.50** ± 0.12	-6.03**± 0.17	-4.60**± 0.03	38.31** ± 0.04	5.74** ± 0.02	0.93** ± 0.08	20696.17**
CST 2001-5 x KMS 5-396	60**± 0.15	2.20**± 0.15	-1.07**± 0.28	-2.43**± 0.05	45.38** ± 0.03	-0.83** ± 0.03	-4.27** ± 0.07	2081.11**
				Seed yield/plant (g)				
KMR-108 x JCS-507	-0.75± 0.42NS	-2.18**± 0.43	-5.33**± 0.59	-1.20**± 0.15	12.52** ±0.14	5.53** ± 0.12	-0.65*± 0.28	403.41**
KKS-98049 x IS 562 B	-4.03 **± 0.41	0.86 *± 0.39	5.49 **± 0.42	4.33 **± 0.23	11.68**± 0.09	0.62** ±0.11	-0.10± 0.16	827.83**
S-0018 x SI-3171	-2.35**± 4.33	1.42**± 0.33	-8.47**± 0.64	-3.77**± 0.19	10.64**± 0.13	-1.03**± 0.09	0.30 ±0.25	459.86**
KKS-98049 x TKG-22	7.13**± 0.40	3.64** ± 0.45	4.29**± 0.60	-3.24**± 0.17	14.04** ± 0.15	0.94** ± 0.13	-2.63** ± 0.28	502.63**
CST 2001-5 x KMS 5-396	-6.89**± 0.35	0.50± 0.36 NS	11.75**± 0.66	9.07** ± 0.23	12.56** ± 0.10	1.12** ± 0.08	4.05** ± 0.21	1977.85**
				Chlorophyll content SPAD units				
KMR-108 x JCS-507	6.50**± 0.87	3.99**± 0.55	14.10**± 0.88	1.80**± 0.37	42.03** ± 0.21	3.31** ± 0.22	7.02** ± 0.39	30.22**
KKS-98049 x IS 562 B	-3.41**± 0.76	4.70**± 0.88	-19.01 **± 1.46	-10.15 **± 0.26	39.86** ± 0.30	1.06** ± 0.15	-3.66** ± 0.60	1632.39**
S-0018 x SI-3171	-4.09**± 0.69	0.44± 0.60NS	-23.32**± 1.17	-9.84**± 0.44	40.31** ±0.22	-0.69** ± 0.18	3.71* ± 0.43	590.01**
KKS-98049 x TKG-22	-0.64± 0.55 NS	-2.86**± 0.44	0.92±0.71 NS	2.21**± 0.23	41.80**± 0.16	2.38** ± 0.14	4.57** ± 0.31	96.42**
CST 2001-5 x KMS 5-396	7.83**± 0.79	0.85± 0.74 NS	5.98**± 1.46	-1.35**± 0.36	41.68** ± 0.29	4.46** ± 0.13	3.84** ± 0.58	124.14**

Table 2 Estimates of general and specific combining ability variances, proportionate gene action and degree of dominance in sesame

Source	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of effective primaries/plant	No. of effective capsules/plant	Capsule length (cm)	No. of seeds/ capsule	1000-seed weight (g)	Seed yield / plant (g)	Oil content (%)	Chlorophyll content (SPAD Units)
σ^2 *gca*	0.0509	0.0221	1.0482	0.0012	1.0491	0.0000	-0.0405	0.0004	-0.0003	0.0102	0.0526
σ^2 *sca*	1.0232	6.0588	68.8840	2.4052	481.6299	0.0154	40.7551	0.0695	5.0707	7.3930	10.3165
σ^2 *gca* / σ^2 *sca*	0.0497	0.0036	0.0152	0.0004	0.0021	0.0000	-0.0009	0.0057	-0.0001	0.0013	0.0050
Degree of dominance $\sqrt{\sigma^2 sca / 2\sigma^2 gca}$	3.1712	11.7017	5.7322	32.2941	15.1510	14.8786	22.4294	9.0792	87.3737	19.0279	9.9058

In conclusion, the A, B, C and D scales and σ^2 test showed highly sig values and departure from zero for more of these values indicated presence of epistasis. But the tests used in the present study helps in only to verify the involvement of epistasis and do not provide the estimate of any kind of gene action. The inadequacy of scaling and joint scaling test indicated the presence of non allelic interactions and involvement of all three kinds of gene effects *viz*., additive, dominance and epistasis and their interactions and suggested the application of higher order interaction model. The next possibility is to include the effect of epistasis which can be estimated as additive x additive, dominance x dominance and additive x dominance gene effects in the inheritance of the characters. Hence, further study was envisaged to involve higher order interaction model to estimate the gene and their interaction effect in superior cross combination.

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In vitro pollen germination and staining methods for pollen viability assessment in sunflower (*Helianthus annuus* L.)

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ABSTRACT

Pollen viability in 207 sunflower (*Helianthus annuus* L.) genotypes were assessed using staining technique and germination method. Pollen viability by staining technique varied from 90.42 to 98.99 % and by germination method it ranged from 27.06 to 79.59 %. Six genotypes *viz*., GP-808, GP-6-794, GP-6-854, GP-6-906, GP-6-1477 and GP-6-83 recorded higher germination per cent ranging from 75 to 79 and pollen tube length ranging from 42.12 to 149.10 µm, indicating that both pollen germination and staining methods can be employed to assess the viability in sunflower to identify highly competitive pollen genotypes.

Keywords: Pollen germination, Pollen tube length, Pollen viability

Sunflower (*Helianthus annuus* L.) is a cross pollinated oilseed crop. Pollen grains transmit male genetic material to ovules to develop into seeds. Unlike varietal seed production, hybrid seed production involves effective crossing of a sterile parent with a selected fertile restorer. Viable pollen play a vital role in deciding the success of fertilization and seed set. Pollen source and maternal influence assumes greater importance in determining seed as well as oil yield (Shanker goud and Giriraj, 1999). Pollen fertility, which can be determined using pollen viability tests *in vitro* is very important in fruit and seed production in flowering plants (Rigamoto and Tyagi, 2002). Therefore, pollen fertility knowledge for any plant species is essential for plant breeders and commercial growers.

MATERIALS AND METHODS

An experiment was conducted at Main Agricultural Research Station, Raichur during winter season of 2011 including 207 genotypes for pollen viability studies. Pollen viability was estimated by using staining technique and germination method. In staining technique, pollen grains were placed on a glass slide containing 2-3 drops of acetocarmine stain (2 %). They were mixed using a clean needle and left for 2-3 minutes for proper staining. The cover slip was then placed on glass slide and examined under projection microscope for staining pattern. The pollen grains which stained red, considered as viable (fertile) and unstained were non-viable (non fertile). Viability percentage was calculated from the mean of fifteen microscopic fields each of two microslides.

Pollen germination and pollen tube length was assessed using the pollen germination media developed by Keshavamurthy *et al.* (1994). The percentage germinated pollen and the pollen tube length were assessed 10 minutes after pollination. A total of two microscopic slides were observed for each pollen parent and from each slide fifteen random microscopic fields were observed for recording the per cent pollen germination and pollen tube length. The data were subjected to statistical analysis by using completely randomised design (Panse and Sukhatme, 1985).

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RESULTS AND DISCUSSION

Analysis of variance indicated significant difference between the genotypes for per cent pollen viability, pollen germination and pollen tube length. The per cent stained pollen indicates per cent fertile pollen and it differed significantly in 33 genotypes. Stained pollen per cent ranged from 90.42 to 98.98 and with a mean of 93.67% significantly higher stained pollen observed in 22 genotypes (>95%). Similar findings with more than 90% pollen fertility with stained pollen were reported Terzic *et al.* (2006) and Rodriguez *et al.* (2007). Shanna *et al.* (2000) and Vischi *et al.* (2002) reported 80% to 100%. Determination of pollen viability with acetocarmine stain is not considered as very accurate (Shivanna *et al*., 1976), however, gives range of indication of pollen viability.

In vitro pollen germination on the artificial pollen germination media gives realistic information on pollen germination and pollen tube growth. The per cent pollen germination ranged from 27.06 to 79.59 and differed significantly in 85 genotypes. The overall mean was 50.84%. Six genotypes *viz*., GP-808 (79.57%), GP-6-794 (78.37%), GP-6-854 (77.87%), GP-6-906 (76.09%), GP-6-1477 (76.03%) and GP-6-83 (75.37%) recorded more than 75% pollen germination. Pollen germination ranging from 48-86% (Shanker goud and Giriraj, 1999), 12-52% (Todorova *et al.,* 2004) and 90% (Keshavamurthy *et al.,* 1994) was also reported.

In vitro pollen germination, a quantitative measure, can also be influenced by temperature, hydration, density of pollen, humidity, genotypes and the presence or absence of a number of ions (Gilbert and Punter, 1991 and Heslop-Harrison and Heslop-Harrison, 1992).

In vitro germinability and subsequent tube growth are found to be best indicators for pollen viability tests. Pollen tube length ranged from 42.12 to 149.10 µm, 95 genotypes differed significantly for mean pollen tube length. Overall mean was 85.86 µm. Out of 207 genotypes, 48 genotypes exhibited significantly higher pollen tube length of more than 100 µm. The highest pollen tube length was noticed in seven genotypes (>145 µm) *viz*., GP-6-952(149.10 µm), GP-6-966 (149 µm), GP-6-1001(148.10 µm), GP-6-561 (146.76 µm), GP-6-1254 (146.76 µm), GP-1000 (146.04 µm) and GP-6-276 (145.24 µm). The mean pollen tube length of more than 50 µm was also reported by Shanker goud and Giriraj (1999) and 14.4 µm by Keshavamurthy *et al.* (1994).

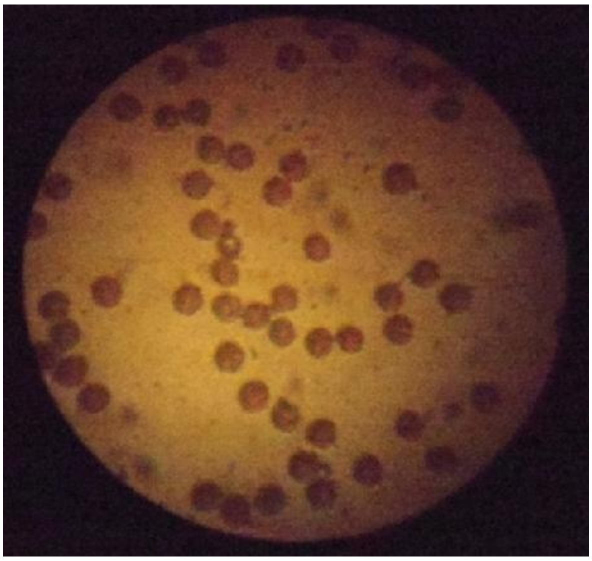

Fig. 1. GK-2002 (98.98%) with highest stained pollens

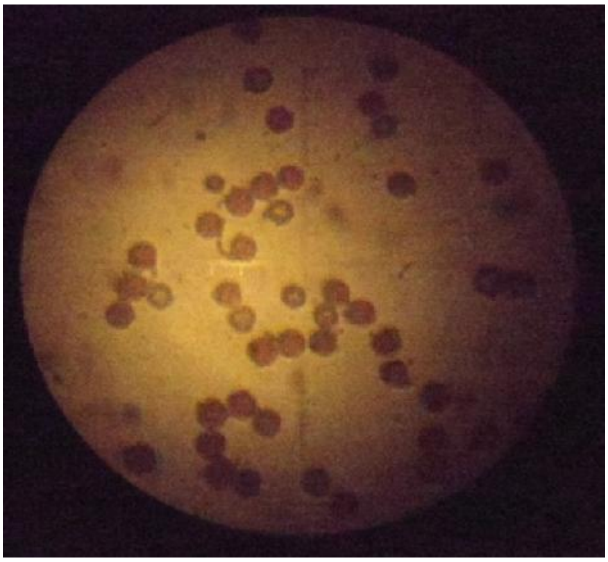

Fig. 2. GP-6-1616 (9.58%) with highest unstained pollens

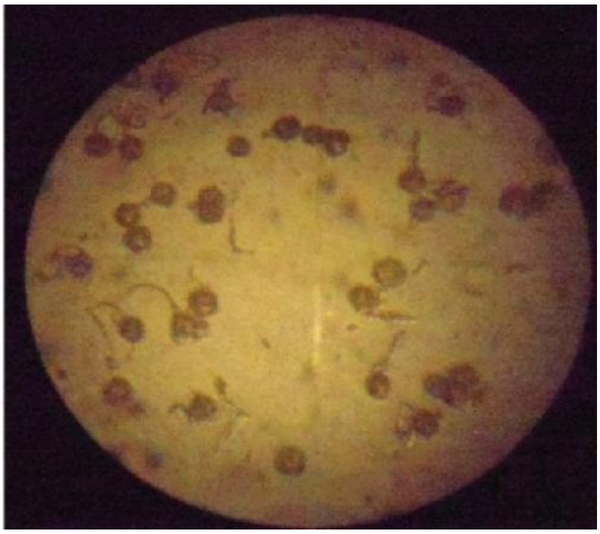

Fig. 3. Pollen germination in GP-808 (79.57%)

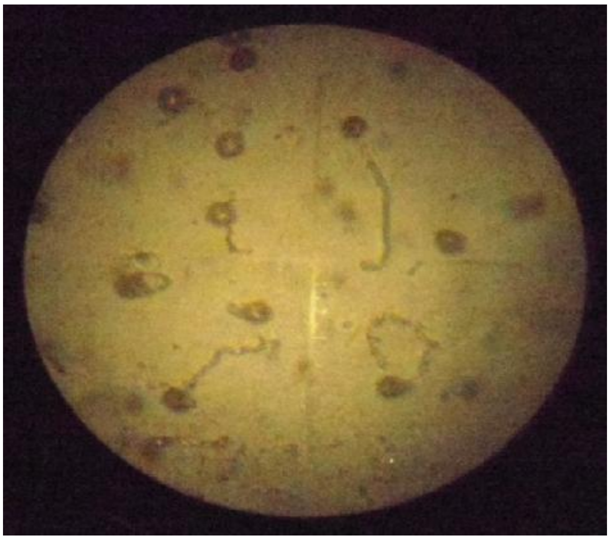

Fig. 4. Mean pollen tube length GP-6-952 (149.10 µm)

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Heterosis and combining ability study for yield and quality traits in castor (*Ricinus communis* L.)

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ABSTRACT

Heterosis and combining ability study for yield and quality traits in castor [*Ricinus communis* (L.)]" was carried out through diallel analysis at Main Castor-Mustard Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar. The experimental material composed of 45 hybrids, 10 parents and standard check GCH 5.The analysis of variance showed highly significant differences among genotypes and hybrids for all the traits. Parents also differed significantly for all the characters indicating considerable amount of genetic variability present in the experimental material. The average performance of hybrids differed from that of the parents for days to flowering, days to maturity, seed yield /plant, oil content in seed and oil content in endosperm. Exploitable heterosis for seed yield/plant was observed in crosses HC 8 x 37504 (155.2%), PRT 44 x 37504 (99.1%), 37504 x 37500 (86.8%) and SKI 1 x 37500 (79.5%), whereas, cross HC 8 x 37504 (149.8%) and PRT 44 x 37504 (86.2%) recorded high heterobeltiosis for seed yield/plant. Crosses showing heterosis for seed yield exhibited noticeable heterosis through important yield components like days to maturity, days to flowering, stem length, oil content in endosperm and oil content in seed. The analysis of variance for combining ability showed highly significant differences for all the traits under investigation. The predictability showed that non-additive gene action was primarily involved in the inheritance of the characters *viz*., days to flowering, days to maturity, seed yield/plant, oil content in seed, endosperm content and oil content in endosperm. Additive gene action was found predominant for stem length, number of effective branches/plant and 100 seed weight. The parent, 37504 was a good combiner for seed yield/plant, while SKI-1 proved good combiner for oil content in seed. The ranking of parents based on *gca* effects was almost similar to that based on *per se* performance for most of the characters. Two hybrids SKI-1 x 37500 and HC-8 x 37504 exhibited significant and positive *sca* effects for seed yield per/plant. The cross HC-8 x 37504 gave highest seed yield/plant which had poor x good general combining parents.

Keywords: Castor, Heterosis, Qaulity, Yield

Castor [*Ricinus communis* (L.)], 2n = 22 belongs to the genus Ricinus of Euphorbiaceae family. It is normally monoecious with about 50 to 70% male flowers occurring towards the base of racemes and 30 to 50% pistillate flowers in the upper portion. The flowers are wind and insect pollinated and from 5 to 50% natural cross-pollination has been reported in normally monoecious strains.

Exploitation of hybrid vigour has been proved to be a potential method for boosting productivity in many cross-pollinated crops. Existence of substantial degree of heterosis for seed yield and other traits has also been reported by several workers in castor. The availability of pistillate lines and exploitation of hybrid vigour in castor on commercial scale has become feasible and economical (Gopani *et al*., 1968). In Gujarat, real breakthrough in castor production has come with development and release of hybrids for commercial cultivation. The state is pioneer in development and release of hybrids *viz*., GCH-3, GAUCH-1, GCH-2, GCH-4, GCH-5, GCH-6 and GCH 7 for commercial cultivation. For improving yield potential of varieties and hybrids, selection of right type of parents for hybridization is of paramount importance. This emphasized the importance of testing the parents for their combining ability because many a times the high yielding parents do not combine well to give better hybrids or segregants in segregating generations. Further, for the systematic and successful breeding programme, the knowledge of gene action involved in the inheritance of various quantitative characters of economic importance will help in framing an efficient breeding plan for rapid improvement in castor. Diallel analysis is a systematic approach for identification of superior parents and their cross combination and it also provides an overall genetic nature of the experimental material in single generation.

MATERIALS AND METHODS

Heterosis and combining ability study for yield and quality traits in castor was undertaken at Main Castor-Mustard Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar. The experimental material composed of 56 entries, comprised of 10 inbred lines/varieties of castor, 45 F_1 crosses generated by crossing these inbreds/varieties in half diallel fashion and

GCH-5 as standard check were grown for evaluation in a randomized block design with three replications during rainy season of 2007. Each entry was grown in a single row of 10 dibbles. The distance between two rows was 90 cm, while between two plants within a row was 60 cm. The characters studied were days to flowering, days to maturity, stem length (cm), number of nodes on main stem, effective length of primary raceme (cm), number of capsules on primary raceme, number of effective branches/plant, seed yield/plant (g), 100 seed weight (g), oil content in seed (%), endosperm content (%) and oil content in endosperm (%). The analysis of variance was carried out based on the following model of Panse and Sukhatme (1967). The analysis of the experimental material was done according to Griffing (1956a and b).

RESULTS AND DISCUSSION

The analysis of variance (Table 1) indicated highly significant differences among genotypes, parents and hybrids for all the traits, indicating considerable amount of genetical variability present in the selected material. The average performance of hybrid was different from that of the parents for days to flowering, days to maturity, seed yield/plant, oil content in seed and oil content in endosperm, as evident from the significant parents vs. hybrids source of variation for the characters studied. Hence, the selected material was appropriate for the study of manifestation of heterosis and also emphasized the need of selecting morphologically and geographically diverse parents for maximization of hybrid vigour for seed yield and its contributing characters.

The comparative study of most promising five hybrids for seed yield/plant with useful and component characters showing desired heterosis is presented in table 2. The data revealed that heterotic hybrids for seed yield did not show heterosis for all component characters. In fact, appreciable heterosis for one or two components was sufficient to manifest heterosis for seed yield/plant. The results are in agreement with the findings of Patel (1994). Of the five crosses, HC-8 x 37504 exhibited significant relative heterosis for days to maturity, oil content in seed and oil content in endosperm; and heterobeltiosis and economic heterosis for days to maturity, respectively. The hybrid PRT-44 x 37504 showed significant relative heterosis, heterobeltiosis and economic heterosis for days to maturity, stem length and oil content in endosperm; oil content in seed and oil content in endosperm; and days to flowering and days to maturity, respectively. Significant heterosis over mid-parent, better parent and standard heterosis in desired direction for cross SKI-1 x 37500 was observed for days to flowering and number of capsules on primary raceme; days to flowering; days to flowering and days to maturity, respectively. Cross PRT-44 x HC-8 showed significant relative heterosis in desired direction for days to maturity and oil content in seed. In the same way, for heterobeltiosis and economic heterosis the characters were oil content in seed and days to maturity, respectively. The cross 37504 x 37500 exhibited significant relative heterosis over mid-parent and standard check in desired direction for the characters *viz*., stem length and oil content in seed; days to flowering and days to maturity, respectively. So, there is a scope for increasing the seed yield by improvement of these characters simultaneously and substantiates the findings of Patel (2005). The expression of yield heterosis arises from the combination of favourable yield components. High associations of these attributes among themselves as well as with seed yield have been reported in case of combinational heterosis (Hegberg, 1952). Out of five crosses for seed yield, the hybrids HC-8 x 37504 and PRT-44 x 37504 showed significant heterotic effects over their mid-parent and better parent. The high heterotic effects of seed yield in these two crosses were mainly with significant heterotic effect of oil content in seed. From these results it is apparent that these crosses have potential for improving yield through oil content in seed.

The analysis of combining ability variances (Table 3) indicated that general combining ability variances were significant for all the characters, except days to flowering, while the specific combining ability variances were significant for days to maturity, stem length, seed yield/plant, oil content in seed, endosperm content and oil content in endosperm. This indicated the importance of both additive as well as non-additive gene actions in the expression of all the traits. The comparison of magnitude of general combining ability and specific combining ability mean square indicated that the additive genetic effects were predominant for the characters *viz*., stem length, number of effective branches/plant and 100 seed weight, which suggested prime role of additive gene action for these characters. These results are in accordance with those obtained by Patel *et al*. (2008b) and Parmar *et al*. (2008). A comparison of relative magnitude of general and specific combining ability variances indicated that non-additive genetic effects were predominant for control of the characters *viz*., days to flowering, days to maturity, seed yield/plant (g), oil content in seed (%), endosperm content and oil content in endosperm. As observed in the present study, the predominant role of non-additive gene action in the inheritance of seed yield was observed by many workers (Tank *et al*., 2003; Patel *et al*., 2008a; Patel *et al*., 2008b; Parmar *et al*., 2008). This has emphasized the use of heterosis breeding approach to exploit hybrid vigour in this crop. Non-additive type of gene action for effective length of primary raceme and number of capsules on main raceme was reported by Patel (1994). While, non-additive gene action for 100 seed weight as well as oil content in seed was reported by Patel (1994) and Tank *et al*. (2003). Non-additive gene action for number of effective branches/plant was also reported by Patel (1994). Days to flowering, number of nodes on stem and stem length recorded additive gene action. Additive gene action for days to flowering was reported by Patel *et al*. (2008a). Under the circumstances, where both additive and non-additive gene actions are in operation, the most appropriate and effective breeding approach would be to mop up the additive genes and simultaneously maintaining degree of heterozygosity for exploiting dominance component i.e., by adopting biparental mating and *inter se* crossing between suitable lines followed by recurrent selection. However, in the present study, the non-additive gene action has played an important role in expression of seed yield and most of its components which justify the heterosis breeding for rapid improvement.

None of the parents was a good general combiner for all the traits. These results are akin to the findings of Tank *et al*. (2003) for high *gca* effects for seed yield and various component traits. The general combining ability effects of different parents for various characters (Table 4) revealed that the parent 37504 was found to be good general combiner for the seed yield/plant, 100 seed weight, oil content in seed and endosperm content. Parents, SKI 215 and 37500 were also spotted as good combiners for almost all the yield attributing characters *viz*., effective length of primary raceme and number of effective branches/plant, while PCS-124, PRT-44 and SKI-166 were good general combiners for days to flowering, days to maturity, stem length and number of nodes on main stem. The parent SKI-1 was found to be good general combiner for effective length of primary raceme, 100-seed weight, oil content in seed and oil content in endosperm. The parent JH 118 was found to be good general combiner for 100 seed weight, endosperm content and oil content in endosperm. It was also observed that parents, who exhibited high *per se* performance, also displayed good general combining ability effects. Hence, *per se* performance may be used effectively for the selection of parents. Similar results of positive association of *per se* performance and general combining ability and its use for selection of the parents were also reported by Joshi *et al.* (2002). It was interesting to note that the involvement of good combining parents had resulted in to hybrids expressing useful heterosis for various traits in majority of cases. In the present study, high yielding parent 37504 in combination with HC-8, PRT-44 and 37500 (i.e., HC-8 x 37504, PRT-44 x 37504 and 37504 x 37500) recorded high seed yield.

The results of *sca* effects of different crosses revealed that none of the crosses showed consistently significant and desirable *sca* effects for all the characters. Comparative study of five most promising hybrids with respect to heterosis and its specific combining ability effects for seed yield/plant and for various characters (Table 5) revealed that top most heterotic hybrid HC- x 37504 (poor x good) exhibited significant *sca* effects in desired direction for seed yield/plant, days to maturity and oil content in endosperm. The hybrid also recorded significant heterosis over mid parents in desired direction for seed yield/plant, days to maturity, oil content in seed and oil content in endosperm, and significant heterosis over better parents and standard check for days to maturity. The hybrid SKI 1 x 37500 (average x average) had significant *sca* effects in desired direction for number of capsules on primary raceme and seed yield/plant. This hybrid also recorded significant heterosis over mid parents in desired direction for seed yield/plant, days to flowering and number of capsules on primary raceme and significant heterosis over better parents in desired direction for seed yield/plant and days to flowering, and also exhibited significant heterosis over standard check for days to maturity and seed yield/plant.

Further, it is interesting to note here that generally high heterotic hybrids involved atleast one good combining parent for yield or its components as could be seen from the crosses HC-8 x 37504 and SKI-1 x 37500. In general, the hybrids showing high *per se* performance also displayed high *sca* effects suggesting that *per se* performance of the crosses was a good indicator of their *sca* effects. Significant and positive specific combining ability effects for seed yield and its component traits have been reported by Tank *et al*. (2003) and Solanki *et al*. (2003). Thus, it could be concluded that crosses showing high *sca* effects for seed yield also manifested high *sca* effects for one or more yield attributing characters.

Two best crosses selected each for *sca* effects, *per se* performance and heterobeltiosis for all the characters are presented in table 6. A perusal of data did not reveal any specific trend. A combination of good general combiners was not necessarily the best cross combination nor was a poor x poor cross always poor cross combination. The crosses *viz*., HC-8 x 37504 and SKI-1 x 37500 which recorded highly significant *sca* effects resulted from poor x good and average x average general combiners, respectively. While the crosses, 37504 x SKI-166 and SH-72 x HC-8 involving good x average and poor combining parents did not record highest and lowest *sca* effects. This indicated the inconsistent expression of *sca* in the specific crosses irrespective of the gca effects of the parents. Tank *et al.* (2003) have also reported similar results. However, a comparative study of the crosses on the basis of *sca* effects and *per se* performance revealed that the majority of crosses which have higher yield had either one or both the parents as good/average general combiners for seed yield (Table 5). The crosses with poor x poor combining parents did not find place among high yielding hybrids. The hybrid, HC-8 x 37504 with poor x good general combiner registered the highest *sca* effect for seed yield/plant, while indicate that parents with higher *gca* effects are desirable for a hybrid having high *sca* effects for realization of the maximum heterosis. The examination of data in table 6 also revealed that the crosses having higher estimates of *sca* resulted from poor x good, average x average, poor x average, good x poor and average x good general combiners. Better performance of hybrids involving average x average and average x poor general combiners indicated dominance x dominance (epistasis) type of gene action (Jinks, 1956). Such crosses could be utilized in the production of high yielding homozygous lines (Darrah and Halluer, 1972). The crosses showing high *sca* effects involving one good general combiner, indicated additive x dominance type of gene interaction, which could produce desirable type of transgressive segregants in subsequent generations. Tank *et al.* (2003) have also reported involvement of additive x additive, additive x dominance and epistatic type of gene action in expression of yield and other traits in castor. However, looking to the *per se* performance, it was obvious that the crosses resulted from good x poor general combiners ranked first for seed yield and yield attributing characters. This showed that the additive gene action has contributed towards better expression of these traits. It was also revealed that atleast one good general combiner was necessary for the better expression of these traits in the hybrids, thereby rendering the hybrids more productive. The overall diallel study indicated that the parent like 37504 was observed to be good general combiner for most of the characters including yield, whereas, the hybrid like HC-8 x 37504 was found to be the best specific combination followed by PRT-44 x 37504 and 37504 x 37500 for yield and other important biometrical traits. Additionally, these hybrids also expressed high heterobeltiotic effects for yield and other traits. Thus, the good combining parents could be utilized in the hybridization programme for improvement of yield and other characters and the hybrids like SKI-1 x 37500 and PRT-44 x HC 8 could be utilized for exploitation of heterosis at commercial level. In addition to this, non-additive gene action played a significant role in the inheritance of most of the characters, which will be useful in producing heterotic hybrids at commercial level and also help in the production of transgressive segregants for the character in question. These transgressive segregants will be useful in the selection of better recombinants for yield and other traits.

Table 1 Analysis of variance (mean squares) for different characters in castor

Source of variation	d.f.	Days to flowering (Primary raceme)	Days to maturity (Primary raceme)	Stem length (cm)	Number of nodes on main stem	Effective length of primary raceme (cm)	Number of capsules on primary raceme	Number of effective branches/ plant	Seed yield/plant (g)	100 seed weight (g)	Oil content in seed (%)	Endosperm content (%)	Oil content in endosperm (%)
Replications	2	11.21	18.62	777.75	2.94	157.07	227.04	0.39	39.24	2.96	1.05	6.907	0.61
Genotypes	54	43.11**	185.67**	2204.07**	6.53**	394.49**	212.78**	0.64**	2323.36**	55.23**	2.18**	18.64**	3.32**
Parents	9	47.79**	433.78**	4825.88**	12.56**	453.70**	323.12**	0.93**	2697.39**	61.31**	5.15**	18.25**	4.62**
Hybrids	44	40.46**	103.27**	1710.38**	5.42**	389.29**	192.73**	0.60**	1904.07**	54.31**	1.37**	19.14**	2.93**
Parent Vs. Hybrids	1	117.21**	1578.19**	329.73	0.88	90.48	101.56	0.12	17406.10**	40.69	10.714**	0.01	8.60**
Error	108	5.09	15.64	2915	1.77	79.01	77.31	0.20	1002.88	13.86	0.424	3.00	1.18
SEm ±		1.30	2.28	31.17	0.77	5.13	5.08	0.26	18.28	2.15	0.38	1.00	0.63

* and ** significant at 5 and 1% level of significance, respectively

Table 2 Comparative study of most promising heterotic hybrids for seed yield/plant with useful component characters showing desired heterosis

Hybrid	Heterosis for seed yield over			Useful and significant heterosis over MP for component trait	Useful and significant heterosis over BP for component traits	Useful and significant heterosis over SC for component trait
	MP (%)	BP (%)	SC (%)			
HC 8 x 37504	156.16**	149.77**	-20.36	DM, OCS, OCE	DM	DM
PRT 44 x 37504	99.12*	86.16*	-32.04**	DM, SL, OCE	OCS, OCE	DF, DM
SKI 1 x 37500	79.54**	70.43**	-11.98	DF, NC	DF	DF, DM
PRT 44 x HC 8	75.05	61.51*	-39.07**	DM, OCS	OCS	DM
37504 x 37500	86.77**	54.84*	-28.14*	SL, OCS	-	DF, DM

DF = Days to flowering; NC = Number of capsules on primary raceme
DM = Days to maturity; OCS = Oil content in seed
SL = Stem length; OCE = Oil content in endosperm

* and ** significant at 5 and 1% level of significance, respectively

Table 3 Analysis of variance for combining ability for various characters in castor

Source of variation	d.f.	Days to flowering (Primary raceme)	Days to maturity (Primary raceme)	Stem length (cm)	Number of nodes on main stem	Effective length of primary raceme (cm)	Number of capsules on primary raceme	Number of effective branches/ plant	Seed yield/ plant (g)	100 seed weight (g)	Oil content in seed (%)	Endosperm content (%)	Oil content in endo-sperm (%)
gca	9	42.36	179.03**	3347.4**	10.63**	6.76.31**	321.23**	0.89**	1068.5**	83.28**	2.00**	12.54**	2.53**
sca	45	8.77	38.46**	212.14**	0.49	22.53	20.87	0.08	715.7**	5.44	0.47**	4.95**	0.82**
Error	108	1.70	5.21	97.18	0.59	26.34	25.77	0.07	334.3	4.62	0.14	1.00	0.93
σ^2 *gca*		2.80	11.71	261.27	0.85	54.48	25.03	0.07	29.40	6.49	0.13	0.63	0.14
σ^2 *sca*		7.08	33.25	114.97	-0.10	-3.80	-4.91	0.01	381.36	0.81	0.33	3.95	0.42
σ^2 *gca/sca*		0.45	0.41	0.82	1.06	1.04	1.13	0.93	0.13	0.94	0.44	0.24	0.40

* and ** significant at 5 and 1% level of significance, respectively

Table 4 Estimates of general combining ability effects associated with each parent

Source of variation	Days to 50% flowering (Primary raceme)	Days to maturity (Primary raceme)	Stem length (cm)	Number of nodes on main stem	Effective length of primary raceme (cm)	Number of capsules on primary raceme	Number of effective branches/ plant	Seed yield/ plant (g)	100 seed weight (g)	Oil content in seed (%)	Endosperm content (%)	Oil content in endosperm (%)
SKI 215	3.48**	6.14**	1.02	1.07**	7.91**	2.13	0.54**	-4.49	0.27	0.17	-0.80	0.11
SH 72	1.96**	2.12**	-7.15**	0.33	12.44**	10.35**	-0.22**	-14.57**	-1.53**	-0.35**	0.73**	-0.67**
PCS 124	-1.02**	-2.16**	-30.70**	-1.23**	-7.76**	-6.76**	0.21**	1.53	-6.25**	0.18	-2.06**	0.12
PRT 44	-1.43**	-3.24**	-6.22*	-0.89**	-7.98**	-6.08**	-0.11	-7.02	1.37*	-0.48**	-0.47	0.16
HC 8	-1.41**	2.09**	12.02**	1.39**	4.52**	2.61	0.35**	-11.68*	-1.29*	0.09	-0.54*	0.13
SKI 1	0.26	5.53**	33.63**	1.11**	-2.88*	-1.70	-0.21**	1.03	2.77**	0.59**	0.35	0.42*
37504	0.09	0.26	4.07	0.10	3.97**	1.31	-0.24**	14.12**	0.50	0.20*	1.16**	-0.19
SKI 166	-2.52**	-4.97**	-12.33**	-0.83*	-10.68**	-4.74**	0.02	3.51	-0.08	-0.76**	-0.24	-0.90**
JH 118	-1.16**	-2.38**	5.71*	-0.43*	-1.66	-0.64	-0.13	6.26	2.62**	0.03	0.66*	0.33*
37500	3.48**	6.14**	1.02	1.07**	7.91**	2.13	0.54**	-4.49	0.27	0.17	-0.80**	0.11
S.E.(gi)±	0.36	0.63	2.70	0.21	1.41	1.39	0.07	5.01	0.59	0.10	0.27	0.17

* and ** significant at 5 and 1% level of significance, respectively

Table 5 Comparative study of most promising hybrids showing high specific combining ability effects for seed yield with *sca* effects of various characters

Hybrid	Seed yield/ plant (g)	Days to flowering (Primary raceme)	Days to maturity (Primary raceme)	Stem length (cm)	Number of nodes on main stem	Effective length of primary raceme (cm)	Number of capsules on primary raceme	Number of effective branches/ plant	100 seed weight (g)	Oil content in seed (%)	Endosperm content (%)	Oil content in endosperm (%)
HC 8 x 37504	60.60**	-1.41	-5.83**	-0.64	0.05	-1.07	-5.85	-0.15	0.72	0.64	1.74	1.15*
PRT 44 x 37504	29.93	-2.24	-7.50**	-17.53	-0.75	-3.97	-0.83	-0.02	0.70	0.90**	-2.46**	1.47*
SKI 1 x 37500	51.02**	-1.49	-0.44	17.41	0.46	1.49	10.19*	-0.28	-0.53	0.00	0.39	-0.40
PRT 44 x HC 8	26.99	-0.10	-1.38	18.95*	0.44	-2.05	-1.51	-0.04	1.46	1.11**	0.01	0.23
37504 x 37500	25.32	-1.49	3.98	-8.33	-0.41	2.44	5.47	-0.14	-0.13	0.25	0.76	-2.07**

* and ** significant at 5 and 1% level of significance, respectively

Table 6 Two best parents, general combiners and best crosses with high *sca* effects for different characters

Character	Best parents	Good general combiner	Best crosses	Two best crosses on heterobeltiosis basis	Crosses with highest *sca* effects
Days to flowering (Primary raceme)	37504	SKI 166	PRT 44 x JH 118	SKI 1 x 37500	SH 72 x 37500
	JH 118	PRT 44	SKI 1 x 37500	PRT 44 x SKI 1	SKI 215 x SKI 1
Days to maturity (Primary raceme)	JH 118	SKI 166	SH 72 x PCS 124	SH 72 x 375044	SH 72 x PCS 124
	SKI 1	PRT 44	PRT 44 x JH 118	SH 72 x HC 8	SH 72 x 37500
Stem length (cm)	PCS 124	PCS 124	PCS 124 x SKI 1	-	SH 72 x 37504
	JH 118	SKI 166	SH 72 x PCS 124	-	PCS 124 x 37504
Number of nodes on main stem	PCS 124	PCS 124	PCS 124 x JH 118	-	-
	JH 118	PRT 44	PCS 124 x PRT 44	-	-
Effective Length of primary raceme (cm)	SH 72	SH 72	SH 72 x HC 8	-	SH 72 x HC 8
	HC 8	SKI 215	SKI 215 x SH 72	-	-
	-	37500	-	-	-
Number of capsules on primary raceme	SH 72	-	SH 72x SKI 1	-	SKI 1 x 37500
	HC 8	-	SH 72 x HC 8	-	-
Number of effective branches/plant	SKI 215	SKI 215	SKI 215 x PCS 124	-	SKI 215 x PCS 124
	JH118	37500	SKI 215 x HC 8	-	-
Seed yield/plant (g)	SKI 166	37500	SKI 1 x 37500	HC 8 x 37504	HC 8 x 37504
	PCS 124	-	HC 8 x 37504	PRT 44 x 37504	SKI 1 x 37500
100 seed weight (g)	37504	SKI 1	37504 x 37500	-	-
	37500	JH 118	SKI 166 x 37500	-	-
Oil content in seed (%)	SKI 1	SKI 1	HC 8 x 37504	PRT 44 x JH 118	PRT 44 x HC 8
	37504	37504	SKI 215 x PCS 124	HC 8 x 37500	PRT 44 x 37504
Endosperm content (%)	SKI 1	37504	SH 72x SKI 1	-	PCS 124 x PRT 44
	SKI 166	SH 72	SKI 1 x JH 118	-	SKI 215 x PRT 44
Oil content in endosperm (%)	SKI 1	SKI 1	PRT 44 x 37504	PRT 44 x 37504	PRT 44 x 37504

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Multi-locational evaluation of Linseed (*Linum usitatissimum* L.) germplasm under rainfed ecology

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ABSTRACT

Field experiments were conducted at three locations in augmented design during the winter season of 2008 allowed for the assessment of broad adaptation to dry and warm growing conditions of 100 linseed (*Linum usitatissimum* L.) accessions. Perusal of results revealed that there exists sufficient genetic variability for seed yield in the studied linseed accessions. Sagar was adjudged best among the locations for harvesting a good yield. EC 704, an exotic line recorded highest seed yield at Sagar and Latur whereas, EC 1066, EC 1534 and EC 1466 recorded higher seed yield than the best check at all the three experimental sites showing a sign of wide adaptation. Such an approach to make efficient use of germplasm collections remains important even today. This contribution summarizes that genotypes EC 704, EC 1066, EC 1534 and EC 1466 having stable yield potential may be exploited in the linseed breeding programme to combat global climate change.

Keywords: Germplasm, Linseed, Multi-locational evaluation

Linseed/flax (*Linum usitatissimum* L.) is today considered to be oldest oilseed in the world having been domesticated in North East region 10,000 years ago and serving as source of both oil and fibre since pre-historic times (Allaby *et al*., 2005). It has been under discussion whether oil or fibre was the primary reason of domestication (Diederichsen *et al*., 2010). An oilseed type of flax is proposed as the first domesticate, while fibre flax appears as a later descendant from oilseed flax (Allaby *et al.*, 2005). The major linseed growing Indian states are Madhya Pradesh, Chhatisgarh, Maharashtra, Uttar Pradesh, Bihar and Jharkhand where the crop is predominantly cultivated under rainfed situation. The adaptation to dry and warm growing conditions is of great importance as climate change may increase the frequency of the occurrence of moisture and temperature stress. Major breeding strategies advocated for rainfed areas include enhancement in harvest index, plant biomass and stress tolerance particularly drought resistance. The first two methods increase yields by altering the plant architecture, while the third focuses on increasing the ability of plants to survive stressful environments.

Since most of the oilseeds including linseed are grown in the marginal lands and rainfed conditions and suffer from moisture stress of varying intensity at different growth stages, hence engineering traits that confer resistance to environmental stress such as drought, frost and/or salinity could contribute to the increased productivity enhancement.

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It is indispensable for crop improvement programme to evaluate the available germplasm in order to identify the superior and desirable genes to exploit the genetic potential in desired direction. It has been observed that plant breeders are using less basic germplasm in research due to lack of information on traits of economic importance, which often shows high genotype x environment interactions and requires multi-locational evaluation. Hence, the present investigation was undertaken to test the adaptability and suitability of linseed germplasm under rainfed cultivation.

MATERIALS AND METHODS

One hundred germplasm along with three checks i.e., NL-97, JLS-9 and T-397 were evaluated in augmented block design comprising five blocks during the winter season of 2008 at three locations *viz*., Kanke, Sagar and Latur. All the accessions were sown in a single row of three meter length and checks were replicated with a set of 20 accessions/ block. Data on seed yield, days to flowering and days to maturity were recorded on plot basis. Five plants were randomly selected to record the observations on plant height, number of capsules/plant and number of seeds/capsule. Meteorological data of three locations representing different agro-ecological zone have been enumerated in table 1. The mean values for various yield related traits were computed for each of the locations and were statistically analysed *vis-à-vis* the checks using the Federer (1961) augumented design for identification of promising accessions.

RESULTS AND DISCUSSION

Perusal of results presented in table 2 revealed that there exists sufficient genetic variability for seed yield in the studied gene pool. Among the locations, maximum variability as well as expression for seed yield was observed at Sagar followed by Latur and Kanke.

Variances due to unreplicated treatments within all the blocks were non- significant for seed yield of all the three locations except Latur within block IV. Likewise, significant variances due to unreplicated treatments vs. checks were observed only at Kanke within block II. Forty five, 26 and 25 germplasm were identified to record higher yield than their respective best yielding checks at Kanke, Sagar and Latur centres, respectively. Five high yielding genotypes selected on the basis of *per se* performances at different locations have been enumerated in table 3. Jarvis *et al.* (2008) have rightly stated that breeding programmes must develop crop specific and region-specific strategies so that the products are relevant to the problems and conditions 10-15 years down the line.

Table 1 Geographical and weather data at experimental sites during crop season (October, 2008-April, 2009)

Parameter	Location		
	Kanke	Sagar	Latur
Region / zone	II	Central III	IV
Geographical coordinates	85°19' East	78°21' East	77°36' East
	23°17' North	24°27' North	18°24' North
Elevation (m above sea level)	625	530	634
Soil	Sandy loam	Medium black	Vertisols
Total rainfall (mm)	31.0	28.6	56.6
Average temperature (°C)			
Max.	26.53	31.07	31.52
Min.	11.99	16.67	13.54
Average relative humidity (%)			
Max.	86.0	45.53	64.00
Min.	49.29		
Average sun shine (Hours)	250	-	-

Table 2 Variability in seed yield (kg/ha) of linseed germplasm at different locations

Character	Location	Range of variation	CV%	Mean values of checks		
				NL 97	JLS 9	T 397
Seed yield (kg/ha)	Kanke	77-710	27.31	370	390	220
	Sagar	60-2407	61.86	500	920	1000
	Latur	164-1409	35.16	592	413	355

Treatment comparisons	Kanke		Sagar		Latur	
	SEm±	CD (P=0.05)	SEm±	CD (P=0.05)	SEm±	CD (P=0.05)
Two unrep. treats – Same block	126.16	290.93	705.69	1627.32	225.40	519.78
Two unrep. treats – diff. block	145.68	335.93	814.86	1879.07	260.27	600.19
Unrep.treats - check	108.04	249.14	604.32	1393.56	193.02	445.11

Table 3 Top ranking five linseed germplasm for seed yield (kg/ha)

Kanke		Sagar		Latur	
Germplasm	Seed yield (kg/ha)	Germplasm	Seed yield (kg/ha)	Germplasm	Seed yield (kg/ha)
EC 1386	710*	EC 704	2407*	EC 704	1409*
EC 1394	610	EC 1475	2307	EC 1066	1356*
EC 1404	577	EC 568-M	1757	EC 1447-A	982
EC 1391	560	EC 1529-B	1707	EC 1322	875
EC 573-CS	543	EC 1410-CS	1607	EC 1534	849
JLS-9 (Best check)	390	T-397	1000	NL 97	592
CD (P=0.05)	249.1		1393.6		445.1

*Significantly superior to the best check

Exotic germplasm EC 704 recorded highest seed yield at Sagar and Latur whereas, EC 1066, EC 1534 and EC 1466 recorded higher seed yield than the best check at all the three locations showing consistency in their performance across locations.

The promising accessions with more than 500 kg/ha seed yield along with their agro-morphological traits have been given in table 4. There is need for good donors having earliness, dwarf and bushy growth habit and more number of capsules and seeds/capsule specially when the target is to breed suitable genotype for rainfed cultivation. Since drought was the limiting factor at all experimental locations, the germplasm identified as performing well in maturity duration, plant height and seed yield may be useful when breeding for broad adaptation of linseed under drought conditions. In most of the breeding programme, for drought tolerance the traditional approach is to look for highly productive lines which are early in duration and can withstand stress during reproductive phase so that reduction in yield components are least. Significant progress made for developing trait based model using physiological parameters in groundnut (Wright *et al*., 1996), sunflower (Subramanian and Maheshwari, 1991) and rapeseed - mustard (Kumar and Singh, 1998) may be replicated in linseed with some modifications to suit the phenology and reproductive biology of linseed.

It is concluded that genotypes EC 704, EC 1066, EC 1534 and EC 1466 having high yield potential coupled with consistent performance may be incorporated in linseed crop improvement programme formulated for rainfed production systems.

Table 4 Characterization of promising accessions of linseed having high seed yield ($\geq$500 kg/ha)

Accession	Seed yield (kg/ha)	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of capsules/ plant	No. of seeds/ capsule
EC 704	2407	58	112	43	38	8
EC 1475	2307	68	114	35	44	9
EC 568 M	1757	66	112	37	25	8
EC 1529-B	1707	68	115	44	31	8
EC 1410 CS	1607	70	113	47	27	7
EC 1066	1356	61	113	48	44	8
EC 1447-A	982	69	108	39	33	7
EC 1322	875	67	111	43	35	7
EC 1534	849	65	115	44	37	9
EC 1386	710	61	111	42	20	7
EC 1394	610	58	111	48	31	9
EC 1404	577	68	111	40	53	8
EC 1391	560	71	112	43	25	8
EC 573-CS	543	67	109	40	24	8

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Assessment of early maturity based on per cent reduction in yield by advancing date of harvest in groundnut (*Arachis hypogaea* L.)

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ABSTRACT

Breeding of short duration groundnut (*Arachis hypogaea* L.) varieties with enhanced productivity is a priority area in the semi-arid tropical regions to evade the end-season moisture deficit stress and for summer cultivation where the harvesting of groundnut coincides with the on-set of monsoon. Eighteen advanced breeding lines were evaluated during rainy and summer seasons for productive capacity and earliness in maturity by estimating the relative reduction in yield and associated traits due to advanced harvesting by 10 or 20 days over normal harvest. During rainy season the test genotypes were also compared with two popular varieties JL 24 and HNG 10 as checks. Harvesting the genotypes 20 days ahead of normal harvest lead to considerable loss in pod and kernel yield, the reduction being larger in summer. When harvesting was advanced by 10 days the relative yield reduction was considerably lower in some of the genotypes (1-4% pod and 3-4% kernel yield reduction during rainy season), and six genotypes recorded superior yield coupled with earliness in comparison to the best check. The genotypes PBS 11029, PBS 21031, PBS 30076, PBS 11066, PBS 15004 and PBS 28008 were found early in maturity during rainy season and PBS 21031 during summer as they registered negligible loss in yield when harvesting was advanced. The proposed concept of least reduction in yield and its component traits when harvested early coupled with high productivity may be used as a field technique for screening large number of advanced breeding lines to identify early and high productive genotypes.

Keywords: Groundnut, Early harvesting, Early maturity, Yield reduction

About 80% of groundnut (*Arachis hypogaea* L.) area in India is under rainfed cultivation and the crop is grown during rainy season mainly in semi-arid regions, which is characterized by uncertain or uneven rainfall and frequent dry spells. In some of these groundnut cultivation regions, particularly in western parts of the country, occurrence of end-of-season drought is very frequent. Summer groundnut is also gaining impetus, this is though grown under assured irrigation condition; crop at maturity is sometimes entrapped in rains in years when onset of monsoon is early. Both these situations, particularly when short duration varieties are not available, force the farmers to advance harvesting of the crop. Although response can be variable and is dependent upon many genetic and non-genetic factors, harvesting groundnut as little as one week prior to or one week following optimum maturity can result in substantial reduction in pod yield (Danesha *et al*., 2009). While growers often assume that harvest should be initiated prior to optimum maturity in field, there is no clear threshold where gain in pod weight and grade is offset by losses due to advancing date of harvest. Determining interactions between genotype and harvesting date would assist growers in making more informed decisions on when to initiate harvest to avoid yield loss.

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Although there are a few crop management approaches to conserve soil moisture to overcome early and/or mid-season drought, limited efforts have been made to mitigate the outcome of the end-of-season drought. Growing short-duration varieties with enhanced per day productivity has been one of the ideal approaches for end-of-season drought areas. Such genotypes are also essential to match the short growing season and to fit into multiple cropping systems of semi-arid tropical regions of the world.

Understanding the genetic control and breeding for early maturity remained difficult because of the inherent difficulty in defining maturity of the otherwise indeterminate and non-senescent groundnut types (Kvein and Ozias-Akins, 1991). In addition, the influence of photoperiod and temperature on maturity further complicates the process of selection for maturity (Bagnall and King, 1991). At present, the maturity of groundnut is determined by well-developed pods and kernels, dark inner colour of shell and testa having normal colour of the genotype (Reddy, 1986). Some of the methods followed around the world to define early maturity are based on early emergence of seedling (Nigam *et al*., 1988), hull-scrape method (Holbrook *et al*., 1989), internal pod colour (Khalfaoui, 1990) and leaf yellowing, seed size and shelling percentage (Gorbet *et al*., 1992). A few varieties have also been released in the United States of America and elsewhere in the world by adopting the above procedures. In

India, mutation breeding for early maturity as defined by yield at early harvest has also been suggested by Mouli and Kale (1989). Alternatively, Vasudeva Rao *et al*. (1992) suggested the use of cumulative thermal time (measured in degree days, °Cd) calculated on a base temperature above which growth and development of groundnut takes place and a maximum temperature above which no development takes place, instead of calendar days in selection for early-maturity. In this paper, we report a simple and effective field technique for evaluating advanced breeding lines of groundnut for early maturity coupled with high productive capacity.

MATERIALS AND METHODS

Eighteen advanced groundnut breeding lines were evaluated to determine their maturity during rainy (2004) and summer (2005) seasons in a randomized complete block design with three replicates. The experiment during rainy season also included two check varieties, JL 24 (Spanish) and HNG 10 (Virginia bunch). JL 24 is a widely adapted short duration (95 days) commercial cultivar, while HNG 10 is a medium duration (115-120 days) cultivar released for commercial cultivation in western India, and both are recommended for rainy season. The genotypes were grown in five rows each of 3 m length. The spacing followed was 45 cm and 10 cm between rows and plants within a row, respectively. All the agronomic practices recommended for Saurashtra region of Gujarat were followed to raise a good crop.

Days to flower initiation and 50% flowering were recorded on plot basis. A single row (boarder rows were not considered) of each test genotype at random was harvested at 85, 95 and 105 days after sowing (DAS). In rainy season of 2004, the cumulative thermal time was 1560, 1735 and 1921 °Cd at 85, 95 and 105 DAS, respectively. The corresponding values for summer 2005 were 1640, 1843 and 2050 °Cd. Observations were recorded on pod and kernel yield (g), shelling per cent (SP), hundred seed mass (HSM, g) and proportion of sound mature kernels (SMK, %) at each harvest in both the growing seasons. In rainy season of 2004, observations were also recorded on surrogates of water-use efficiency *viz*., specific leaf area (SLA) and SPAD chlorophyll meter reading (SCMR), on fully expanded second leaf from the apex of 20 plants at 55 DAS during the morning (08.00-09.30) hours.

Observations recorded on pod and kernel yield, SP, HSM and SMK at each harvest were analyzed over three dates of harvest across two seasons to understand the interactions between seasons, genotypes and duration. When the season × genotype interaction component was found significant, season-wise analysis was performed for these traits. Relative yield reduction in each of the genotypes harvested at 85 and 95 DAS upon the yield obtained at 105 DAS harvest was calculated to identify test genotypes endowed with early-maturity. Pearsons' correlation of flowering attributes, considered to be components of early maturity, were computed with the per cent reduction resulted in pod and kernel yield, and HSM by advancing date of harvest to 85 and 95 DAS from the 105 DAS.

RESULTS AND DISCUSSION

Analysis of variance (ANOVA) carried out for all the traits studied over two seasons indicated that the mean squares due to seasons were significant indicating the seasonal differences in the expression of the traits. Hence, the analysis was carried out separately for rainy and summer season for all the traits. ANOVA carried out over the three dates of harvest (85, 95, 105 DAS) for pod and kernel yield, SP, HSM, proportion of SMK indicated the presence of highly significant differences among dates of harvest as well as genotypes for these traits during rainy 2004 and summer 2005 seasons. Absence of interactions due to date of harvest × genotypes observed for these yield and component traits indicated that the variation among the genotypes as influenced by date of harvest was minimal and non-significant. However, date of harvest × genotype interaction was significant for two traits; SP in rainy season of 2004 and proportion of SMK in summer season of 2005. Shelling per cent and proportion of SMK are highly dependent on partitioning of photosynthates to the developing kernels and are influenced by short day length, temperature and other factors as also reported by Bagnall and King (1991). Therefore, significant interaction observed for the above two traits in the present study is being substantiated.

During the rainy season of 2004, the genotypes took 21 to 27 days for flower initiation and 25 to 30 days for 50% of the plants to flower indicating the synchrony of flowering in these genotypes. While in summer season of 2005, the genotypes took 33 to 40 days for flower initiation and 42 to 49 days for 50% flowering. The delayed flowering observed among the genotypes during summer may be attributed to the low mean temperature (23-27°C) that prevailed at the time of sowing which had delayed the germination (data not presented) and consequently delayed the flowering as compared to rainy season.

The mean values of SCMR measured at 55 DAS during rainy season of 2004 ranged from 32.3 (PBS 18062) to 39 (PBS 29063). The SLA estimated using the same leaf samples varied from 175.8 cm^2/g (HNG 10) to 250 cm^2/g (PBS 11048). Significant variability was present for both the morpho-physiological traits among the genotypes included. The genotypes exhibiting low SLA and high SCMR can be denoted as water-use efficient lines (Chuni Lal *et al*., 2006). Some of the advanced breeding lines included that show low SLA and high SCMR values are PBS Nos. 29063, 21031, 11029, 11026, 11019 and 11066. Further, both the check varieties also exhibited low SLA and high SCMR values denoting the improved WUE. During the rainy season of 2004, the pod yield ranged from 855 to 2281 kg/ha when harvested at 85 DAS with an experimental mean of 1558 kg/ha, and from 1135 to 2608 kg/ha with a mean of 1759 kg/ha at 95 DAS harvest. The corresponding figures for normal harvest (105 DAS) were from 1251 to 2824 kg/ha and 1973 kg/ha. Therefore, on an average there is an increment of 200 kg pod yield at successive harvest or in other words a per day productivity of around 20 kg. In case of kernel yield again the increment was around 20 kg or less between 85 and 95 DAS and slightly above 20 kg per day between 95 and 105 DAS with mean values 1020, 1216 and 1420 kg/ha at 85, 95 and 105 DAS, respectively. As the rate of maturity towards the end of the crop growth is faster, the above-mentioned variation in per day productivity is justifiable. The test genotypes that yielded higher than the best check (JL 24) when harvested at 85 DAS were PBS 29063 followed by PBS 11066, PBS 21031, PBS 30076, PBS 12038, PBS 11029, PBS 18064, PBS 15004, PBS 11026. At 95 DAS harvest the entries out-yielding JL 24 remained almost same but the order was slightly different (PBS 29063 followed by PBS 12038, PBS 11029, PBS 30076, PBS 11066, PBS 21031, PBS 18064, PBS 15004). At normal harvest again the entries remained same except for two. The order of entries was PBS 29063 followed by PBS 12038, PBS 18064, PBS 11026, PBS 30076, PBS 11029, PBS 11066, PBS 21031, PBS 18062. The mean performances of some of the selected lines are presented in Table 1.

Table 1 Mean performance of some of the groundnut genotypes during the rainy season of 2004 and summer season of 2005

Genotypes		DFI	DF50	SCMR	SLA (cm^2/g)	Pod yield (kg/ha)			Kernel yield (kg/ha)			Shelling outturn (%)			HSM (g)			SMK (%)		
						85d	95d	105d	85d	95d	105d	85d	95d	105d	85d	95d	105d	85d	95d	105d
PBS 29063	R	22	26	39	192	2281	2608	2825	1489	1796	2079	65	69	74	38	45	50	24	37	51
	S	35	42	-	-	586	745	997	183	383	614	29	51	61	20	29	40	7	14	35
PBS 12038	R	22	25	35	244	1898	2342	2702	1171	1543	1857	62	66	69	21	26	27	43	63	79
	S	33	42	-	-	681	1009	1114	229	529	660	34	53	59	14	15	19	20	19	21
PBS 18064	R	22	26	35	222	1849	1902	2275	1283	1340	1722	69	71	76	33	36	42	69	72	91
	S	38	45	-	-	244	310	666	66	138	348	27	43	52	13	15	22	15	22	26
PBS 11026	R	24	27	35	211	1718	1869	2269	1251	1289	1584	73	69	70	27	29	30	57	67	79
	S	40	44	-	-	525	873	1288	161	484	822	28	54	63	13	21	29	6	18	25
PBS 30076	R	22	26	35	238	1929	2178	2244	1204	1464	1596	62	67	71	29	37	43	65	82	90
	S	35	44	-	-	323	361	901	87	130	484	19	36	53	16	18	26	14	19	25
PBS 11029	R	24	27	37	205	1860	2197	2222	1143	1490	1560	62	68	70	25	30	32	50	67	76
	S	39	49	-	-	358	470	810	110	237	497	25	48	60	15	19	26	5	20	22
PBS 11066	R	23	26	39	217	1941	2044	2121	1227	1314	1412	63	64	67	25	26	29	57	72	86
	S	37	44	-	-	525	675	991	170	343	605	29	50	61	13	18	26	7	30	59
PBS 21031	R	25	27	36	192	1931	1981	2041	1217	1329	1414	63	67	69	29	32	36	47	56	77
	S	37	47	-	-	668	1162	1150	259	661	717	39	57	63	18	28	32	10	27	39
JL 24	R	24	27	36	205	1701	1873	1994	1156	1368	1502	68	73	75	31	40	40	77	82	88
HNG 10	R	26	30	37	176	855	1237	1418	455	830	980	53	67	69	13	24	26	10	26	35
CD (P=0.05)	R	2	2	3	33	837	785	890	614	573	652	7	3	3	6	6	4	3	4	4
	S	4	3	-	-	360	449	558	153	281	355	10	9	5	6	5	6	13	9	25

d = Days after sowing, DFI = days to flower initiation, DF50 = days to 50% flowering; R = Rainy season; S = Summer season

The pod and kernel yield obtained at different dates of harvest during the summer season of 2005 were in general low as compared to the rainy season. The mean pod yield values of the experiment were 449, 674 and 924 kg/ha at 85, 95 and 105 DAS harvest, respectively. The corresponding kernel yield were 160, 367 and 569 kg/ha. The low mean yield recorded for the genotypes during summer confirms the observed interaction between season × dates of harvest × genotypes. This further indicates that some of the genotypes included are suited only for rainy season. Such genotype × environment interactions have been reported for yield and its component traits in groundnut (Norden *et al*., 1986; Cofflet *et al*., 1993).

The shelling outturn had mean values of 65, 69 and 72% at 85, 95 and 105 DAS harvest, respectively during rainy 2004, while the corresponding values during summer 2005 were considerably low at 33, 52 and 61%. As SP is highly influenced by day length and temperature (Bagnall and King, 1991), the poor shelling outturn obtained during summer could be attributed to the weather, which also determines the crop duration or maturity. The proportion of SMK varied widely depending upon the date of harvest both in rainy and summer seasons. At 85 DAS harvest, the mean SMK was 58% and 11.8% during rainy and summer seasons, respectively. At 95 DAS harvest, SMK was 64% (rainy) and 26% (summer), while at normal harvest the recovery of SMK was better with 70% (rainy) and 39% (summer). However, there was significant reduction in recovery of SMK during summer compared to rainy season even at normal harvest. The poor SMK obtained during summer could be again attributed to the prevailing weather as in case of SP. Another important yield attribute that denotes maturity also along with proportion of SMK is HSM. During rainy season the mean HSM values were 25, 30 and 32 g at

85, 95 and 105 DAS harvest, respectively, while the corresponding figures for summer were 14, 19 and 26 g.

Harvesting before the physiological maturity leads to considerable reduction in pod and kernel yield, seed mass and recovery of SMK. A genotype with shorter duration will have lesser reduction when harvesting is advanced compared to the one with longer duration, as the terminal phase of the crop growth is critical in determining the maturity. This formed the basis for the present study. The per cent reduction in yield and related traits when harvested at 85 and 95 DAS calculated over the corresponding yield levels of each of the genotypes at 105 DAS, or in other words the relative yield reduction due to advance in harvest, indicated genotypic differences for most of the traits. The test entries showed considerable reduction in pod and kernel yield when harvested at 85 DAS. However, at 95 DAS harvest the relative yield reduction was negligible in some of the genotypes. For pod yield, the reduction ranged from 5% (PBS 21031) to 40% (HNG 10) and 39% (PBS 12038) to 67% (PBS 11048) during the rainy and summer seasons, respectively when the crop was harvested 20 days before the normal harvest. But when harvesting was taken up only 10 days in advance the reduction was from 1% (PBS 11029 and PBS 28008) to 27% (PBS 18029) (rainy) and -1% (PBS 21031) to 60% (PBS 30076) (summer). The negative value actually indicates that there was some pod loss at normal harvest due to over maturity in the particular genotype. The relative reduction in yield and its component traits in some of the selected genotypes are presented in tables 2 and 3, respectively.

Table 2 Relative reduction (%) in yield component traits due to early harvesting over normal harvest in selected groundnut genotypes during rainy season of 2004

Genotype	Shelling outturn		HSM		SMK	
	85d	95d	85d	95d	85d	95d
PBS 11029	12	3	22	6	27	9
PBS 28008	4	1	7	2	9	4
PBS 21031	9	3	19	11	30	21
PBS 30076	12	6	33	15	25	8
PBS 11066	5	4	15	10	29	14
PBS 15004	8	3	28	12	37	20
PBS 29063	11	7	23	9	27	14
JL 24	10	3	22	1	11	6
HNG 10	23	3	51	8	25	9

d = Days after sowing

During rainy season the least reduction (< 10%) in pod yield was exhibited by genotypes PBS 21031 and PBS 11066 while PBS 15004 and 30076 recorded above 10% yield reduction but less than that observed in JL 24 at 85 DAS. At 95 DAS harvest, seven out of 18 genotypes (PBS Nos. 11029, 28008, 21031, 30076, 11019, 11066 and 15004) exhibited comparatively very low (< 5%) reduction in pod yield over the harvest at 105 DAS and the values were less than that observed in JL 24. The pod yield reduction at 85 DAS harvest during summer in PBS 12038 and PBS 21031 was 39% and 42%, respectively. However, PBS 21031 recorded pod yield on a par with the normal harvest when harvested at 95 DAS and less than 8% loss in kernel yield, thus indicating early maturity. Two other genotypes, PBS 28008 and 15004, which had exhibited very low yield reduction during rainy season, also showed less yield reduction (< 20%) during summer.

Table 3 Relative reduction (%) in yield component traits due to early harvesting over normal harvest in selected groundnut genotypes during summer season of 2005

Genotype	Shelling outturn		HSM		SMK	
	85d	95d	85d	95d	85d	95d
PBS 21031	39	10	44	12	29	12
PBS 12038	43	11	29	21	4	2
PBS 14027	41	7	47	14	29	10
PBS 28008	32	11	51	19	49	20
PBS 15004	38	10	51	30	52	36
PBS 29063	52	17	50	27	28	21
PBS 11066	53	17	51	30	52	29
PBS 11029	59	24	41	28	17	2

d = Days after sowing

During the rainy season of 2004, reduction in kernel yield varied from 13 to 54%, and 3 to 30% at 85 and 95 DAS harvest, respectively. The least reduction was observed in the genotype PBS 11066 (13%) followed by PBS 21031 (14%) at 85 DAS harvest. The reduction in kernel yield was less than 10% at 95 DAS harvest in seven genotypes, the least being in PBS 28008 (3%) and PBS 11029 (4%). The check varieties, JL 24 (9%) and HNG 10 (15%), showed comparatively larger reduction in kernel yield than the test genotypes. During the summer season, like pod yield, for kernel yield also there was larger reduction ranging from 60 to 82% (85 DAS) and 8 to 73% (95 DAS). Less than 10% reduction was recorded only in PBS 21031, while less than 25% reduction was recorded in PBS 12038 followed by PBS 14027, PBS 28008 and PBS 11019.

Perusal of data on both relative yield reduction (as a measure of earliness) and higher yield, the advanced breeding lines PBS 21031, PBS 11066, PBS 15004 and PBS 30076 exhibited lower yield loss than JL 24 with superior pod yield when harvested at 85 DAS. The highest yielder PBS 29063 had slightly higher yield loss. When harvested at 95 DAS four advanced breeding lines *viz*., PBS 11029, PBS 30076, PBS 11066 and PBS 21031 had numerical superiority over JL 24 for pod yield (17%, 16%, 13% and 6%, respectively) with below 5% yield loss, thus signifying earliness with high productivity. The reduction in kernel yield due to early harvest was also below 8% in these lines. The test entry PBS 29063, though recorded a slightly higher yield loss than JL 24, is found to be highly promising with high per day productivity and yield advantage of 39% over JL 24. The reduction in SP and HSM is also relatively low in these lines due to early harvesting. During summer, yield obtained at 85 DAS was extremely low and at 95 DAS, PBS 21031, the highest yielder, has shown no change in pod yield and least reduction in kernel yield over the produce obtained at 105 DAS, thus demonstrating early maturity. Besides, this culture had the least reduction in seed size as well as shelling out turn (< 10%). PBS 12038 that showed yield reduction less than 10% also had higher pod yield. During rainy season also this culture performed well next only to PBS 29063.

The promising cultures identified such as PBS 29063, PBS 21031, PBS 11066 and PBS 30076 had high SCMR and low to moderate SLA indicating the improved WUE in these advanced lines. Therefore, these cultures hold immense promise for semi-arid tropical regions.

To conclude, the present technique adopted taking into consideration the performance as well as relative yield reduction on advancing the harvest to identify early maturing genotypes holds promise in identifying cultures endowed with shorter duration coupled with high productivity. Among the genotypes, PBS 11029, PBS 21031, PBS 30076, PBS 11066, PBS 15004 and PBS 28008 were found early in maturity compared to the check JL 24 during rainy season, and PBS 21031 during summer along with high pod and kernel yield. These genotypes can be used as potential sources for early maturity, and can also be tested further to recommend for commercial cultivation in the end-of-season drought prone regions. The current field technique not only includes the maturity criteria followed by several workers like shelling, proportion of mature pods and kernels but also nullifies the influence of photo period and temperature through the identification of the genotypes which show considerably the least reduction in pod and kernel yield when harvesting was advanced over 10-20 days as compared to its corresponding yield levels at the normal period of harvest. The genotype which shows the least reduction at early harvest indicates the efficient partitioning of the assimilates from the source to sink which will indirectly aid in circumventing the moisture stress due to the ingress of drought especially at the later period of the crop.

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Sustainability of different cropping systems under varying sowing dates in Marathwada region

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ABSTRACT

The field experiments were carried out at Instructional Farm, AICRP on Dry land Agriculture, Marathwada Agricultural University, Parbhani during the rainy season of 2001-2005 on eight different cropping systems consisting of important food, pulse and oilseed crops of Marathwada region under varied weather conditions. The results revealed that intercropping of sorghum (CSH-9)+ pigeonpea, pear millet + pigeonpea and castor + soybean sown in 26 meteorological week (MW) produced the highest grain yield and average productivity of the system during all the years of experimentation as compared to rest of the cropping systems. Similarly, castor + soybean produced the highest sorghum grain equivalent which was at par with soybean + pigeonpea, *Arborium* cotton + soybean and cotton (NHH-44) + soybean. The sowing of all the crops and cropping systems on 26 MW recorded significantly highest sustainable yield index (0.52) as compared to sowing of all cropping systems on delayed sowing dates.

Keywords: Cropping systems, Grain yield, Oilseeds, Sustainable yield index

For feeding the burgeoning population and to meet the protein requirements there is an urgent need to increase production and productivity of grain legumes and oilseeds. As the scope to increase area under sole cropping is limited, the only alternative left is to increase the area through cropping systems intercropping and double cropping. The intercropping is a potentially beneficial system having substantial yield advantage over sole cropping with reduction in risk. Whereas, with the introduction of short duration hybrids and high yielding varieties, scope of double cropping is increased. Sowing time is the most important non monetary input affecting the crop yield. Even in photo and thermo insensitive crops, it is a critical input for higher yield. Delayed sowing invariably reduces the yields, whereas sowing early in the season may also not be advantageous as the crops does not receive favourable environment at various phenological stages. Therefore the present investigation was planned to study effect of different cropping systems under varied sowing dates.

MATERIALS AND METHODS

The field research was carried out during the rainy season of 2001 to 2005 at Instructional Farm, AICRP on Dryland Agriculture, Marathwada Agricultural University, Parbhani. Eight different promising cropping systems of important crops of Marathwada region were tested in varied weather condition under rainfed agriculture.

The experiment was laid out in split plot design with three replications. The treatment consisted of four sowing dates as a main plot D_1-26 meteorological week (MW) (29 June, 2000), D_2-28MW (14 July, 2000), D_3-30MW (28 July, 2000) and D_4-32MW (10 August, 2000) and eight cropping systems as a sub plot treatment having 32 treatment combinations. Eight cropping system comprises C_1-sorghum (CSH-9) + pigeonpea (BSMR-853) (4:2), C_2-HYV of sorghum (PVK-801) + pigeonpea (BSMR-853) (4:2), C_3-cotton (NHH-44) + soybean (MAUS-47) (1:1), C_4- improved *Arborium* cotton (TURAB) + soybean (MAUS-47) (1:1), C_5-pearlmillet (AIMP-92-901) + pigeonpea (BSMR-853) (3:3), C_6-soybean (MAUS-47) + pigeonpea (BSMR-853) (4:2), C_7-castor (DCS-9) +soybean (MAUS-47) (1:1) and C_8 - greengram (BM-4) + winter sorghum (M-35-1). The recommended dose of fertilizer was given as per recommendations for individual crops. All the recommended inter cultivation and plant protection measures were followed:

Sustainable Yield Index (SYI)

The sustainable yield index (SYI) is defined as:

$$SYI = \frac{\overline{Y} - \sigma}{Y_{max}}$$

Where y is the estimated average yield of a practice over years, σ is its estimated standard deviation and Y_{max} is the observed maximum yield in the experiment. In calculating SYI the negative values of (y - σ) should be taken as zero since yield is always a positive quantity. With this premise, the index taken values between zero and unity. In this index σ quantify the risk associated with the average performance y of a treatment. When σ =0 and y = y_{max}, SYI = 1. This is an ideal treatment. This treatment gives consistently maximum yield in all the years. But invariably in biological system σ is always greater than zero since there exits variations in the yield over years because of the variation in the distribution of rainfall and other factors of the standard deviation is very high then the value of the index will be less, there by indicating the unstable nature of the practice. In case when there is no significant difference in the variances associated with each treatment over years, then the index is proportional to the mean values of the treatments. But in general, under dryland conditions, heterogeneity exists in treatment variances since the treatments interact with the environment. For generalizing the interpretations of the values of the index, there should be sufficient number of years representing the range of variations commonly observed at a given locations. Further, characterization of the environment is important for interpreting index, particularly when comparing the values of the index at different locations. Therefore, data from the experiments conducted for at least two years and in most of the cases more than two years have been considered for this study.

In general, the treatment having high mean and low standard deviation is preferred. But the possible types of situations to come across are: (I) High mean and low standard deviation; (ii) High mean and high standard deviation; (iii) Low mean and low standard deviation and (iv) Low mean and high standard deviation

The last and the first situations are duly distinguished by the index SYI. The first situation leads to high value and the fourth situation leads to low value of the index. In some cases the index may fail to distinguish between the second and the third situations. In the second group, the treatments are responsive but unstable, whereas in the third group they are not responsive but stable. When the index has similar values for the treatments failing in the second and third group, the selection of the treatments depends on certain constraints on Y and σ. The risk aversive farmer may select the treatment with greater Y. The index does not say anything about the absolute value of the average yield. Hence the index may be supplemented with average yield. However, SYI denotes the minimum guaranteed yield as a per cent to the maximum observed yield with high probability. Under dryland conditions, maximization of minimum sustainable yield over years is important as mentioned earlier. The index SYI will help in assessing the treatments in the light of sustainable yield.

The mean and the standard deviation are estimated by

$$\textbf{Estimated mean} = \overline{\mathbf{Y}} = \frac{\sum \mathbf{y_i}}{\mathbf{N}}$$

$$\textbf{Estimated standard deviation} = \frac{\sqrt{\sum \mathbf{Y_i^2} - (\sum \mathbf{Y_i})\mathbf{2/n}}}{(\mathbf{n-1})}$$

Where,
Y_i is the yield in the i[th] year and
n = number of years

RESULTS AND DISCUSSION

Grain yield: Intercropping of sorghum (CSH-9) + pigeonpea (BSMR-853) (C_1), pearl millet (AIMP-92-901) + pigeonpea (BSMR-853) (C_5) and castor (DCS-9) + soybean (MAUS-47) sown on 26 MW produced the highest grain yield of the cropping systems in all the years of experimentation as compared to rest. It was followed by *Arborium* cotton (TURAB) + soybean (MAUS-47) (D_1C_4) which was comparable with the treatment combination of soybean (MAUS- 47) + pigeonpea (BSMR-853) (D_1C_6). Similarly, under late sown condition (15 days after normal sowing), soybean (MAUS-47) + pigeonpea (BSMR-853) recorded highest grain yield followed by pearl millet (AIMP-92-901) + pigeonpea (BSMR-853) cropping system.

Productivity of the system: Normal sowing on 26 MW recorded the highest mean productivity during all the years of experimentation and in pooled data, respectively. The lowest mean productivity was observed when sowing of all the cropping systems was taken up in D_4 (32 MW).

Amongst the different cropping systems under study, C_5- pearl millet (AIMP-92-901) + pigeonpea (BSMR-853) and castor (DCS-9) + soybean (MAUS-47) (C_7) recorded significantly higher productivity of 2154 and 1954 kg/ha in pooled data and was significantly higher than the productivity obtained in rest of the cropping systems. The lowest productivity was recorded by sorghum (CSH-9) + pigeonpea (BSMR-853) (C_1) followed by sorghum (PVK-801) + pigeonpea (BSMR-853) (C_2). Decrease in yield with delayed sowing was reported in pigeonpea (Saxena *et al.*, 1977); sorghum; castor (Deokar *et al.*, 1977); pearl millet (Kaushik and Gautam, 1984) and *deshi* cotton (Sharma *et al.*, 1989).

Sorghum grain equivalent yield: The pooled analysis revealed that castor (DCS-9) + soybean (MAUS-47) (C_7) produced the highest sorghum grain equivalent which was at par with soybean (MAUS-47) + pigeonpea (BSMR-853), *Arborium* cotton (TURAB)+ soybean (MAUS-47) and cotton (NHH-44) + soybean (MAUS-47) and they were found significantly superior over rest of the cropping systems. The lowest sorghum grain equivalent yield was recorded by green gram (BM-4)+ winter sorghum (M-35-1) (C_8) and sorghum (CSH-9) + pigeonpea (BSMR-853) (C_1).

Table 1 Grain yield of various cropping systems under different sowing dates (Average of 5 years from 2000-2005)

Treatment	Mean grain yield (kg/ha)							
	D_1 (29 June)		D_2 (14 July)		D_3 (28 July)		D_4 (10 August)	
	M	I	M	I	M	I	M	I
Cropping system								
C_1 Sorghum (CSH-9) + Pigeonpea (BSMR853) (4:2)	2104	874	--	894	--	756	--	536
C_2 HYV.Sorghum (PVK-801)+Pigeonpea (BSMR-853) (4:2)	1732	1034	--	912	--	735	--	571
C_3 Cotton(NHH-44)+Soybean (MAUS-47) (1:1)	1078	1462	791	802	561	484	448	433
C_4 *Arborium* Cotton (TURAB)+ Soybean (MAUS-47) (1:1)	918	1655	613	990	446	531	417	435
C_5 Pearlmillet (AIMP-92-901) +Pigeonpea (BSMR-853) (3:3)	1861	1013	1721	818	1379	675	1047	520
C_6 Soybean (MAUS-47) + Pigeonpea (BSMR-853) (4:2)	1535	1006	826	896	554	753	400	517
C_7 Castor (DCS-9)+ Soybean (MAUS-47) (1:1)	1757	1104	1695	741	1348	476	1108	357
C_8 Greengram (BM-4)+ Winter Sorghum (M-35-1)	667	1434	301	1421	110	1198	73	1154
Mean	1457	1198	991	934	733	701	582	565

Note: The sowing of all the treatments were undertaken as D_1 (29 June), D_2 (14 July), D_3 (28 July), D_4 (10 August) and sowing dates were kept constants from 2001 to 2005 for every year.

Table 2 Productivity of different cropping systems as influenced by various sowing dates

	Productivity (kg/ha)						Sorghum grain equivalent yield (pooled)	Sustainable yield index
	2001	2002	2003	2004	2005	Pooled mean		
Sowing date								
D_1-26 MW	2211	2704	2128	2689	2845	2515	6058	0.523
D_2-28 MW	1508	1150	1648	1994	1820	1704	4702	0.376
D_3-30 MW	906	969	856	1633	1557	1184	3208	0.174
D_4-32 MW	752	822	421	1069	1320	878	2257	0.08
CD (P=0.05)	104	69	62	125	182	200	1130	0..72
Cropping system								
C_1 Sorghum(CSH-9)+Pigeonpea (BSMR-853) (4:2)	956	1065	1170	1373	1365	1158	3308	0.185
C_2 HYV.Sorghum (PVK-801) +Pigeonpea (BSMR-853) (4:2)	982	1100	1159	1278	1634	1231	3393	0.178
C_3 Cotton(NHH-44)+Soybean (MAUS-47) (1:1)	1062	1107	811	1733	2045	1351	4501	0..68
C_4 *Arborium* Cotton (TURAB) + Soybean (MAUS-47) (1:1)	1235	1515	1043	2003	1427	1444	4662	0.205
C_5 Pearlmillet (AIMP-92-901)+Pigeonpea (BSMR-853) (3:3)	1765	1985	1788	2510	2723	2154	4074	0.458
C_6 Soybean (MAUS-47) + Pigeonpea (BSMR-853) (4:2)	1243	1450	1133	1871	1857	1510	4642	0.211
C_7 Castor (DCS-9) + Soybean (MAUS-47) (1:1)	1539	2078	1640	2282	2231	1954	4760	0.562
C_8 Greengram (BM-4)+Winter Sorghum (M-35-1)	1573	1567	1361	1319	1401	1524	3112	0.439
CD (P=0.05)	116	84	116	160	291	164	CD at 5%	116
Interaction (DxC)								
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	0.195

Note: The sowing of all the treatments were undertaken as D_1 (29 June), D_2 (14 July), D_3 (28 July), D_4 (10 August) and sowing dates were kept constants from 2001 to 2005 for every year.

Sustainable yield index: Sowing of all the crops and cropping systems on 26 MW (D_1) recorded significantly highest values of sustainable yield index (0.52) as compared to delayed sowing. This clearly indicates significance and suitability of this sowing date (26 MW) in maintaining the sustainability of cropping systems. It was followed by D_2 i.e., 28 MW (0.376) which was significantly superior over rest of the sowing dates. However, sowing at 32 MW had recorded lowest values (0.08) indicating non suitability of this sowing date for most of the cropping systems under study.

Among all the cropping system under study, castor (DCS-9) + soybean (MAUS-47) (D_1C_7) recorded highest values for sustainable yield index thereby clearly indicating its high degree of stability and sustainability under all the dates of sowing under varied environmental conditions. It was followed by pearl millet (AIMP-92-901) + pigeonpea (BSMR-853) (D_1C_5) which was comparable with green gram (BM-4) + winter sorghum (M-35-1) (D_1C_8) and both of them recorded significantly higher sustainable yield index as compared to rest of the crops and cropping systems. The cropping systems cotton (NHH-44) + soybean(MAUS-47), sorghum (CSH-9) + pigeonpea (BSMR-853) and HYV sorghum (PVK-801) + pigeonpea (BSMR-853) recorded lowest values for sustainable yield index thereby indicating their unstability and unsuitability under varied environmental conditions over a period of time. Further on the basis of two way table, it can be stated that pearl millet (AIMP-92-901) + pigeonpea (BSMR-853) sown on 26 MW and castor (DCS-9) + soybean (MAUS-47) sown on 28 MW and 26 MW recorded highest degree of sustainability as compared to rest of the treatment combinations. Similarly, Mulik *et al.* (1996) reported that pearl millet + pigeon pea integrated cropping system was more sustainable. Similarly, stable productivity under varied weather conditions in intercropping of pigeon pea with soybean and sorghum was observed (Anonymous, 1999).

Table 3 Interaction effect of cropping system and sowing dates as sustainable yield index

Treatment	Sustainable yield index				
Cropping System	D_1 (29 June)	D_2 (14 July)	D_3 (28 July)	D_4 (10 August)	Mean
C_1 Sorghum(CSH-9)+Pigeonpea (BSMR-853) (4:2)	0.50	0.17	0.05	0.01	0.18
C_2 HYV.Sorghum (PVK-801)+Pigeonpea (BSMR-853) (4:2)	0.53	0.13	0.01	0.02	0.17
C_3 Cotton(NHH-44)+Soybean (MAUS-47) (1:1)	0.44	0.33	0.07	-0.42	0.06
C_4 *Arborium* Cotton (TURAB)+ Soybean (MAUS-47) (1:1)	0.47	0.35	0.02	-0.02	0.20
C_5 Pearlmillet (AIMP-92-901)+Pigeonpea (BSMR-853) (3:3)	0.68	0.45	0.37	0.23	0.45
C_6 Soybean (MAUS-47)+Pigeonpea (BSMR-853) (4:2)	0.46	0.47	0.06	-0.14	0.21
C_7 Castor (DCS-9)+ Soybean (MAUS-47) (1:1)	0.61	0.64	0.50	0.48	0.56
C_8 Greengram (BM-4)+Winter Sorghum (M-35-1)	0.48	0.35	0.43	0.48	0.43
Mean	0.52	0.37	0.17	0.08	0.28

SEm± = 0.071; CD (P=0.05) = 0.195

Note: The sowing of all the treatments were undertaken as D_1 (29 June), D_2 (14 July), D_3 (28 July), D_4 (10 August) and sowing dates were kept constants from 2001 to 2005 for every year.

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Effect of chemical fertilizers and microbial inoculants on nodulation, yield, uptake of nutrients and quality of soybean [*Glycine max* (L.) Merrill.]

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ABSTRACT

Field experiments were conducted during the rainy season of 2009 and 2010 at Research Farm of Marathwada Agricultural University, Parbhani, to study the effect of chemical fertilizers and microbial inoculants on nodulation, yield, uptake of nutrients (NPKS) and quality of soybean [*Glycine max* (L.) Merrill.]. The experimental soil was clayey with pH 8.30. It was low in organic carbon, nitrogen and medium in phosphorus and high in potassium. Treatments comprised of three levels of fertility (100% RDF, 75% RDF and control) and four treatments of bioinoculants (*Bradyrhizobium*, PSB, *Bradyrhizobium* + PSB and uninoculated control). The experiment was laid out in factorial randomized block design with four replications. The results revealed that application of 75% RDF showed significantly higher number of nodules and leghaemoglobin content in nodules, 100% RDF found to have higher grain and straw yields, total nutrient uptake (NPKS) and quality parameters of soybean. Combined inoculation with *Bradyrhizobium* + PSB recorded significantly higher nodule character leghaemoglobin content of nodule, yield, nutrient, uptake and quality parameters of soybean

Keywords: Bioinoculants, Nodule character, Nutrients uptake, Quality, Soybean, Yield

Biofertilizers enhance soil fertility and crop yield by fixing atmospheric nitrogen and solubilizing fixed sources of elemental nitrogen (N) and bound phosphate (P) into available forms in order to facilitate the plant to absorb them. It is well established that Rhizobium and phosphate solubilizing bacteria (PSB) have capability in augmenting the productivity of pulses through N and P needs considerably (Singh and Pareek, 2003). Oilseed and legumes have relatively higher P requirements over other crops as it is a constituent of phospholipids, which are important in the formation of cell membrane and its permeability. In P deficient soils, seed inoculation or soil based application of phosphate solubilizing microorganisms may benefit the crops by increasing P availability. Integrated use of chemical fertilizers and manures along with biofertilizers has potential to achieve sustained food production. The present investigation was carried out to evaluate the effect of combined application of fertilizers and biofertilizers on growth and quality of soybean [*Glycine max* (L.) Merrill.].

MATERIALS AND METHODS

A field experiment was carried out during 2009-10 and 2010-11 at the Research Farm of Marathwada Agriculture University, Parbhani. It was laid out in factorial randomized block design with four replications. Factor 1 consist of three levels of chemical fertilizers (T_1:100% RDF, T_2: 75% RDF and T_3:Control) and factor 2 was having four levels of biofertilizers i.e., (S_1:*Bradyrhizobium*, S_2:PSB, S_3:Bradyrhizobium + PSB and S_4=uninoculated control). Seed inoculation was done with *Bradyrhizobium japonicum* and *Bacillus megaterium* (PSB) @ 250 g each/10 kg seed as seed treatment before sowing. The mixture of 250 g of Bradyrhizobium japonicum, PSB culture + 150 ml jaggery solution (2%) was added to 10 kg seed and mixed thoroughly. After mixing, the uniformly coated seeds were dried under shade. The sowing of soybean (cv. MAUS 71) was done by dibbling at 75 cm x 45 cm spacing. The recommended dose of chemical fertilizers was applied @ 30:60:30 N, P_2O_5 and K_2O kg/ha through urea, SSP and muriate of potash. A basal dose of fertilizer was applied as per treatment at the time of sowing to soybean. Plant protection measures were followed as per recommendations. Observations were recorded on five plants randomly selected from each plot. The grain and straw yields were recorded in the net at crop maturity. Nutrient content and uptake by in seed and straw was estimated. The seed and oil yield (kg/ha) were computed.

RESULTS AND DISCUSSION

During both the years, significant increase in the nodule number, fresh nodule weight, dry weight of nodule and leghaemoglobin of nodule was noticed because of the application of 75% RDF (Table 1). Nodule number, fresh and dry weight of nodule was recorded highest at flowering stage than at pod formation stage. Application of 100% RDF suppressed the nodulation at flowering and pod formation stage of soybean as compared to 75% RDF. Higher doses of N through fertilizers might have resulted in poor activity of

Rhizobium in the soybean rhizosphere. This could be the reason for antagonistic effect between *Rhizobium* and higher doses of N application (Lanier *et al*., 2005). The improvement in leghaemoglobin content in nodule with the corresponding increase in P_2O_5 levels might be attributed to profuse nodulation leading to increase N fixation.

Bioinoculation either as single or in combination resulted in significant improvement in nodule number, fresh weight of nodules, dry weight of nodules and leghaemoglobin content of nodule. Better nodulation in combined application might be due to increased P availability through PSB and enchased biological N_2 fixation (Jat, 2004 and Gupta, 2006).

The seed yield differences were found significant due to different fertility levels during both the years (Table 1). An application of 100% RDF recorded maximum grain (1732 and 1811 kg/ha) and straw yield (2331 and 2378 kg/ha), which was found significantly superior over 75% RDF and control. The study clearly proved the role of N in the promotion of vegetative growth. The increase in seed yield with the application of P might be due to the beneficial effect of P on root development, flower primordial initiation, stimulation of growth, formation and maturity of seeds as given by Patel *et al*. (2010).

Seed inoculation with bioinoculants proved superior to no inoculation with respect to grain and straw yield. Yield of soybean was significantly influenced by different bioinoculants treatments during both the years. Combined application of *Bradyrhizobium* + PSB might be responsible for higher seed yield. The synergistic effect of *Rhizobium* and PSB in seed yield might be due to increased enzyme activities and available P status of soil. Similar findings were reported by Rajpal *et al*. (2003).

Total nutrient (NPKS) uptake was increased significantly with each successive increase of fertilizer upto 75 and 100% RDF (Table 2). The uptake of N,P,K and S was highest due to 100% RDF and was least in control during both the years (Table 2).

Nutrient uptake increased significantly due to inoculation with biofertilizers as compared to control. Combined application of *Rhizobium* + PSB had superior effect on nutrient uptake over their individual application during both the years. The increase in total NPK uptake might be attributed to more biological N-fixation by *Rhizobium*, N-assimilation and increased availability of P in soil due to greater solubilization of insoluble phosphates by PSB. (Sarawgi *et al*., 1998). Singh *et al*. (2007) reported that the higher P, N and S uptake with seed inoculation of *Rhizobium* and PSB in pea.

Progressive and significant increase in protein content, protein yield, oil content and oil yield in soybean grain was obtained with the increasing levels of fertility during both the years (Table 3). Application of 100% RDF significantly improved above parameters. The supply of sufficient quantities of N and P from the soil may have assisted the plant to maintain higher crude protein content (Nandhagopal *et al*., 2003). The increased protein yield and oil yield might be attributed to higher content of protein, oil content and seed yield under better treatments.

Table 1 Effect of chemical fertilizers and bioinoculants on nodule characters and yield of soybean

Treatment	Nodule/plant (No)				Fresh weight of nodules (g)				Dry weight of nodule (g)				Leghaemoglobin (mg/g) nodules		Grain yield (kg/ha)		Straw yield (kg/ha)	
	2009		2010		2009		2010		2009		2010		2009	2010	2009	2010	2009	2010
	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2						
Chemical fertilizer (T)																		
T_1-100% RDF	37.51	25.23	35.44	22.11	0.54	0.37	0.56	0.40	0.28	0.19	0.28	0.20	0.51	0.48	1732	1811	2331	2378
T_2-75% RDF	44.32	29.32	41.74	25.50	0.67	0.42	0.71	0.45	0.34	0.22	0.36	0.24	0.57	0.57	1609	1714	2212	2294
T_3-Control	33.00	21.95	30.95	20.11	0.47	0.28	0.47	0.29	0.22	0.16	0.26	0.19	0.42	0.37	1336	1501	1937	2049
SEm±	1.69	0.19	0.20	0.59	0.001	0.001	0.002	0.002	0.02	0.009	0.02	0.01	0.01	0.01	30.0	25.8	42.0	26.9
CD (P=0.05)	4.50	0.51	0.54	1.65	0.004	0.004	0.005	0.005	0.05	0.024	0.05	0.03	0.03	0.04	83.1	71.3	116.2	74.4
Biofertilizer (S)																		
S_1- *Bradyrhizobium*	42.51	27.53	38.61	23.70	0.60	0.39	0.63	0.41	0.31	0.20	0.33	0.22	0.55	0.53	1608	1717	2198	2267
S_2- PSB	37.49	25.06	35.64	22.36	0.56	0.36	0.58	0.39	0.28	0.18	0.29	0.20	0.52	0.49	1525	1647	2152	2237
S_3- *Bradyrhizobium* + PSB	43.17	29.37	40.65	24.72	0.68	0.43	0.72	0.45	0.35	0.24	0.37	0.25	0.59	0.58	1707	1806	2285	2356
S_4- Control	30.31	20.37	29.27	19.52	0.40	0.25	0.40	0.26	0.22	0.14	0.20	0.15	0.33	0.28	1396	1531	2006	2101
SEm±	2.07	0.21	0.23	0.69	0.001	0.002	0.002	0.002	0.02	0.010	0.02	0.01	0.01	0.02	34.7	21.0	48.5	31.1
CD (P=0.05)	5.73	0.59	0.63	1.91	0.004	0.005	0.006	0.006	0.05	0.027	0.05	0.04	0.04	0.04	96.0	82.3	134.1	85.9

S_1 : Flowering stage; S_2:Pod formation stage

Table 2 Effect of chemical fertilizers and bioinoculants on nutrient uptake of soybean

Treatment	Uptake (kg/ha)							
	N		P		K		S	
	2009	2010	2009	2010	2009	2010	2009	2010
Chemical fertilizer (T)								
T_1-100% RDF	128.75	132.83	22.87	23.19	53.97	55.34	12.43	12.66
T_2-75% RDF	114.22	118.89	18.32	18.44	45.71	47.98	9.75	10.32
T_3-Control	89.47	96.63	11.23	12.35	34.06	36.68	6.80	7.48
SEm±	2.11	3.12	0.62	0.62	2.02	1.33	0.45	0.52
CD (P=0.05)	7.90	9.03	1.68	1.68	5.88	4.04	1.26	1.48
Biofertilizer (S)								
S_1- *Bradyrhizobium*	116.38	121.24	17.75	18.01	45.46	47.71	10.39	10.65
S_2- PSB	107.96	113.84	18.28	19.04	45.09	46.73	9.33	10.02
S_3- *Bradyrhizobium* + PSB	126.62	131.07	21.65	22.53	52.48	54.51	11.66	12.25
S_4- Control	92.28	98.33	12.20	12.39	35.20	37.71	7.26	7.69
SEm±	3.05	4.03	0.75	0.68	2.08	2.01	0.55	0.63
CD (P=0.05)	8.91	10.68	1.80	1.86	5.97	5.92	1.48	1.69

Table 3 Effect of chemical fertilizers and bioinoculants on quality parameter of soybean

Treatment	Crude protein content (%)		Protein yield (kg/ha)		Oil content (%)		Oil yield (kg/ha)	
	2009	2010	2009	2010	2009	2010	2009	2010
Chemical fertilizer (T)								
T_1-100% RDF	37.68	37.61	653.91	682.62	19.37	19.67	336.74	357.36
T_2-75% RDF	36.32	36.22	586.23	622.22	18.28	18.54	294.89	318.65
T_3-Control	34.41	34.29	460.81	515.02	17.22	17.49	230.28	262.63
SEm±	0.09	0.04	1.78	0.90	0.03	0.008	0.62	0.50
CD (P=0.05)	0.26	0.12	4.91	2.68	0.07	0.023	1.71	1.36
Biofertilizer (S)								
S_1- *Bradyrhizobium*	36.82	36.65	594.39	631.27	18.64	18.83	301.68	324.74
S_2- PSB	36.09	36.04	551.70	595.01	18.19	18.56	278.53	306.83
S_3- *Bradyrhizobium* + PSB	37.58	37.36	644.37	677.29	19.02	19.41	326.87	352.29
S_4- Control	34.04	34.11	477.47	522.90	17.30	17.47	242.12	267.66
SEm±	0.11	0.05	2.05	1.08	0.03	0.010	0.71	0.50
CD (P=0.05)	0.30	0.14	5.67	3.00	0.08	0.027	1.97	1.50

Seed inoculation with *Bradyrhizobium* + PSB recorded significant higher crude protein content and oil content in soybean. At the same time inoculation of *Bradyrhizobium* or PSB alone also improved the above parameters. This improvement might have been due to increased N and grain, as N is an integral part of P contents in grain. Similar results were also obtained by Panwar *et al.* (2002). Zalate and Padmini (2009) reported that seed inoculation with *Rhizobium* + PSB significantly increased protein content and oil yield in groundnut. Singh and Sinsinwar (2006) noted that N levels with biofertilizer increased the oil content positively and hence, resulted in increasing trend in oil yield of mustard.

Thus, application of 75% RDF significantly increased nodule characters and leghaemoglobin content of nodule in soybean. However, 100% RDF improved seed and straw yields, nutrients uptake (NPKS) and quality parameters of soybean. Combined inoculation of *Bradyrhizobium* + PSB also significantly improved nodule character, leghaemoglobin content of nodule nutrients uptake yield, and quality parameters of soybean.

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Studies on yield and economics of sunflower (*Helianthus annuus* L.) hybrids and varieties as influenced by different fertilizer levels

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ABSTRACT

A field experiment was conducted during the rainy season of 2008, 2009 and 2010 on Vertisol at Oilseeds Research Station, Latur to assess the productivity and response of sunflower (*Helianthus annuus* L.) hybrid and varieties to fertilizer inputs. Three hybrids along with two varieties were evaluated with four levels of fertilizer inputs. The result indicated that hybrids were superior over varieties. Sunflower hybrid LSFH-35, gave highest seed yield and monetary returns. The response to fertilizer was significant up to 150% RDF (90:45:45 NPK kg/ha).

Keywords: Fertilizer, Sunflower

Nutrient requirement of sunflower (*Helianthus annuus* L.) hybrids is different as that of varieties. Sunflower hybrids require more nutrients than varieties. The low productivity of sunflower has been thus linked with imbalanced and inadequate nutrient application to highly rich energy crop. Nutrient management is one of the important factors for getting high yield of sunflower. Keeping this in view, an attempt has bee made to assess the fertilizer requirement of sunflower hybrids over varieties.

MATERIALS AND METHODS

A field experiment was conducted in rainy season of 2008, 2009 and 2010 at Oilseeds Research Station, Latur. The field experiment was laid out in split plot design on Vertisol with four fertilizer levels *viz*., 0, 50, 100 and 150% RDF as main plot treatments and five genotypes *viz*., DRSF-108, LSF-08, DRSH-01, LSFH-35 and Jwalamukhi as sub-plot treatments replicated twice. Among these five genotypes DRSF-108 and LSF-08 are varieties while DRSH-01, LSFH-35 and Jwalamukhi are hybrids. The soil was clayey in texture, slightly alkaline in nature containing low available nitrogen (152, 145 and 168 kg/ha), medium in available phosphorus (24.20, 20.71 and 26.07 kg/ha) and high in available potassium (478, 432 and 512 kg/ha). Half dose of nitrogen and full dose of phosphorus and potassium was applied at planting and remaining half dose of nitrogen was applied after one month after sowing. The crop was planted with spacing of 60 cm x 30 cm. The sowing was done on 27th, 8th and 9th July and harvested on 25th, 1st and 2nd October during 2008, 2009 and 2010, respectively. Standard package of practices were adopted for raising the crop. Data on various variables were analyzed by analysis of variance (Panse and Sukhatme, 1967) and pooled analysis for three years was computed (Cochran and Cox, 1957). Total rainfall received during experimental period was 873.3, 661.5 and 992.2 mm during 2008, 2009 and 2010 distributed over 29, 38 and 63 rainy days, respectively.

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RESULTS AND DISCUSSION

Performance of sunflower varied significantly due to different levels of fertilizer. Results during 2008 revealed that the application of 150 % RDF recorded highest seed yield of sunflower which was at par with 100% RDF but significantly superior over 50% RDF and control. During 2009, 2010 and pooled results application of 150% RDF produced significantly higher seed yield over 100, 50% RDF and control. The linear response of sunflower to fertilizer up to 150% RDF may be because of higher photosynthetic activity and effective translocation of photosynthates to sink, which resulted in better development of thalamus, good seed filling and consequently higher yield. Similar findings were also reported by Sabale (2003), Sivamuruygan *et al.* (2003) and Gudade *et al.* (2009).

Seed yield of sunflower hybrids and varieties varied significantly among themselves. During 2008 sunflower hybrids LSFH-35 recorded significantly highest seed yield over all the hybrids and varieties. During 2009 sunflower hybrid Jwalamukhi produced significantly higher seed yield over all the hybrids and varieties except hybrid DRSH-01. During 2010 and pooled results sunflower hybrids LSFH-35 recorded significantly highest seed yield, which was at par with hybrid Jwalamukhi but significantly superior over the hybrid DRSH-01 and varieties DRSF-108 and LSF-08. In general, performance of sunflower hybrid was found to be superior over varieties in producing sunflower yield. The results are in concordance with the findings of Hegde (2009).

Table 1 Seed yield of sunflower as influenced by different treatments

Treatment	Yield (kg/ha)			
	2008	2009	2010	Pooled mean
Fertilizer level (4)				
0 % RDF	1234	1030	592	952
50 % RDF	1467	1176	717	1120
100 % RDF	1674	1278	892	1281
150 % RDF	1798	1440	1058	1432
SEm±	49	43	22	26
CD (P=0.05)	146	128	65	72
Genotype (5)				
DRSF-108	1243	1202	556	1000
LSF-08	1358	832	613	935
DRSH-01	1462	1473	802	1246
LSFH-35	2010	1144	1083	1412
Jwalamukhi	1641	1504	1020	1389
SEm±	38	39	32	58
CD (P=0.05)	114	118	95	161
Interaction (FxG)				
SEm±	76	79	63	116
CD (P=0.05)	NS	NS	NS	NS

Table 2 Gross momentary returns, net monetary returns and benefit : cost ratio of sunflower as influenced by different treatments

Treatment	GMR (₹/ha)				NMR (₹/ha)				B:C ratio			
	2008	2009	2010	Pooled mean	2008	2009	2010	Pooled mean	2008	2009	2010	Pooled mean
Fertilizer level (4)												
0 % RDF	24680	22660	14800	20713	11930	9380	3000	8103	1.94	1.70	1.25	1.63
50 % RDF	29340	25872	17925	24379	15730	11732	5375	10946	2.15	1.83	1.42	1.8
100 % RDF	33480	28116	22300	27965	19020	13116	9000	13712	2.32	1.87	1.67	1.95
150 % RDF	35960	31680	26450	31363	20640	15820	12400	16287	2.35	2.00	1.87	2.07
SEm±	977	943	544	519	977	943	544	544	0.06	0.05	0.04	0.04
CD (P=0.05)	2925	2823	1630	1437	2925	2823	1630	1504	NS	0.14	0.12	0.11
Genotype (5)												
DRSF-108	24860	26444	13900	21735	10825	12249	1530	8201	1.76	1.87	1.12	1.58
LSF-08	27160	18326	15325	20270	13125	4131	2955	6737	1.93	1.28	1.23	1.48
DRSH-01	29240	32406	20050	27232	15205	17586	6755	13182	2.08	2.18	1.50	1.92
LSFH-35	40200	25168	27075	30814	26165	10348	13780	16764	2.84	1.69	2.02	2.18
Jwalamukhi	32820	33088	25500	30469	18785	18268	12205	16419	2.32	2.22	1.88	2.14
SEm±	762	867	793	1258	762	867	793	1255	0.05	0.05	0.06	0.09
CD (P=0.05)	2282	2596	2373	3482	2282	2596	2373	3474	0.16	0.17	0.18	0.25
Interaction (FxG)												
SEm±	1525	1734	159	2517	1525	1734	159	2510	0.11	0.11	0.12	0.18
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Prices considered (₹-qt) = 2008 : ₹ 2000/q; 2009: ₹ 2200/q; 2010: ₹ 2500/q

Gross monetary returns (GMR), net monetary returns (NMR) and benefit : cost ratio (B:C ratio) of sunflower were affected significantly with the increasing levels of fertilizer. During 2008 application of 150% RDF recorded significantly highest GMR and NMR over 50% RDF and control and was at par with 100% RDF. Benefit-cost ratio was found to be non-significant. During 2009 significantly highest GMR was recorded with the application of 150% RDF over all the lower levels of fertilizers. Application of 150% RDF recorded highest NMR and B:C ratio which was at par with 100% RDF but significantly superior over 50% RDF and control. During 2010 and pooled results application of 150% RDF recorded significantly highest GMR, NMR and B:C ratio over 100%, 50% RDF and control.

Among genotypes sunflower hybrids LSFH-35 recorded significantly highest GMR , NMR and B:C ratio over all the hybrids and varieties during 2008. During 2009 sunflower hybrid Jwalamukhi recorded significantly higher GMR, NMR and B:C ratio over all the hybrids and varieties except hybrid DRSH-01. During 2010 and pooled results sunflower hybrids LSFH-35 recorded significantly highest GMR, NMR and B:C ratio, which was at par with hybrid Jwalamukhi but significantly superior over the hybrid DRSH-01 and varieties DRSF-108 and LSF-08. The present findings corroborate with earlier reporter of Kandalkar *et al.* (2009).

From the above investigation it can be concluded that in Vertisols, under rainfed conditions, sunflower hybrids were superior over varieties and application of 150% RDF i.e., 90:45:45 kg NPK/ha was more beneficial for getting higher sunflower yield and returns.

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Evaluation of sunflower genotypes for phosphorus acquisition and phosphorus partitioning

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ABSTRACT

Field trials were conducted during winter season of 2010 and 2011 to evaluate a total of 111 (52+59) sunflower genotypes for phosphorus (P) acquisition in Vertisols having low status of available phosphorus (9.8 kg/ha). During the study the best genotypes were selected based on the following parameters: shoot drymatter yield, seed yield/plant, shoot P content, seed P content and total P removal. In the first year 22 best performing genotypes out of 52 were selected while, 20 genotypes were selected out of 59 in second year (2011-12). Genotype CMS-42-B had recorded highest P removal (1.71g/plant) followed by KBSH-44 (1.62 g/plant)> 150-R (1.41 g/plant) >ARM-239-B (1.33 g/plant) > GMU-389 (1.31 g/plant) > KBSH-1 (1.30 g/plant) in first year. The phosphorus acquisition in sunflower genotypes depended on their shoot drymatter, seed yield and their P contents. During 2011-12, the highest P removal was recorded in GMU-38 (2.2 g/plant) followed by GMU-128, KBSH-1, KBSH-44, GMU-3, GMU-5, DRSH-1, GMU-116 and CMS-42-B in descending order. It was noticed that genotype CMS-42-B was found best in acquiring P in both the years of study with 51% of its uptake was partitioned into seeds in 2010-11 and 52.3% in 2011-12. Though, CMS-42-B had removed lower amounts of total phosphorus (1.68 g/plant), it showed high internal distribution of acquired phosphorus towards seed (52.3%) in comparison to genotypes GMU-38, GMU-5 and KBSH-1.

Keywords: Acquisition, Biomass, Genotypes, Phosphorus, Sunflower, Uptake

Among many inorganic nutrients required by plants, phosphorus (P) is one of the most important elements that significantly affect plant growth and metabolism. It plays an important role in photosynthesis, respiration and regulation of a number of enzymes. Phosphorus can be a major limiting factor for plant growth with increasing demand of agricultural production and it is receiving more attention as a non renewable resource (Cordell *et al*., 2009 and Gilbert, 2009). Availability of P in neutral to calcareous soils is a matter of great concern, as its retention is dominated by precipitation reactions (Lindsay *et al*., 1989) and it can also be adsorbed on the surface of calcium carbonate and clay minerals (Devau *et al*., 2010). Phosphate can precipitate with free Ca thereby forming dicalcium phosphate (DCP) that is available to plants. Ultimately, DCP can be transformed into more stable forms (not easily available to crops) such as octocalcium phosphate and hydroxyapatite, which accounts for more than 50% of total inorganic phosphate in calcareous soils. Thus, the availability of P to plants is dominantly determined by interactions among plants, soil and microorganisms in the rhizosphere. On the other hand, P levels in many agricultural soils are building up, because 80-90% of P applied as fertilizer is sorbed by soil particles, rendering it unavailable for plants that lack specific adaptation to access sorbed P. With decreasing global P reserves, P-fertilizer prices are bound to increase. Thus, there is an urgent need to develop crops that are more efficient in acquiring inorganic phosphates from soil and/or in using P more efficiently. Phosphate acquisition by plants is one of the more thoroughly studied aspects of plant nutrition and there is an extensive literature on the biochemical, morphological, and physiological effects of P deficiency on plants. Successful P management can be achieved by breeding crop cultivars or genotypes more efficient in its acquisition and use. In plants, the integration of root morphological and physiological adaptive strategies can help to maximize the efficiency of plant roots to mobilize and acquire P from the rhizosphere. In this study, an attempt was made to screen sunflower genotypes over a period of two years (2010-12) in field experiment to identify genotypes for high P acquisition capacity in Vertisols under native P conditions without addition through fertilizers.

MATERIALS AND METHODS

A total of 111 sunflower genotypes were evaluated in two years (i.e., 52 in first year and 59 in second) in deep black soils belonging to Vertisol soil order at DOR-ICRISAT research farm located at Patancheru, Hyderabad. A fixed plot of 50m x 60m size in BM-3 block was selected for conducting this trial. However, the site for genotypes was not fixed as it is difficult to maintain fixed rows (for each genotype). The soils of experimental site was alkaline in reaction (pH=8.3), with low electrical conductivity (0.35 dS/m) and organic carbon content (5.38 g/kg soil). The soils had low available nitrogen (233 kg/ha) and phosphorus (9.8

kg P/ha) but had high levels of potash (816 kg/ha). Before growing sunflower, in every rainy season maize was grown as preceding crop for exhaust without the application of phosphorus in order to create P stress in experiment site. Screening experiment was conducted during the winter season of 2010 and 2011. Sunflower genotypes were sown in last week of November and harvested in second week of March in both the years. To all the sunflower genotypes 12.5 kg N/ha and 15.0 kg K_2O/ha was uniformly applied at the time of sowing, remaining 12.5 kg N/ha was applied as top dress at 30 day after sowing. Phosphorus was not applied to genotypes so as to evaluate them for P acquisition under native fertility. Rest of the package of practices was uniformly followed in all the genotypes. The genotypes comprised elite germplasm, inbred lines, CMS and R-lines and released hybrids KBSH-1 and KBSH-44. Each genotype was planted in three rows with spacing of 60 cm between rows and 30 cm between plants. Ten plants were maintained in each row. Three random plants (as three replications) were labelled in the middle row for recording biometric observations at physiological maturity stage and yield parameters at the time of harvest. Soil samples were collected at harvest and analyzed for available P. Biometric observations (plant height, number of leaves and head diameter) were recorded at the physiological maturity of genotypes. At harvest, the shoot drymatter (stem+ leaves+thalamus) and seed yield were recorded for all genotypes. Processed plant sample (leaves, stem, thalamus and seed) for each genotype was digested in diacid (nitric acid + perchloric acid 9:4) and the P content in the digest was estimated with yellow colour method as described by Dhyan Singh *et al*. (2005). Available P in soil samples was extracted with 0.5*M* sodium bicarbonate extracting solution and the P concentration in extracts was measured by blue colour method described by Watanabe and Olsen (1965). The data generated were statistically analyzed adopting single factor randomized block design with three replications with M-STATC.

RESULTS AND DISCUSSION

Shoot drymatter, seed yield and phosphorus content in genotypes: During the year 2010-11, 52 sunflower genotypes were screened to study the P acquisition capacity in black soils belonging to Vertisol soil order. The data presented in table 1 showed variation in the shoot dry matter (SDM), seed yield and the P content in SDM and seed of different sunflower genotypes.

It was noticed that genotype KBHS-44 produced significantly highest shoot drymatter yield (218 g/plant), followed by KBSH-1 (206 g/plant) > CMS 42 B (203 g/plant) > 150-R (179 g/plant) > GMU-389 (162 g/plant) > PS-1047 (155 g/plant). The highest seed yield was recorded in KBSH-44 (30.8 g/plant). However, the seed yield of KBSH-1 (28.5 g/plant), CMS-42 B (27.6 g/plant) and PS-1047 (27.6 g/plant) were found to be statistically at par with released hybrid KBSH-44. The P concentration in the shoot biomass varied significantly. The highest P content was noticed in the genotype 150-R (0.97%) followed by CMS-42 B (0.88%) and ARM 239 B (0.79%). However, it was noticed that P content in the shoots of genotypes CMS- 17 B (0.71%), GMU-389 (0.71), NDR-71 (0.71%), GMU-310 (0.70%), KBSH-44 (0.66%) and PS- 2016 (0.64%) were at par. The P content in the seeds of genotypes GMU-420, CMS-42 B and CMS-17 B was 0.99, 0.93 and 0.93%, respectively was at par to each other but significant over rest of the genotypes. The results presented in table 1 showed that genotype CMS 42 B had recorded highest P removal (1.84 g/plant) followed by KBSH-44 (1.62 g/plant)> 150-R (1.41 g/plant) >ARM-239-B (1.33 g/plant) > GMU-389 (1.31 g/plant) > KBSH-1 (1.30 g/plant). The greater amount of P removal or uptake by these genotypes might be due to their high shoot biomass yield, seed yield and their respective P contents. The results showed that among all the genotypes screened for P acquisition during the year 2010-11, RHA-214 had lowest values for SDM yield (81.3 g/plant), seed yield (14 g/plant) and removal of phosphorus (0.6 g/plant) from the soil.

In the year 2011-12, a total of 59 sunflower genotypes were screened for acquisition of native P in Vertisols. The results of 20 best performing genotypes for selective biometric parameters like shoot dry matter (SDM) yield, seed yield, phosphorus concentration in SDM and seed has been presented in table 2.

Highest SDM yield was recorded in KBSH-1 (275 g/plant) followed by genotypes GMU-136 (268 g/plant), GMU-128 (253 g/plant) and GMU-38 (241 g/plant). The SDM of genotypes KBSH-44, GMU-5 and CMS-42-B were 224.3, 222.4 and 221.3 g/plant, respectively, were at par to each other. The highest seed yield was noticed in GMU-116 (35.1 g/plant) and KBSH-44 (35.0 g/plant). However, genotypes GMU-116, KBSH-44, GMU-136, KBSH-1 and GMU-13 were statistically at par to each other in seed yield. The results also showed that genotypes CMS-42-B, GMU-9, DRSH-1, GMU-20 and GMU-38 had produced at par seed yield within this group. Significant highest SDM P content was recorded in the genotype GMU-3 (1.06%) followed by DRSH-1, GMU-38 and GMU-116 which had similar amounts of P (0.83%). These genotypes were significantly superior in SDM P content over GMU-5 (0.75%), KBSH-44 (0.72%), CMS-42-B (0.66%) and KBSH-1 (0.65). For seed P content, among all the genotypes only two genotypes *viz*., KBSH-1 and CMS-339-B recorded P content below 0.7%. The highest seed P content was noticed in GMU-142 (0.95%) which was at par with GMU-9 (0.90%) followed by GMU-3= GMU-38> GMU-11> GMU-51> GMU-116= GMU-136= CMS-42-B> GMU-32=GMU-16> KBSH-44= DRSH-1>KBSH-1. The P removal by sunflower genotypes depended on their shoot drymatter, seed yield and their P contents. The highest P removal was recorded in GMU-38 (2.2 g/plant) followed by GMU-128, KBSH-1, KBSH-44, GMU-3, GMU-5, DRSH-1, GMU-116 and CMS-42-B in descending order (Table 2).

Table 1 Shoot drymatter (SDM), seed yield, SDM-P and seed P contents of sunflower genotypes screened during 2010-11

Genotype	SDM (g/plant)	Seed yield (g/plant)	SDM- P (%)	Seed P (%)	Total P removal (g/plant)	Available P after harvest (kg/ha)
RHA 214	81.3	13.9	0.63	0.70	0.61	09.7
CMS 17 B	113.1	22.5	0.71	0.93	1.01	10.8
R 649	107.2	24.3	0.57	0.74	0.79	10.2
KBSH 1	206.7	28.5	0.56	0.46	1.30	10.3
KBSH 44	218.2	30.8	0.66	0.60	1.62	09.8
CMS 335 B	129.5	15.6	0.61	0.75	0.91	09.0
GMU 389	162.0	23.9	0.71	0.66	1.31	11.8
GMU 420	129.8	20.9	0.62	0.99	1.02	09.4
GMU 302	148.5	26.3	0.64	0.62	1.11	08.3
GMU 310	147.7	21.9	0.70	0.54	1.15	09.2
ARM 239 B	152.9	21.7	0.79	0.59	1.33	10.2
CMS 42 B	203.4	27.5	0.78	0.93	1.71	09.7
PS 1040	128.8	21.9	0.72	0.65	1.07	11.2
150-R	178.8	16.8	0.97	0.74	1.41	11.7
PS 1047	155.0	27.5	0.45	0.43	0.82	14.5
L 33-1	134.2	18.2	0.54	0.52	0.82	16.1
LDM 02	146.0	26.5	0.62	0.51	1.04	10.9
NDR 71	145.6	22.6	0.71	0.53	1.15	12.6
PS 2016	154.9	22.6	0.64	0.88	1.19	10.2
CMS 40 B	147.5	25.4	0.48	0.74	0.90	11.7
ARM 242 B	114.5	14.5	0.60	0.60	0.77	09.9
EC 5126-79	128.2	20.5	0.51	0.63	0.78	12.1
LSD (0.05)	6.0	3.2	0.07	0.09	--	--
C.V (%)	2.5	8.7	6.2	8.4	-	-

Table 2 Shoot drymatter (SDM), seed yield, SDM-P and seed P contents of sunflower genotypes screened during 2011-12

Genotype	SDM (g/plant)	Seed yield (g/plant)	SDM-P content (%)	Seed P (% P)	Total P removal (g/plant)	Available P after harvest (kg/ha)
GMU-38	241.5	27.3	0.83	0.83	2.23	06.5
GMU-20	106.3	27.8	0.60	0.72	0.84	09.0
GMU-142	198.0	22.5	0.70	0.95	1.60	18.9
GMU-5	222.4	24.9	0.74	0.70	1.83	10.8
GMU-32	168.7	21.8	0.51	0.78	1.03	09.3
GMU-128	253.0	24.9	0.72	0.70	1.99	08.3
R-649	107.9	15.6	0.68	0.74	0.85	09.2
KBSH-1	275.2	32.5	0.65	0.62	1.98	09.6
CMS-42B	221.3	29.2	0.66	0.79	1.68	09.8
KBSH-44	224.2	35.0	0.72	0.72	1.86	09.2
CMS-339B	186.9	24.4	0.51	0.67	1.11	08.6
DRSH-1	193.8	28.4	0.83	0.72	1.80	10.0
GMU-136	268.2	34.4	0.61	0.79	1.06	12.2
GMU-116	209.6	35.1	0.83	0.79	1.71	11.6
GMU-9	150.0	28.8	0.70	0.90	1.31	16.4
GMU-3	154.3	25.9	1.06	0.84	1.85	08.2
GMU-13	219.4	33.2	0.54	0.72	1.27	09.4
GMU-11	226.8	27.6	0.59	0.82	1.51	09.9
GMU-51	144.8	26.4	0.48	0.80	0.91	13.6
GMU-16	171.5	26.2	0.57	0.78	1.18	10.3
LSD (0.05)	9.2	3.1	0.07	0.07	-	-
C.V (%)	3.1	5.6	6.1	6.3	-	-

The available P status in soil after the harvest of sunflower genotypes showed variations and the values were within the range of low to medium in both the years (Table 1 and 2). The site for genotypes was not fixed and therefore, the data on available P after harvest of genotypes depicts the actual P fertility condition of soils in which they were evaluated. Thus, most of the genotypes including CMS-42-B and released hybrids KBSH-1 and KBSH-44 were screened for P acquisition under marginal conditions of available P.

Partitioning of phosphorus in sunflower genotypes:

Year 2010-11: The internal distribution of P content in the plants during its stress is very essential in determining the yield and quality parameters of crop. Based on P content in plant parts and its partitioning (percent distribution) in to different parts for the total uptake was worked out for the genotypes. Partitioning of P was done in genotypes whose seed yield was at par with checks *viz*., KBSH-1 and KBSH-44 in both the years. The data presented in figure 1 depicts the partitioning of P content into different plant parts for sunflower genotypes screened during the year 2010-11.

Genotype CMS-42-B had distributed 51.7% of total P content into seeds and the rest 48.3% was left in the biomass of the plants compared to check KBSH-44 with 47.6% of total P content was partitioned into seeds and the rest 52.4% was left back in the biomass. Hence, in the year 2010-11, genotype CMS-42 B was found to be superior in acquiring phosphorus in the plant and efficient in its internal distribution towards the economic produce (seed) when compared to checks KBSH-44 and KBSH-1. This was followed by GMU-302 (50%)> CMS-40 B = LDM-02 (48.7).

Year 2011-12: The ability of genotypes to internally distribute the P of the total P absorbed into different plant parts has been depicted in figure 2 for the promising sunflower genotypes screened during year 2011-12.

The results showed that highest internal distribution towards seed was recorded in GMU-136 with a value of 56.8% out of total P absorbed, followed by CMS-42-B (52.3%). It has been noticed that though genotypes GMU-3 and GMU-38 had absorbed maximum P (i.e., total plant P was 1.90 and 1.66%, respectively) but their internal distribution of P towards seeds was low compared to GMU-136 and CMS-42-B. Among the 22 genotypes, the lowest distribution of P towards seed was noticed in GMU-5 (45.1). During second year study though genotype CMS-42-B had removed lower amounts of total P 1.68 g/plant with a seed yield of 29.2 g/plant had showed profound distribution of absorbed P towards seed with 52.3% as compared to genotypes GMU-38 (49.0%), GMU-5 (45.1%) and KBSH-1 (50.0%). The integration of genetically improved P-efficient crops with advanced P management in the soil-plant system is important for improving nutrient-use efficiency and sustainable crop production. Successful P management can be achieved by breeding crop cultivars or genotypes which are more efficient in P acquisition and internal distribution. Great progress has been made in traditional plant breeding programs in China toward selecting crop varieties for high P-use efficiency. Phosphorus efficient wheat variety 'Xiaoyan54' was identified, which secreted more carboxylates (e.g. malate and citrate) into the rhizosphere than P-inefficient genotypes (Li *et al*., 1995).

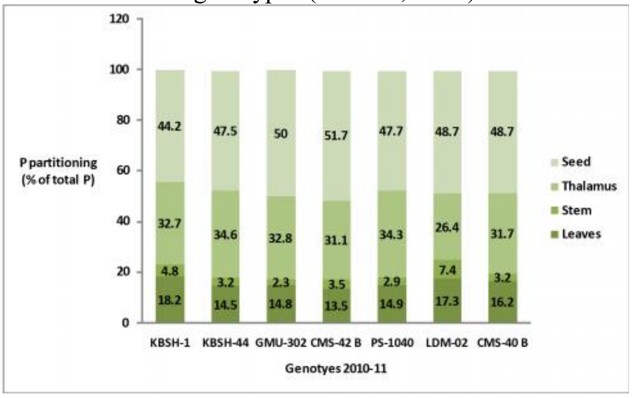

Fig. 1. Internal distribution of phosphorus of promising sunflower genotypes during 2010-11

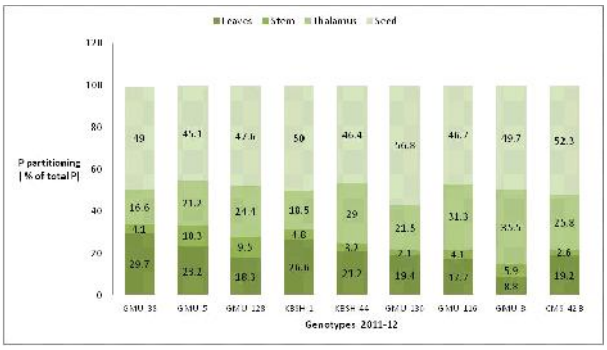

Fig. 2. Partitioning of phosphorus in different plant parts of promising sunflower genotypes during 2011-12

In soybean, genotype 'BX10' had superior root traits showing better adaptation to low-P soils (Yan *et al*., 2006). Some important root genetic traits have been identified with potential utility in breeding P-efficient crops, including root exudates, root hair traits, topsoil foraging through basal, or adventitious rooting (Gahoonia and Nielsen, 2004; Lynch and Brown, 2008). In addition, the ability to use insoluble P compounds in soils can be enhanced by engineering crops to exude more phytase, which results from over expression of a fungal phytase gene (George *et al*., 2005).

Among the 52 sunflower genotypes screened for P acquisition during 2010-11, four genotypes *viz*., GMU-420, CMS-335-B, PS-2016 and CMS-42-B had showed better P acquisition for the total P removed from soil. During 2011-12, seven genotypes *viz*., GMU-136, GMU-13, GMU-38, CMS-42-B and KBSH-1 showed better P acquisition from native soil P. It was noticed that genotype CMS-42-B was best in P acquisition during 2010-11 with 51% of its uptake was partitioned into seeds and 52.3% during 2011-12. This genotype had removed lower amounts of total P 1.68 g/plant however; it had showed high internal distribution of acquired P towards seed (52.3%) in comparison genotypes GMU-38, GMU-5 and KBSH-1. To conclude, genotype CMS-42-B showed repeated performance for P acquisition and the acquired P was better distributed towards seeds in black soils with low phosphorus fertility.

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Long-term effect of nutrients on castor (*Ricinus communis* L.) productivity, soil fertility, nutrient uptake and nutrient-use efficiency in rainfed Alfisols

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ABSTRACT

A fixed-plot field experiment was conducted since 2005 to study the long-term effect of nutrients on the productivity, soil fertility, nutrient uptake and nutrient-use efficiency of castor (*Ricinus communis* L.) in castor-sorghum (*Sorghum bicolor*) cropping system in rainfed Alfisols of Andhra Pradesh. Application of recommended dose of fertilizers, RDF (60-40-30 kg NPK/ha) + 5 t/ha farm yard manure (FYM) recorded significantly higher yield attributes, seed (1645 kg/ha) and oil yield (817 kg/ha) of castor compared to RDF (1306 kg/ha) but was comparable with integrated use of 75 % NPK + 25 % N through FYM (1427 kg/ha). Imbalanced application of N alone or NP or 50 % NPK and control plots recorded significantly the lowest castor seed yields. At the end of six years of cropping (2011), the treatment RDF-NPK + 5 t/ha FYM significantly improved the soil organic carbon (0.38 %) and resulted in a positive balance of 42, 12.4 and 80 kg/ha of available soil N, P and K besides improving the nutrient uptake of castor (65.1, 10.63 and 33.2 kg/ha of N, P and K, respectively). Agronomic efficiency of nutrients (N, P and K) was found higher in the treatment, 75 % RDF + 25 % N through FYM. However, apparent recovery of N, P and K was highest in NPK + 5 t/ha FYM treatment.

Keywords: Castor, Nutrient uptake, Nutrient use efficiency, Productivity, Soil fertility

Castor (*Ricinus communis* L.) is one of the important non-edible oilseed crops having immense industrial and commercial value, and India is the major producer of castor in the world. At present castor was grown in an area of 8.85 lakh ha producing 13.37 lakh t. with an average yield of 1512 kg/ha. However, wide regional disparities are encountered in yield of this crop, the lowest being 509 kg/ha in Andhra Pradesh. The low productivity of this crop was due to its cultivation in marginal and poor soil fertility conditions by the resource poor farmers under uncertain rainfall conditions (Hegde, 2010). By and large, soil moisture and nutrients are the limiting factors for crop production under rainfed conditions in dry lands. Continuous use of imbalanced and inadequate dose of fertilizers can have adverse effect on crop productivity and soil health on long-term basis (Dwivedi and Dwivedi, 2007). Application of organic manures in conjunction with recommended fertilizers can have beneficial effect on crop productivity through reducing soil bulk density, enhancement in water holding capacity besides supplying macro and micronutrients (Ramesh *et al*., 2009). Hence, the present investigation was carried out to study the long-term effect of individual nutrients and their combinations with and without FYM on castor productivity, soil fertility, nutrient uptake and nutrient-use efficiency.

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MATERIALS AND METHODS

A fixed plot field experiment was conducted since 2005 at Narkhoda research farm of the Directorate of Oilseeds Research, Hyderabad, Andhra Pradesh on Alfisols under rainfed conditions. The eco-region is characterized as semi-arid tropical (SAT) climate and the soil has been classified as red sandy loam with pH 6.3, EC 0.35 dS/m, low in organic carbon (0.29%) and available nitrogen (160 kg/ha), medium in available phosphorous (23.6 kg/ha) and potassium (262 kg/ha) at the initiation of the experiment. Castor variety 48-1 was sown during the first week of July, 2011 and harvested during January, 2012.

The treatments comprised: T_1-recommended N alone (60 kg N/ha), T_2- recommended dose of NP (60 kg N + 40 kg P_2O_5/ha), T_3-100% recommended dose of NPK (60 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha), T_4 - 50% recommended dose of NPK (30 kg N, 20 kg P_2O_5 + 15 kg K_2O/ha), T_5 - 75% NPK + 25% N through FYM (45 kg N + 30 kg P_2O_5 + 22.5 kg K_2O/ha + 3 t/ha FYM). T_6 - 100% recommended dose of NPK, P through single super phosphate, T_7-100% recommended dose of NPK + 10 kg Zn/ha for sorghum, T_8 - 100% recommended dose of NPK + 5 t/ha FYM and T_9 - no fertilizer (control). These nine treatments were replicated thrice in randomized block design. The dosage of farm yard manure according to different treatments was applied two weeks before sowing. In all the treatments, diammonium phosphate (DAP) was used as a source of N and P except in treatments T_1 and T_6. Half the dose of nitrogen (N) and full dose of phosphorus (P) and potash (K) as per treatments was applied as basal dose at the time of sowing. The remaining N was top dressed in 2 splits ¼ at 30 days and ¼ at 60 days after sowing of castor. Castor was sown at 90 cm x 60 cm spacing. The net plot size was 7.2 m x 4.8 m. The total rainfall received during the crop season of 2011 (July-December) was 553 mm.

After harvest, seed and straw samples were collected for N, P and K nutrient analysis and for uptake. Nutrient-use efficiency of N, P and K were calculated based on the formulae given by Duncan and Baligar (1990). At the end of the cropping cycle, the soil samples (0-15 cm) were collected and analyzed for organic carbon, available N, P and K, by adopting standard analytical methods (Singh *et al*., 2005). Statistical analysis of the data was carried out using standard analysis of variance.

RESULTS AND DISCUSSION

Yield attributes and seed yield of castor: Application of recommended dose of NPK + 5 t FYM/ha recorded maximum plant height (89.3 cm), higher number of spikes/plant (7.4), capsules/spike (45.0) and 100 seed weight (28.2 g) compared to control, but was on par with 75 % NPK + 25 % N through FYM (Table 1). NPK + 5 t FYM/ha recorded the highest seed yield by primaries (503 kg/ha), secondaries (1142 kg/ha) and resulted in the total seed yield of 1645 kg/ha, which was 25.9 % higher than in NPK alone (1306 kg/ha). 75 % NPK + 25 % N through FYM recorded comparable seed yield (1427 kg/ha) with NPK + 5 t FYM/ha, but was higher by 9.2 % than in NPK alone. Application of N alone, NP, 50 % NPK and control plots recorded 31.2, 17.6, 32.3 and 56.3 % less seed yields compared to 100 % NPK. Straw yields of castor followed the similar trend to that of seed yields. Harvest index of castor varied from 24.8 % in control to 34.3 % in NPK, but was not differed significantly among the treatments. Highest oil content (49.66 %) and oil yield (817 kg/ha) was obtained in NPK + 5 t FYM /ha, which was comparable with the treatment receiving 75 % NPK + 25% N through FYM (49.47% and 707 kg/ha) and the lowest being in control (46.71% and 266 kg/ha).

Higher yield in castor with high fertilizer input was due to readily available plant nutrients leading to greater photosynthetic activity in comparison with low doses of fertilizers. 25% of N could be substituted by application of farm yard manure as it gave similar yields. Application of FYM facilitates N availability during entire crop growth phases due to slow mineralization of organic N from farm yard. Enhancement of castor yield due to adoption of integrated nutrient management (INM) practices was also reported by Patel *et al*. (2007).

Soil fertility status: At the end of 6 cropping cycles, the treatment, NPK + 5 t FYM/ha recorded significantly higher soil organic carbon (0.38 %) compared to NPK alone (0.30%) and the lowest (0.25 %) being in control plot (Table 2). The soil available N, P and K status was the highest (202, 36 and 342 kg/ha) in NPK + 5 t FYM/ha resulting in net positive balance of 42, 12.4 and 80 kg/ha of N, P and K compared to the initial soil test values at the beginning of the experiment. In the plot where manures were not applied (control), the soil fertility declined by 18 kg N, 5.0 kg P and 24 kg K. This clearly showed the importance of balanced and integrated use of fertilizers and manures for sustaining soil fertility and crop productivity on a long term basis. The sulphur status of soil increased from the initial 22.4 mg/kg to 45.1 mg/kg in NPK treatment with P supplied through single super phosphate (SSP). However, the differences in S-status of soil among the treatments were not significant. The zinc status of soil improved from the initial 0.60 mg/kg to 0.86 mg/kg where zinc is applied @ 10 kg/ha for the sorghum in rotation. Application of FYM along with NPK also improved the zinc status up to 0.73 mg/kg soil. Increased soil fertility and micro nutrient availability due to application of organic amendments was also reported by Ramesh *et al*. (2009).

Nutrient uptake and nutrient-use efficiency: Application of NPK + 5 t FYM/ha recorded significantly the highest uptake of N (65.1 kg/ha), P (10.63 kg/ha) and K (33.2 kg/ha) compared to NPK alone (50.2, 7.73 and 22.8 kg NPK/ha), but was comparable with75 % NPK + 25 % N through FYM (54.2, 8.55 and 25.3 kg NPK/ha). Agronomic efficiency of N, P and K was the highest (19.04, 38.0 and 38.0 kg grain/kg nutrient applied) in integrated use of 75 % NPK + 25 % N through FYM followed by NPK + 5 t FYM/ha treatment (Table 3). However, apparent recovery of N, P and K were the highest (0.69, 0.22 and 0.64 kg nutrient uptake/kg nutrient applied) in NPK + 5 t FYN/ha treatment. Physiological efficiency of N was the highest (27.9) in 75 % NPK + 25% N through FYM, whereas physiological efficiency of P and K were the highest (194 and 84.2) in NPK + zinc treatment. Nutrient harvest index (NHI) of N varied from 65 5% in control to 75.4 % in NPK + 5 t FYM/ha. NHI of P varied from 58.4 % in control to 69.5 % in NPK, where P was supplied through SSP. NHI of K differed from 12.6 in control to 17.7 % in recommended dose of NPK. Similar differences in nutrient use efficiency due to fertility levels were reported by Ramesh and Sammi Reddy (2004) in soybean and sorghum crops in rainfed vertisols.

From the study, it can be concluded that the conjunctive use of recommended dose of NPK (60-40-30 kg/ha) along with 5 t FYM/ha results in not only higher castor productivity but also sustain the long-term soil fertility in terms of soil organic carbon, nutrient status and improved nutrient uptake and nutrient-use efficiency.

Table 1 Long-term effect of fertilizers on crop growth, yield attributes, seed and oil yield of castor

Treatment	Plant height (cm)	Spikes/ plant	Capsules/ spike	100-seed weight (g)	Seed yield (kg/ha)			Straw yield (kg/ha)	Harvest Index	Oil content (%)	Oil yield (kg/ha)
					Primaries	Secondaries	Total				
N (60 kg/ha)	74.6	4.4	39.0	25.2	384	514	898	2123	29.7	46.97	421
NP (60-40 kg/ha)	80.3	5.0	42.6	25.9	442	634	1076	2468	30.3	47.95	515
NPK (60-40-30 kg/ha)	83.1	5.8	44.0	26.2	474	832	1306	2500	34.3	48.81	638
50 % NPK (30-20-15 kg/ha)	71.6	4.6	35.6	25.4	358	526	884	2012	30.5	48.02	428
75 % NPK + 25 % N (FYM)	82.0	6.4	42.3	27.1	463	964	1427	2784	33.8	49.47	707
NPK (P through SSP)	81.3	5.6	41.0	26.4	458	814	1272	2637	32.5	49.27	644
NPK (60-40-30 kg/ha)+ Zn	82.6	5.5	42.0	26.1	458	803	1261	2420	34.2	48.88	616
NPK + 5 t FYM/ha	89.3	7.4	45.0	28.2	503	1142	1645	3731	30.5	49.66	817
No fertilizer (control)	63.6	3.5	25.3	23.8	235	335	570	1620	24.8	46.71	266
SEm±	3.2	0.4	2.3	0.6	20	91	93	175	2.1	0.4	47
CD (P=0.05)	9.8	1.2	6.9	2.0	60	274	280	524	NS	1.2	142

Table 2 Long-term effect of fertilizers on soil organic carbon, available N, P, K, S and Zn status

Treatment	Soil organic carbon (%)	Nitrogen (kg/ha)	Change over the initial (+/-)	Phosphorus (kg/ha)	Change over the initial (+/-)	Potassium (kg/ha)	Change over the initial (+/-)	Sulphur (mg/kg)	Zinc (mg/kg)
N (60 kg/ha)	0.28	167	+ 7	19.3	- 4.3	244	-18	33.9	0.44
NP (60-40 kg/ha)	0.29	172	+ 12	28.6	+ 5.0	252	-10	36.3	0.40
NPK (60-40-30 kg/ha)	0.30	180	+ 20	31.2	+ 7.6	294	+32	37.0	0.37
50 % NPK (30-20-15 kg/ha)	0.29	182	+ 22	26.2	+ 2.6	272	+10	34.4	0.40
75 % NPK + 25 % N (FYM)	0.32	190	+ 30	32.2	+ 8.6	306	+44	43.0	0.72
NPK (P through SSP)	0.30	188	+ 28	31.0	+ 7.4	282	+20	45.1	0.47
NPK (60-40-30 kg/ha)+ Zn	0.30	186	+ 26	31.0	+ 7.4	280	+18	36.9	0.86
NPK + 5 t FYM/ha	0.38	202	+ 42	36.0	+ 12.4	342	+80	42.7	0.73
No fertilizer (control)	0.25	142	- 18	18.6	- 5.0	238	-24	27.0	0.37
SEm±	0.02	4.1		2.1		8.4		2.7	0.04
CD (P=0.05)	0.05	12.2		6.2		25.1		NS	0.12
Initial soil nutrient status	0.29	160		23.6		262		22.4	0.60

Table 3 Nutrient uptake and nutrient use efficiency of castor as influenced by fertilizers

Treatment	Nutrient uptake (kg/ha)			Agronomic efficiency (kg grain/kg nutrient applied)			Apparent recovery (kg nutrient uptake e/kg nutrient applied)			Physiological efficiency (kg grain/kg nutrient uptake)			Nutrient harvest index (%)		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
N (60 kg/ha)	35.5	6.31	18.7	5.46	-	-	0.20	-	-	27.3	-	-	70.1	66.4	-
NP (60-40 kg/ha)	42.7	7.26	21.8	8.43	16.8	-	0.32	0.11	-	26.3	160	-	71.2	66.1	-
NPK (60-40-30 kg/ha)	50.2	7.73	22.8	12.26	24.5	24.5	0.44	0.12	0.29	27.5	192	82.6	75.0	67.5	17.7
50 % NPK (30-20-15 kg/ha)	35.5	5.98	17.8	10.46	20.9	20.9	040	0.14	0.26	26.1	151	80.5	71.8	66.3	15.3
75 % NPK + 25 % N (FYM)	54.2	8.55	25.3	19.04	38.0	38.0	0.68	0.20	0.50	27.9	184	75.1	74.3	67.4	17.4
NPK (P through SSP)	50.1	8.55	23.7	11.70	23.4	23.4	0.44	0.15	0.32	26.3	147	71.6	73.6	69.5	16.6
NPK (60-40-30 kg/ha) +Zn	49.2	7.46	22.1	11.51	23.0	23.0	0.42	0.12	0.27	26.8	194	84.2	75.4	67.5	17.6
NPK + 5 t FYM/ha	65.1	10.63	33.2	17.91	35.8	35.8	0.69	0.22	0.64	25.8	159	55.6	71.4	64.9	15.3
No fertilizer (control)	23.5	3.90	13.9	-	-	-							65.5	58.4	12.6
SEm±	3.9	1.1	2.0												
CD (P=0.05)	11.7	3.2	5.9												

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Maximization of flower yield in safflower (*Carthamus tinctorius* L.)

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ABSTRACT

A study was carried out on a non-spiny hybrid safflower (*Carthamus tinctorius* L.) NARI-NH-1 for maximization of flower yield by altering the agronomic practices *viz*., dates of sowing, fertilizer levels and plant spacings. The study showed that the differences due to sowing dates, fertilizer levels and plant spacings were significant for flower and seed yield in safflower. Delayed sowing beyond first fortnight of October resulted in a decrease in both flower and seed yield. Significantly highest flower yield (199 kg/ha) and seed yield (2014 kg/ha) were recorded with an application of 150% recommended dose (RD) of fertilizers, with flower yield being 26.85% higher and seed yield 28.89% higher than the control. However, if the net returns are considered, there is no advantage in applying more than 100% RD of fertilizer to the crop. The spacing of 45 cm x 10 cm gave significantly higher flower and seed yield over the recommended spacing of 45 cm x 20 cm. The interaction effects between dates of sowing, spacings and fertilizer levels suggested that sowing of safflower in the first week of October either with a spacing of 45 cm x 10 cm and an application of 100% or 150% RD of fertilizer or with a spacing of 45 cm x 20 cm with an application of 150% RD of fertilizer can be recommended for obtaining maximum flower and seed yield in safflower.

Keywords: Flowers, Safflower, Sowing dates, Spacing

Safflower (*Carthamus tinctorius* L.) is an important oilseed crop producing quality oil rich in polyunsaturated fatty acids, which helps in reducing cholesterol level in blood. In addition, safflower also produces brightly coloured flowers which are known as a source of natural colour for food and have many pharmacological properties for curing chronic diseases such as coronary artery diseases, cardiovascular diseases, diabetes, spondylosis, arthritis and sterility in men and women apart from disorders related to menstrual cycle in women. Recently an increasing demand for safflower flowers due to their popularization as herbal health tea and their potential for export to Japan and European countries has been witnessed. Non-spiny cultivars NARI-6 and NARI-NH-1 and others giving high seed and flower yield have been developed to grow them for flower production apart from harvesting the seed yield. The cultural practices presently followed to grow safflower were primarily developed to maximize seed yield. With the rising demand for safflower flowers for various purposes and to harness full potential of the non-spiny cultivars it was necessary to develop cultural practices maximizing both flower and seed yield in non-spiny safflower. In view of the above an investigation was carried out to study the effect of different dates of sowing, fertilizer levels and spacings between plants and rows on flower and seed yield in safflower.

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MATERIALS AND METHODS

In order to maximize both flower and seed yield in safflower, an agronomic experiment using recently released non-spiny hybrid NARI-NH-1 was carried out in a split-split plot design with three replications for three winter seasons of 2001-02, 2002-03 and 2003-04. The trial consisted of three sowing dates *viz*., D_1 = October 3, D_2 = October 18, and D_3 = November 1 as main plots, four levels of fertilizers *viz*., F_0 = no fertilizer, F_1 = 50% recommended dose (RD) of fertilizers, F_2 = 100% RD of fertilizers and F_3 = 150% RD of fertilizers as sub plots and six plant population levels by altering spacings between rows and plants i.e., S_1 = 45 cm x 10 cm, S_2 = 45 cm x 20 cm, S_3 = 45 cm x 30 cm, S_4 = 60 cm x 10 cm, S_5 = 60 cm x 20 cm, S_6 = 60 cm x 30 cm as subsub plots. A fertilizer dose containing 60:30:30 kg/ha of N:P:K, respectively was considered as the 100% RD. The plot size for each treatment was 2.7 m x 5 m. Three irrigations were given to each date of sowing in the experiment. The schedule for irrigation included the irrigation given for germination of the seed as the first irrigation and second and third irrigations were given at 35 and 70 days after sowing, respectively. Standard cultural practices were followed to grow a good crop. The flowers were harvested at the maturity of the crop. The physiological observations were recorded at the time of harvest. The mean data over three years were used to analyse the results.

RESULTS AND DISCUSSION

The study showed that differences due to different dates of sowing were significant for flower and seed yield in safflower (Table 1). The results suggested that the sowing delayed beyond the recommended time of sowing of safflower i.e., first fortnight of October, showed significant decrease in flower and seed yield. Physiological traits like number of primary branches/plant, number of capitula/plant, capitulum diameter, number of seeds/capitulum and 100 seed weight were significantly reduced when sowing was delayed to October 18 and further to November 1 instead of on October 3. However, height of plants increased significantly when the sowing was delayed beyond October 3. Net returns and benefit cost ratios were also significantly highest for the first date of sowing i.e., October 3. The mean data over three years showed that the delayed sowing of safflower by only 15 days from October 3, exhibited a reduction of 7.89% in flower yield and a reduction of 18.41% in seed yield. Similar results for seed yield in safflower have also been reported by Ghorpade *et al.* (1993) and Singh *et al*. (1995). Therefore, to obtain the maximum flower and seed yield from non-spiny safflower hybrid NARI-NH-1, sowing should be carried out in the first week of October.

The mean data over three years for fertilizer levels revealed that fertilizer application at higher levels significantly increased the flower and seed yield over the control. Significantly, highest flower (199 kg/ha) and seed yield (2014 kg/ha) (Table 1) were obtained at 150% RD of fertilizer, which was found to be 26.85% higher for flower yield and 28.89% higher for seed yield over the untreated control. This was mainly due to a significant increase in the estimates of physiological attributes like number of primary branches/plant, number of capitula/plant, number of seeds/capitulum and 100 seed weight in 150% RD of fertilizer treatment over the control. But considering the net returns, there appeared to be no advantage in applying more than 100% RD of fertilizer to the crop as 100% RD of fertilizer gave net returns on par with those from 150% RD. Benefit cost (B:C) ratio was also the highest in the treatment of 100% RD and was significantly higher than that of all other treatments. Thus, considering the B:C ratio, 100% RD of fertilizer gave the significantly highest net returns and profit from the crop.

The effect of spacings on non-spiny safflower hybrid NARI-NH-1 showed that denser spacing of 45 cm x 10 cm gave significantly higher yields of both flower and seed over the recommended spacing of 45 cm x 20 cm, though estimates of all the yield contributing characters like number of primary branches/plant, number of capitula/plant, capitulum diameter and number of seeds/capitulum were found to be significantly lower in the treatment of 45 cm x 10 cm as compared to all other treatments (Table 1). Only 100 seed weight significantly increased in the treatment of 45 cm x 10 cm as compared to spacing of 45 cm x 20 cm. Thus, the results indicate that the loss caused due to a decrease in yield contributing parameters of safflower in denser spacing of 45 cm x 10 cm was not only compensated well with the increased 100 seed weight and plant population but it also showed an additional gain of 8.88% in flower yield and 10.12% in seed yield over the recommended spacing of 45 cm x 20 cm. The spacing of 45 cm x 10 cm also recorded the significantly highest net returns of ₹ 26558 as compared to net returns of ₹ 23734 from safflower sown at standard spacing of 45 cm x 20 cm. The B:C ratio was found significantly highest in the treatment 45 cm x 10 cm. The wider spacings between rows and plants exhibited significant reduction in both flower and seed yield when compared to the recommended spacing of 45 cm x 20 cm. Present results for seed yield are in conformity with the earlier studies in safflower (Singh *et al*., 1994; Singh *et al.,* 1995). Therefore, the spacing of 45 cm 10 cm between rows and plants may be followed to obtain maximum production of flower and seed from non-spiny hybrid NARI-NH-1.

Mean data over three years showed that interaction between dates of sowing and fertilizer levels for flower and seed yield in safflower was significant (Table 2). Safflower when sown on October 3 i.e., first date of sowing (D_1) with 150% RD of fertilizer recorded the maximum flower (218 kg/ha) and seed yield (2434 kg/ha). However, these yield levels were on par with those of 100% recommended fertilizer levels (F_2) in a crop sown on October 3. Results also showed that interaction between dates of sowing and spacings was significant for flower and seed yield in safflower (Table 3). Safflower when sown on October 3 with 45 cm x 10 cm spacing recorded the significantly highest flower yield of 233 kg/ha and seed yield of 2618 kg/ha. Similarly, the interaction between fertilizer levels and spacings was also observed to be significant for both flower and seed yield (Table 4). Safflower hybrid NARI-NH-1 when given a 150% recommended fertilizer dose (F_3) and sown at 45 cm x 10 cm (S_1) spacing recorded the maximum flower yield of 233 kg/ha and seed yield of 2395 kg/ha. However, the flower and seed yields of safflower sown with a 100% recommended fertilizer dose (F_2) with the spacings of 45 cm x 10 cm (S_1) were found to be at par with this treatment. Thus, it can be concluded that there is no additional gain in applying higher doses of fertilizer to the crop than those commercially recommended.

The interaction between dates of sowing, fertilizer levels and spacings for flower yield was significant (Table 5). Among the treatments, safflower with spacing of 45 cm x 20 cm and an application of 150% RD sown on October 3, showed the highest flower yield and was at par with the treatment of sowing on October 3 with 150% RD of fertilizers and the spacing of 45 cm x 10 cm.

For seed yield the pooled data over three years indicates that the interaction between dates of sowing, fertilizer levels and spacings was significant (Table 6). Among the treatments, safflower with a spacing of 45 cm x 10 cm and an application of 150% RD of fertilizer sown on October 3 exhibited the highest seed yield of 2824 kg/ha which was at par with the treatments of 45 cm x 20 cm spacing with sowing on October 3 and 150% RD of fertilizer and treatment of sowing on October 3 with 100% RD of fertilizer and a spacing of 45 cm x 10 cm.

Thus, the results suggested that sowing of safflower in the first week of October either with a spacing of 45 cm x 10 cm and an application of 100% or 150% RD of fertilizer or with a spacing of 45 cm x 20 cm with an application of 150% RD of fertilizer can be recommended for obtaining maximum flower and seed yield in safflower.

Table 1 Effect of date of sowing, fertilizer levels and plant spacings on yield contributing characters in safflower hybrid NARI-NH-1

Treatment	Final plant stand (000s/ha)	Days to 50% flowering	Plant height (cm)	No. of primary branches/ plant	No. of capitula/ plant	Capitulum diameter (cm)	No. of seeds/ capitulum	100 seed weight (g)	Days to maturity	Flower yield (kg/ha)	Seed yield (kg/ha)	Net returns (₹/ha)	B:C ratio
Date of sowing													
D_1 = October 3	88.87	83.60	88.46	9.32	26.67	2.57	53.26	4.08	140.34	202.15	2249.56	27907.61	1.88
D_2 = October 18	88.62	86.68	100.45	7.64	19.90	2.47	48.87	3.88	142.72	186.20	1835.32	21402.88	1.70
D_3 = November 1	92.59	88.33	111.45	7.27	21.09	2.38	41.48	3.58	144.76	157.21	1398.52	13155.45	1.47
LSD (P=0.05)	2.00	1.42	3.12	0.16	0.86	0.03	2.86	0.16	1.16	3.54	18.77	237.44	0.01
Fertilizer level													
F_0 = No fertilizer (Control)	90.43	86.18	98.53	7.42	19.74	2.43	46.20	3.71	142.43	156.93	1562.99	16717.97	1.59
F_1 = 50% RD	89.72	85.81	100.33	7.96	21.81	2.47	47.36	3.88	142.42	178.64	1794.97	20625.79	1.70
F_2 = 100% RD	91.05	86.57	101.40	8.34	23.67	2.50	48.44	3.93	142.95	192.77	1938.74	22666.53	1.73
F_3 = 150% RD	88.92	86.19	100.23	8.58	25.00	2.50	49.48	3.86	142.62	199.07	2014.50	23277.64	1.71
LSD (P=0.05)	1.20	N.S.	N.S.	0.44	1.91	0.02	1.52	0.11	N.S.	3.22	48.80	655.44	0.02
Spacing													
S_1 = 45 cm x 10 cm	160.20	84.58	101.73	6.31	15.31	2.43	44.67	4.05	141.04	214.19	2205.76	26557.61	1.78
S_2 = 45 cm x 20 cm	93.81	85.87	99.69	7.76	21.14	2.48	47.41	3.84	142.41	195.16	1982.47	23733.74	1.75
S_3 = 45 cm x 30 cm	68.44	86.77	98.17	8.73	25.25	2.52	50.04	3.72	143.16	181.96	1817.94	21198.15	1.71
S_4 = 60 cm x 10 cm	106.89	85.90	102.73	6.95	18.55	2.43	45.47	4.00	142.40	184.85	1848.62	20836.83	1.68
S_5 = 60 cm x 20 cm	63.91	86.68	100.36	8.46	23.90	2.47	49.28	3.78	142.83	162.03	1622.00	17294.86	1.62
S_6 = 60 cm x 30 cm	46.92	87.32	98.04	10.24	31.18	2.52	50.35	3.69	143.80	152.94	1490.00	15310.70	1.56
Mean	90.03	86.19	100.12	8.08	22.55	2.47	47.87	3.85	142.61	181.85	1827.79	20821.98	1.68
LSD (P=0.05)	1.13	0.61	1.46	0.33	1.13	0.02	1.11	0.09	0.60	4.27	34.74	603.24	0.02

RD = Recommended dose of fertilizers N:P:K=60:30:30 kg/ha

Table 2 Effects of dates of sowing x fertilizer levels on flower and seed yield in safflower (average of three years)

Treatment	Flower yield (kg/ha)				Seed yield (kg/ha)			
	D_1	D_2	D_3	Mean	D_1	D_2	D_3	Mean
F_0 = No fertilizer (Control)	172.65	166.51	131.62	156.93	1944.49	1633.83	1110.66	1562.99
F_1 = 50% RD	201.43	178.48	156.02	178.64	2240.16	1772.43	1372.30	1794.97
F_2 = 100% RD	216.04	193.31	168.97	192.77	2379.83	1894.65	1541.73	1938.74
F_3 = 150% RD	218.49	206.49	172.22	199.07	2433.74	2040.37	1569.38	2014.50
Mean	202.15	186.20	157.20	181.85	2249.55	1835.31	1398.51	1827.79
LSD* (P = 0.05)	5.94				62.48			
LSD** (P = 0.05)	5.58				69.01			

* Between date of sowing means for same or different fertilizer levels; ** Between fertilizer level means for same date of sowing

Table 3 Effects of dates of sowing x spacings on flower and seed yield in safflower (average of three years)

Treatment	Flower yield (kg/ha)				Seed yield (kg/ha)			
	D_1	D_2	D_3	Mean	D_1	D_2	D_3	Mean
S1 = 45 cm x 10 cm	233.51	222.13	186.92	214.19	2617.90	2269.75	1729.63	2205.76
S2 = 45 cm x 20 cm	219.70	198.63	167.14	195.16	2459.14	1951.30	1536.97	1982.47
S3 = 45 cm x 30 cm	200.64	186.45	158.78	181.96	2279.07	1786.91	1387.84	1817.94
S4 = 60 cm x 10 cm	207.83	190.37	156.37	184.85	2269.20	1900.62	1376.05	1848.62
S5 = 60 cm x 20 cm	181.26	164.89	139.93	162.03	2010.99	1618.64	1236.36	1622.00
S6 = 60 cm x 30 cm	169.96	154.73	134.12	152.94	1861.05	1484.69	1124.26	1490.00
Mean	202.15	186.20	157.20	181.85	2249.55	1835.31	1398.51	1827.80
LSD* (P=0.05)	6.77				57.81			
LSD** (P=0.05)	7.40				60.17			

* Between date of sowing means for same or different spacings; ** Between spacing means for same date of sowing

Table 4 Effects of fertilizer levels x spacings on flower and seed yield in safflower (average of three years)

Treatment	Flower yield (kg/ha)					Seed yield (kg/ha)				
	F_0	F_1	F_2	F_3	Mean	F_0	F_1	F_2	F_3	Mean
S_1 = 45 cm x 10 cm	182.57	211.49	229.20	233.49	214.19	1864.28	2198.93	2364.44	2395.39	2205.61
S_2 = 45 cm x 20 cm	172.58	182.84	205.35	219.86	195.16	1722.30	1887.74	2072.35	2247.49	1982.47
S_3 = 45 cm x 30 cm	154.87	179.74	197.17	196.04	181.96	1563.79	1796.21	1934.73	1977.04	1817.94
S_4 = 60 cm x 10 cm	164.98	180.58	192.19	201.66	184.85	1648.81	1788.56	1951.19	2005.92	1848.62
S_5 = 60 cm x 20 cm	138.62	162.37	172.47	174.66	162.03	1348.07	1594.73	1716.38	1828.80	1622.00
S_6 = 60 cm x 30 cm	127.93	154.85	160.27	168.70	152.94	1230.70	1503.62	1593.33	1632.35	1490.00
Mean	156.92	178.64	192.77	199.06	181.85	1562.99	1794.96	1938.73	2014.49	1827.79
LSD* (P=0.05)	8.44					91.69				
LSD** (P=0.05)	8.55					69.48				

* Between fertilizer level means for same or different spacings; ** Between spacing means for same fertilizer level

Table 5 Effect of dates of sowing x fertilizer levels x spacings on flower yield (kg/ha) of safflower (average of three years)

Main plot	Sub plot	Sub sub plot						Mean
		S_1	S_2	S_3	S_4	S_5	S_6	
D_1 = October 3	F_0 = No fertilizer (Control)	203.51	184.77	170.13	190.19	153.42	133.87	172.64
	F_1 = 50% RD	232.85	209.07	198.83	209.78	183.51	174.53	201.42
	F_2 = 100% RD	241.54	227.19	224.87	218.44	192.04	192.18	216.04
	F_3 = 150% RD	256.16	257.18	208.74	212.90	196.09	179.27	218.49
	Mean	233.51	219.70	200.64	207.82	181.26	169.96	202.15
D_2 = October 18	F_0 = No fertilizer (Control)	193.69	183.72	167.60	177.93	142.74	133.39	166.51
	F_1 = 50% RD	217.90	179.98	180.28	170.13	166.72	155.89	178.48
	F_2 = 100% RD	236.26	203.50	186.10	202.23	176.65	155.11	193.30
	F_3 = 150% RD	240.66	227.32	211.81	211.19	173.46	174.53	206.49
	Mean	222.130	198.629	186.449	190.372	164.89	154.72	186.20
D_3 = November 1	F_0 = No fertilizer (Control)	150.51	149.25	126.90	126.83	119.69	116.52	131.61
	F_1 = 50% RD	183.72	159.46	160.11	161.82	136.90	134.13	156.02
	F_2 = 100% RD	209.80	185.37	180.53	155.91	148.70	133.53	168.97
	F_3 = 150% RD	203.64	174.47	167.57	180.91	154.43	152.29	172.21
	Mean	186.91	167.14	158.77	156.36	139.92	134.11	157.20
Spacing mean		214.18	195.15	181.95	184.85	162.02	152.93	181.85
Fertilizer mean (kg/ha)		F_0	F_1		F_2		F_3	
		156.92	178.64		192.77		199.68	

General mean = 181.854 kg/ha; LSD (5%)

(1) Between spacing means for same date of sowing and fertilizer level = 14.81
(2) Between fertilizer level means for same date of sowing and same or different spacings = 14.63
(3) Between date of sowing means for same or different fertilizer levels and spacings = 14.75
(4) Between date of sowing means = 3.54
(5) Between fertilizer level means = 3.22
(6) Between spacing means = 4.27

SEM + (Main plot) = 4.42 kg/ha C.V. (Main plot) = 4.21%
SEM + (Sub plot) = 4.60 kg/ha C.V. (Sub plot) = 4.38%
SEM + (Sub sub plot) = 5.29 kg/ha C.V. (Sub sub plot) = 5.04%

Table 6 Effect of dates of sowing x fertilizer levels x spacings on seed yield (kg/ha) of safflower (average of three years)

Main plot	Sub plot	Sub sub plot						Mean
		S_1	S_2	S_3	S_4	S_5	S_6	
D_1 = October 3	F_0 = No fertilizer (Control)	2244.44	2104.44	2007.65	2075.31	1716.54	1518.52	1944.486
	F_1 = 50% RD	2690.12	2396.54	2155.06	2309.63	1989.14	1900.49	2240.164
	F_2 = 100% RD	2713.08	2588.39	2481.73	2356.05	2102.96	2036.79	2379.835
	F_3 = 150% RD	2823.95	2747.16	2471.85	2335.80	2235.31	1988.39	2433.745
	Mean	2617.900	2459.136	2279.074	2269.197	2010.988	1861.049	2249.557
D_2 = October 18	F_0 = No fertilizer (Control)	1953.09	1736.05	1632.84	1808.39	1407.16	1265.43	1633.827
	F_1 = 50% RD	2223.21	1837.04	1869.63	1683.95	1578.52	1442.22	1772.428
	F_2 = 100% RD	2427.90	1966.17	1787.90	1959.26	1693.09	1533.58	1894.650
	F_3 = 150% RD	2474.81	2265.93	1857.28	2150.86	1795.80	1697.53	2040.370
	Mean	2269.753	1951.296	1786.913	1900.617	1618.641	1484.691	1835.319
D_3 = November 1	F_0 = No fertilizer (Control)	1395.31	1326.42	1050.86	1062.72	920.49	908.15	1110.658
	F_1 = 50% RD	1683.46	1429.63	1363.95	1372.10	1216.54	1168.15	1372.304
	F_2 = 100% RD	1952.35	1662.47	1534.57	1538.27	1353.09	1209.63	1541.728
	F_3 = 150% RD	1887.41	1729.38	1601.97	1531.11	1455.31	1211.11	1569.383
	Mean	1729.630	1536.975	1387.839	1376.049	1236.358	1124.259	1398.518
Spacing mean		2205.761	1982.469	1817.942	1848.621	1621.996	1490.000	1827.798

Fertilizer mean (kg/ha)	F_0	F_1	F_2	F_3
	1562.99	1794.96	1938.73	2014.49

General mean = 1827.798 kg/ha; LSD (5%)

(1) Between spacing means for same date of sowing and fertilizer level = 120.35
(2) Between fertilizer level means for same date of sowing and same or different spacings = 129.67
(3) Between date of sowing means for same or different fertilizer levels and spacings = 126.31
(4) Between date of sowing means = 18.77
(5) Between fertilizer level means = 48.80
(6) Between spacing means = 34.74

SEM + (Main plot) = 23.42 kg/ha C.V. (Main plot) = 2.20%
SEM + (Sub plot) = 56.89 kg/ha C.V. (Sub plot) = 5.38%
SEM + (Sub sub plot) = 42.98 kg/ha C.V. (Sub sub plot) = 4.08%

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Evaluation of insecticides for the control of serpentine leaf miner (*Liriomyza trifolii* Burgess) in castor

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ABSTRACT

Field experiments were conducted with seven treatments *viz*., Carbaryl 50 WP @ 0.2%, Endosulfan 35 EC @ 0.05%, Triazophos 40 EC @ 0.05%, Spinosad 45 SC @ 0.018%, Fipronil 5 SC @ 0.01%, Neem seed extract @ 5% (w/v) and untreated treatment for the control of serpentine leaf miner (*Liriomyza trifolii* Burgess) on castor (*Ricinus communis* L.) cultivar DCS-9 during the rainy seasons of 2007, 2008 and 2010. Two sprays of all the treatments except untreated control were applied 30 and 45 days after sowing. The treatment with 0.018% Spinosad was the most effective in suppressing leaf miner infestation and resulted in to higher seed yield (803 kg/ha) followed by 0.05% spray of Triazophos (761 kg/ha). The economics of the treatments revealed the highest B:C ratio (1.98) by Triazophos 0.05% followed by Spinosad 0.018% (1.52), Carbaryl 0.2% (1.28), Endosulfan 0.05% (1.25) and Fipronil 0.01% (1.11). The other treatments were found relatively less effective for the control of leaf miner.

Keywords: Castor leaf miner, Insecticides

Castor (*Ricinus communis* L.) is an industrially important non-edible oilseeds crop of the world. Among the biological constraints in castor production, insect pests dominate the scenario. In India, several insect pests infesting castor have been recorded (Rai, 1976). The most important ones are the defoliators *viz*., red hairy caterpillar (*Amsacta moorei* Butler), semilooper (*Achoea janata* L.), tobacco caterpillar (*Spodoptera litura* F.) and recently serpentine leaf miner (*Liriomyza trifolii* Burgess) (Lakshminarayana, 2010). The serpentine leaf miner is a polyphagous pest feeding on seventy nine host plants belonging to various vegetables, ornamentals and field crops (Srinivasan *et al*., 1995). In the study of crop-pest weather relationship in castor, Srinivasrao (2003) reported the live mines due to *Liriomyza trifolii* associated positively and significantly with minimum temperatures and the maximum temperatures had non-significant effect in June and July sown castor whereas rainfall, sunshine hours and relative humidity had non-significant relation with live mines. So far plant types are concern castor plants with 'papaya' leaf types, red stem and single, double and triple blooms showed resistance to leaf miner (Hegde *et al*., 2009). Population dynamics of serpentine leaf miner on tomato and its relation with meteorological parameters was also studied by Galande and Ghorpade (2010). They recorded the peak activity of this pest during January to April with highest incidence in February when the maximum temperature and morning relative humidity was at 34.14°C to 35.23°C and 70.25 to 77.32%, respectively. The magnitude of the pest problem is quite high mostly in rain fed area. It has high potential for the development of resistance to commonly used insecticides. Present investigation was therefore, undertaken with an objective to evaluate different insecticides for the control of serpentine leaf miner in castor.

MATERIALS AND METHODS

The field experiments were conducted at NARP, Zonal Agricultural Research Station, MPKV, Solapur- 413 002 (MS), India during the rainy season of 2007, 2008 and 2010. The susceptible castor cultivar, DCS-9 was selected for sowing. Similar cultural and agronomic practices were followed in all the plots. Total seven treatments including absolute control (Table 1) were considered for the evaluation. The sowing was done at 90 cm x 45 cm spacing in the gross plots of 5.40 x 6.00 m^2 with three replications in a randomised block design. Two sprays were given at 30 and 45 days after sowing (DAS) by using knapsack sprayer. The spray formulation volume @ 500 l/ha (w/v) was applied. The periodical observations on the incidence of leaf miner i.e. number of live mines/leaf/plant were recorded 7 days after both the sprays in top, middle and bottom leaves of five randomly selected plants in each plot. Seed yield (kg/ha) was recorded at harvest. The data were analyzed using ANOVA (Panse and Sukhatme, 1967).

RESULTS AND DISCUSSION

The data on leaf damage by leaf miner after both first and second spray and seed yield as influenced by different treatments are given in table 1 and 2, respectively. The individual and three years pooled results revealed the significant differences among the treatments studied in average leaf mines/leaf/plant after both the sprays and seed yield at harvest during all the three years. However, significantly highest mean leaf damage (24.78, 28.17 and 94.42 mines/leaf/plant) was recorded in absolute control over rest of the treatments, respectively during the years 2007-08, 2008-09 and 2010-11. Among the treatments, Spinosad 45 SC 0.018% recorded the minimum average leaf damage of 14.42, 8.84 and 20.00 mines/leaf/plant after first and second spray during 2007-08, 2008-09 and 2010-11, respectively. It was followed by Triazophos 40 EC 0.05% (15.75, 10.00 and 24.75 mines/leaf/plant) and thus controlled the leaf miner very effectively. According to pooled results also, these two treatments (Spinosad 45 SC 0.018 % and Triazophos 40 EC 0.05%) were statistically at par with each other in respect of leaf damage. However, after first spray Spinosad was statistically at par with all other treatments except Endosulfan 35 EC 0.05% and untreated control during 2007-08 (Table 1). During the year 2008-09 and 2010-11 also Spinosad 45 SC 0.018% and Triazophos 40 EC 0.05% were statistically at par with each other in respect of live leaf mines due to leaf miner.

The data on seed yield (Table 2) revealed that significantly highest average seed yield of 803 kg/ha obtained in 0.018% Spinosad 45 SC spray which was however, at par with 0.05% spray of Triazophos 40 EC (761 kg/ha) and both the treatments were significantly superior over rest of the treatments. This was followed by 0.2% Carbaryl 50 WP (533 kg/ha), 0.05% Endosulfan 35 EC (471 kg/ha) and 0.01 Fipronil 5 SC (449 kg/ha). Looking to individual year data regarding seed yield, the treatments *viz*., Triazophos 0.05% and Spinosad 0.018% were statistically at par with each other during all the three years. The highest B:C ratio of 1.98 was recorded by Triazophos 0.05% followed by Spinosad 0.018% (1.52), Carbaryl 0.2% (1.28), Endosulfan 0.05% (1.25) and Fipronil 0.01% (1.11). Remaining treatments were economically ineffective (Table 2).

Table 1 Efficacy of pesticides for the control of castor leaf miner

Treatments	Average. leaf mines/leaf/plant								
	2007-08			2008-09			2010-11		
	I Spray	II Spray	Mean	I Spray	II Spray	Mean	I Spray	II Spray	Mean
Carbaryl 50 WP @ 0.2 %	14.39	17.28	15.84	12.33	17.00	14.67	32.17	44.17	38.17
Endosulfan 35 EC @ 0.05 %	17.17	15.33	16.25	15.00	18.00	16.50	35.17	32.00	33.59
Triazophos 50 EC @ 0.05 %	16.11	15.39	15.75	08.00	12.00	10.00	22.17	27.33	24.75
Spinosad 45 SC @ 0.018 %	13.55	15.28	14.42	07.00	10.67	8.84	21.17	18.83	20.00
Fipronil 5 SC @ 0.01%	15.50	19.39	17.45	20.00	22.33	21.17	27.67	29.17	28.42
NSE @ 5 % (w/v)	15.50	18.11	16.81	21.00	23.00	22.00	36.17	124.17	80.17
Control	24.28	25.28	24.78	26.33	30.00	28.17	56.33	132.50	94.42
SEm±	00.88	01.53	-	00.68	01.20	-	03.16	02.29	-
CD (P=0.05)	02.70	04.71	-	02.10	03.69	-	09.72	07.04	-
CV (%)	9.11	14.69	-	07.52	10.92	-	16.58	06.79	-

Table 2 Average seed yield of castor (kg/ha) influenced due to different pesticides

Treatment	07-08	08-09	10-11	Mean	B : C Ratio
Carbaryl 50 WP @ 0.2 %	651.40	529.80	416.40	533	1.28
Endosulfan 35 EC @ 0.05 %	641.70	362.10	408.30	471	1.25
Triazophos 50 EC @ 0.05 %	1015.30	656.40	610.80	761	1.98
Spinosad 45 SC @ 0.018 %	1072.11	694.40	640.80	803	1.52
Fipronil 5 SC @ 0.01%	527.90	432.10	387.20	449	1.11
NSE @ 5 % (w/v)	360.60	370.40	308.10	346	0.91
Control	73.10	149.20	198.10	140	0.39
SEm±	24.60	48.86	27.97	20.48	-
CD (P=0.05)	75.79	150.54	86.16	58.73	-
CV (%)	06.87	18.54	11.42	-	-

The castor yield losses due to defoliators were reported earlier (Anonymous, 2006). Efficacy of insecticides on defoliator is supported by Ahuja *et al.* (1998). Singh and Kanujia (2003) reported NSKE to be less effective against the defoliator which is in agreement with the present findings. However, in the studies on insect pests and their management in castor seed production an application of Chlorpyriphos 0.05% was found effective against the leaf miner (*Liriomyza trifolii* Burgess) (Basappa *et al*., 2010).

Based on the individual and three years pooled results, it is concluded that for the effective control of leaf miner and increasing the seed yield of castor, two sprays of 0.018% spinosad 45 SC or 0.05% Triazophos 50 EC at 30 and 45 DAS are beneficial under rainfed condition particularly in the rain scarcity zone of Maharashtra.

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Frontline demonstration for boosting the oilseeds production in Rajasthan: A case study in Pali

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ABSTRACT

The oilseed crops grown in India are groundnut, rapeseed, mustard, sesame, sunflower, safflower, niger and soybean. The oilseed crops are well-distributed over different agro-climatic regions in India. The major growing belt of oilseeds spreads from arid to semi-arid regions, covering large areas in Rajasthan, Punjab and Haryana, which contribute more than 37.9% of the total oilseed production in the country. This study was conducted in Pali district of Rajasthan during the years 2007 to 2010. The productivity of oilseeds crops continues to be quite low due to gaps in adoption of oilseeds technologies. The yield of oilseeds can be increased by demonstrating their cultivation technologies at the farmers' fields under the supervision of scientists working in the operational area. Keeping the importance of frontline demonstrations, the KVK, CAZRI, Pali conducted demonstrations on improved agricultural technologies of oilseeds crops in farmers' fields during the year 2007-08, 2008-09 and 2009-10 and achieved the expected yields.

Keywords: Adoption and TOT, Demonstration, Oilseeds

Oilseeds play the second important role in the Indian agricultural economy, next only to food grains in terms of area and production. Oilseed crops occupy 13-14 % of gross cropped area and are cultivated in an area of 26.82 m. ha, with a production of 31.1 m. t. (Anonymous, 2011). The average productivity of annual oilseeds revolves around 1159 kg/ha, which is about a tonne less than that of world's average. The diverse agro-ecological region in the country is favourable for growing all the nine annual oilseeds which include seven edible oilseeds *viz*., groundnut, mustard, soybean, sunflower, sesame, niger and safflower and two non-edible oilseeds *viz*., linseed and castor. Among different oilseeds, groundnut, mustard and soybean account for about 80% of the oilseeds are 88% of oilseeds production in the country. In Rajasthan during 2011-12, major area covered under different oilseeds is 24.41 lakh ha in mustard, 5.13 lakh ha in sesame, 4.15 lakh ha in groundnut, 26.40 lakh ha in castor and 6.09 lakh ha in tarameera, producing 29.50, 16.63, 8.06, 38.25 and 2.59 lakh t. having productivity of 1209, 324, 1931, 1449 and 426 kg/ha, respectively (Anonymous, 2011). The area and production of oilseeds in Pali district is very low as compare to state and national acreage and production.

The major objective of frontline demonstrations (FLDs) is to show the production potential and profitability of improved technologies *vis-à-vis* farmers practices under real farm situations. Now, the FLDs also conducted through KVKs all over the country. The area and production of oilseed in Pali district is very low as compare to state and national acreage and production. Therefore, it is very essential to demonstrate the high yielding varieties, resistant to biotic and abiotic stress and other oilseed production technologies which the farmers generally do not adopt. Keeping the importance of FLDs, the KVK, CAZRI, Pali conducted demonstrations on oilseed crops *viz*., mustard, sesame, groundnut and castor at farmers' field under un-irrigated situations in winter/rainy season during the years 2007-08, 2008-09 and 2009-10. The specific objectives of the study were to demonstrate the performance of recommended high yielding varieties in mustard and sesame and performance of recommended dose of phosphatic fertilizers in groundnut and castor to harvest higher crop yield and to compare the yield level of local check (farmers' field) and FLDs fields.

MATERIALS AND METHODS

Farmers' operational area of CAZRI, KVK, Pali were selected. Accordingly, the FLDs under mustard, sesame, groundnut and castor laid out in the eight adopted villages namely, Dhamli, Kusalpura, Nayagoa, Bagawas, Khetawas, Nimbali, Khandi and Rampura which were selected randomly for the present study. The area under each demonstration was 0.50 ha. Regular visits by the KVK, CAZRI scientists to demonstration fields were ensured and to guide the farmers. These visits were also utilized to collect feedback information for further improvement in research and extension programmes. Field days and group meetings were also organized at the demonstration site to provide the opportunities for other farmers to see the benefits of demonstrated technologies. The critical inputs were supplied to the farmers by the CAZRI, KVK, Pali. Data were

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collected from the FLDs farmers and analyzed with statistical tools to compare the yield of farmers' field and FLDs.

RESULTS AND DISCUSSION

Performance of recommended high yielding varieties of mustard: The progress of FLDs on oilseed during the year 2009 and 2010 to exhibit the performance of recommended high yielding variety i.e. Maya of mustard is presented in table 1. The data in table 1 revealed that in the winter season 2009, 10 demonstrations of mustard covering 3.0 ha in 2 villages with variety Maya and local check were planted. An average yield of 14.10 q/ha of test variety was obtained, as compared to 1070 kg/ha of local check with a per cent increase of 31.8. During the winter season 2010, five demonstrations of mustard covering 2.0 ha in one village with variety Maya and local check were planted. An average yield of 1480 kg/ha of test variety was obtained, as compared to 1140 kg/ha of local check with a per cent increase of 29.8. These findings are conformity with Lakhera and Sharma (2003); Singh *et al*. (2007) and Jatav (2010).

Table 1 Performance of recommended high yielding varieties of mustard (Maya)

Crop season and year	Village	HYVs in FLDs	No. of FLDs	Area (ha)	Yield (kg/ha)		Increase in %
					Maya	Local	
Winter, 2009	Dhamali	Maya	5	1.5	1450	1050	38.1
	Kusalpura	Maya	5	1.5	1380	1090	26.7
	Weighted	Mean	10	3.0	1410	1070	31.8
Winter, 2010	Nayagoa	Maya	5	2.0	1480	1140	29.8

HYV : High yielding varieties; FLD : Frontline demonstrations

Performance of high yielding variety (RT 346) of sesame: The progress of frontline demonstrations on oilseeds during rainy season 2008, 2009 and 2010 to show the performance of recommended high yielding variety, *viz*., RT 346 of sesame is presented in table 2.

During the rainy season (2007-08), 17 demonstrations of sesame covering 7 ha of land in four villages resulted in 1820 and 530 kg/ha yield in test variety RT 346 and local check, respectively. This accounted for 54.72% average increase in the yield. In rainy season (2008-09), 18 demonstrations of sesame covering 7 ha of land in four villages resulted in 860 and 610 kg/ha yield in test variety RT 346 and local check, respectively. This accounted for 40.98% average increase in the yield. Five demonstrations of sesame in 2008-09 season, covering 2 ha of land in one village resulted in 980 and 570 kg/ha yield test variety RT 346 and local check, respectively. This accounted for 71.93% average increase in the yield (Table 2). These findings corroborate the findings of Padmaiah and Venkattakumar (2009) and Gaikwad *et al*. (2011).

Table 2 Performance of high yielding variety sesame (RT 346)

Crop season and year	Village	HYV, FLDs	No. of FLDs	Area (ha)	Yield (kg/ha)		Increase in %
					RT 346	Local	
Rainy, 2007-08	Khandi	RT 346	5	2	840	580	24.97
	Nasyagoa	RT 346	5	2	790	510	54.90
	Bagawas	RT 346	5	2	850	480	77.08
	Khetawas	RT 346	2	1	790	500	58.00
	weighted		17	7	820	530	54.72
Winter, 2008-09	Nimbali	RT 346	5	2	950	620	53.23
	Bagawas	RT 346	5	2	830	580	43.10
	Rampura	RT 346	4	1.5	790	590	33.90
	Khandi	RT 346	4	1.5	860	630	36.51
	Weighted		18	7	860	610	40.98
Winter, 2009-10	Khetawas	RT 346	5	2	980	570	71.93

HYV : High yielding varieties; FLD : Frontline demonstrations

Performance of recommended dose of phosphetic fertilizer application @ 60 kg DAP/ha in groundnut: The progress of FLD on oilseeds during rainy season, 2008, 2009 and 2010 to exhibit the performance of recommended dose of 60 kg/ha DAP in groundnut is presented in table 3.

The data in table 3 indicated that in the rainy season 2008, the application of 60 kg DAP/ha, as demonstrated in 20 demonstrations covering 8 ha of land in three villages resulted in 1820 and 1380 kg/ha yield in DAP and non-DAP plots of groundnut (RTG 37A), respectively. This accounted for 31.1% average increase in the yield. During the rainy season 2009, the application of 60 kg DAP/ha, as demonstrated in 10 demonstrations covering 5 ha of land in one village resulted in 1760 and 1430 kg/ha yield in DAP and non-DAP plots of groundnut (TG 37A), respectively. This accounted for 23.1% average increase in the yield. In the rainy season 2010, the application of 60 kg DAP/ha, as demonstrated, factor in six demonstrations covering 3 ha of land in one village in 1890 and 1350 kg/ha yield in DAP and non-DAP plots of groundnut (TG 37A), respectively (Table 3). This accounted for 40% average increase in the yield. The findings confirm with the findings of Yadav *et al.* (2007) and Meena *et al.* (2013).

Performance of recommended dose of phosphatic fertilizer (40 kg/ha) in castor: The progress of FLDs on oilseeds during rainy season 2007-08, 2008-09 and 2009-10 to demonstrate the performance of recommended dose of phosphatic fertilizer (50 kg/ha) in castor is presented in table 4.

During the rainy season (2007-08), five demonstrations of castor covering 2 ha in one village with variety GCH 7 using DAP @ 40 kg/ha yielded 1000 kg seed as compared to 750 kg/ha of check. The per cent increase was accounted as 33.33%. Demonstrations conducted in a similar way during 2008-09 rainy season showed an average yield of 840 kg/ha seed yield was obtained, as compared to 500 kg/ha of local check and the per cent increase was accounted at 68% (Table 4). During rainy season (2009-10) in castor, five demonstrations covering 2.0 ha in one village with variety GCH 7 using DAP @ 40 kg/ha and without DAP (check) were conducted. An average yield of 910 kg/ha of demonstrations was obtained, as compared to 610 kg/ha of local check which accounts at 49.18% (Table 4). The results of this study are in conformity with the findings of the study carried out by Kumawat (2008), Singh *et al.* (2007), Mishra, *et al.* (2007), Singh (2007) and Meena *et al.* (2012).

The yield of demonstrated plots was higher than in local-check plots. There is a need for high yielding mustard varieties in this area to fit well in to mustard-greengram cropping pattern for timely sowing of mustard after harvesting of greengram crop. The location based nutrient application for oilseeds to be thoroughly reviewed and investigated.

Table 3 Performance of recommended dose of phosphatic fertilizer application (60 kg/ha) in groundnut

Crop season and year	Village	HYV in FLDs	No. of FLDs	Area (ha)	Yield (kg/ha)		Increase in %
					DAP	No DAP	
Rainy 2008	Kusalpura	TG 37A	10	4	1860	1450	28.3
	Bagawas	TG 37A	5	2	1790	1310	36.6
	Dhamali	TG 37A	5	2	1810	1390	30.2
	Weighted mean		20	8	1820	1380	31.1
Rainy 2009	Khetawas	TG 37A	10	5	1760	1430	23.1
Rainy 2010	Nimbali	TG 37A	6	3	1890	1350	40.0

HYV : High yielding varieties; FLD : Frontline demonstrations; DAP : Diammonium phosphate

Table 4 Performance of recommended dose of phosphatic fertilizers (40 kg/ha) in castor

Crop season and year	Village	HYV, FLDs	No. of FLDs	Area (ha)	Yield (kg/ha)		Increase in %
					DAP	No DAP	
Rainy 2008	Rampura	GCH 7	5	2	1000	750	33.33
Rainy 2009	Kusalpura	GCH 7	5	2	840	500	68.00
Rainy 2010	Nayagoa	GCH 7	5	2	910	610	49.18

HYV : High yielding varieties; FLD : Frontline demonstrations; DAP : Diammonium phosphate

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Combining ability analysis in Indian mustard (*Brassica juncea* L. Czern & Coss.)

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ABSTRACT

A line x tester analysis involving five males (lines) and 10 female (testers) parents were carried out for five traits in Indian mustard. (*Brassica juncea* L. Czern & Coss.). Among the parents, MCN-75, Ornamental Rai, Rohini, Kranti, Vardan, RH-8812, and NDR-8501 were found to be significantly superior general combiners for seed yield and yield components. The cross MCN-75 x Rohini, MCN-75 x NDR-8501, MCN-75 x Vardan and MCN-73 x Kranti showed high heterosis for seed yield and some of the yield contributing traits. The cross MCN-75 x RH-8812, MCN-73 x Pusa Bold, Ornamental Rai x NDR-8501 and MCN-70 x RH-8813 had higher *sca* effects. For most of the major characters including seed yield both additive and non-additive gene action were of prime importance.

Key words: *gca* effects, Heterobeltiosis, Mid-parent heterosis, Mustard *sca* effects

Indian mustard (*Brassica juncea* L. Czern & Coss.) is one of the most important oilseed crops grown during winter season. The realisable yield potential in this crop based on various observations is reported to be much more than what has been achieved so far. The increase in productivity through breeding efforts has not been adequate because of hybridization. Heterosis breeding could be a potential alternative for achieving quantum jumps in production and productivity. Since, commercial exploitation of heterosis in several crop plants has caused a major breakthrough in yield levels. The magnitude of heterosis particularly for yield is of paramount importance and if the heterosis is practically and economically feasible it can help to reach high yield levels in mustard. Information about general and specific combining ability effects is very important in making the next phase of a breeding program. It is necessary to have detailed information about the desirable parental combination in any breeding program which can reflect a high degree of heterotic response. Therefore, heterotic studies can provide the basis for the exploitation of valuable hybrid combinations in future breeding programs in brassica. The main Objective of the present study was to identify the best combiners and their crosses on the basis of their general, specific combining ability and high heterotic crosses for yield and its component traits. The present study was undertaken to select parents for effective hybridization programme as well as rapid selection advance in segregating generations.

The experiment was conducted at crop improvement research of Banaras Hindu University, Varanasi. The experimental material consisted of five lines (MCN-129, MCN-70, MCN-73, MCN-75 and Ornamental Rai) and 10 (Varuna, Vardan, Kranti, Pusa Bold, Rohini, RH-8812, RH-8813, RH-8814, RLM-1359 and NDR-8501) testers were selected on the basis of phenotypic diversity in respect of yield and yield components from the genetic stock of mustard. The lines were selected on the basis of their reaction to leaf blight; all the lines taken in the present investigation were tolerate to leaf blight. But they suffer from low productivity. These 15 genotypes were sown in a crossing block during winter season of 2003. The line x tester model of mating design was adapted to produce 50 F_1 hybrids. These 50 F_1 hybrids along with their 15 parents were sown in a randomized block design with two replications during winter season of 20045. Each entry was sown in a single row of 4.5 m length at spacing of 45 cm x 10 cm. Five competitive plants were selected randomly from each plot for recording observations on length of siliqua, number of siliquae/plant, number of seeds/siliquae, seed yield/plant and for 1000-seed weight. The data were subjected to analyses of variance according to Steel and Torrie (1980). The estimates of combining ability effects were computed as per procedure suggested by Griffing (1956).The estimate of heterosis over the mid-parent and better-parent was calculated using the procedure of Matzingar *et al.* (1962).

The analysis of variance (Table 1) revealed significant differences for all the characters except length of siliqua studied in case of lines, which indicated the existence of genetic diversity in the parental materials. On the other hand, among testers highly significant differences were observed for number of siliquae/plant and numbers of seeds/siliqua.The mean squares due to females were found to be smaller than those due to males except seed yield/plant, length of siliqua and 1000-seed weight (Table 1). Variations among line x tester interactions were significant for all the characters except seed yield/plant and length of siliqua. This indicated the manifestation of parental genetic variability in their crosses and presence of uniformity among the hybrids.

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The variance due to *sca* was found to be considerably higher than that of *gca* for all characters except number of siliqua/plant, indicating greater importance of non-additive gene action for exploitation of heterosis.

General combining effects of all lines and testers are presented in table 2. For seed yield the genotypes appeared as best general combiners were MCN-75, Rohini, Kranti, Vardan and NDR-8501 (Table 3). Among the parents, Rohini was found to be good general combiner for other contributing traits like, number of siliquae/plant and number of seeds/siliqua. The genotypes Kranti and NDR-8501 were the best general combiner for number of siliquae/plant and seed yield/plant. The genotype RH-8812 was the best general combiner for 1000-seed weight.

Specific combining ability effect estimates revealed a very wide range of variation for all the characters. The crosses with significant desirable *sca* effects are presented in Table 4. Cross combinations MCN-70 x Rohini, MCN-70 x Vardan, MCN-70 x RH-8813 and MCN-129 x Varuna had high significant *sca* effect for seed yield coupled with high *gca* of female parent for seed yield and major yield components. Therefore, both additive and non-additive type of gene action seemed to influence seed yield. Similar results were also reported by Satwinder *et al.* (2000). Oian *et al.* (2003). Crosses like, MCN-73 x Pusa Bold and MCN-70 x Pusa Bold were the best specific combiners for number of siliquae/plant. Teklewold and Becker (2005), found significant specific combining (SCA) effects for number of siliquae/plant, whereas, MCN-75 x RH-8812 and Ornamental Rai x Varuna for number of seeds/siliqua Teklewold and Becker (2005) reported that *gca* of parents and *sca* of F_1's hybrids was significant for seeds/siliqua. Kumar *et al.* (2002) and Yadav *et al.* (2004) also reported similar results. Crosses Ornamental Rai x RLM-1359, Ornamental x NDR-8501 and Ornamental Rai x Vardan were the good specific combiners for length of siliqua Teklewold and Becker (2005), found significant specific combining effects for length of siliqua. Crosses MCN-73 x Pusa Bold, MCN-70 x RLM-1359 and MCN-129 x Varuna also performed as the best specific combiner for 1000-seed weight.

Table 1 Analysis of variance for combining ability analysis in Indian mustard

Source of variation	D. F.	Mean Sum of Square				
		No. of siliquae/plant	No. of seeds/siliqua	Seed yield/plant	Length of siliqua	1000-seed weight
Females	9	13401.82**	2.37**	12.94**	0.13	0.76**
Males	4	3451.90**	4.66**	0.57	0.11	0.42
Female x Male	36	2368.25**	3.83**	1.12	0.13	0.97**
Error	49	335.02	0.52	0.78	0.08	0.23

*, ** Significant at 5% and 1% level, respectively

Table 2 Estimates of general combining ability effects in line x tester analysis in Indian mustard

Parent	No. of siliquae/plant	No. of seeds/siliqua	Seed yield/plant	Length of siliqua	1000-seed weight
Line					
MCN-129	-3.97	0.20	0.13	0.04	0.12
MCN-70	-7.12	-0.48*	-0.26	-0.05	0.19
MCN-73	-4.97	-0.55*	-0.05	-0.09	-0.04
MCN-75	23.36**	0.30	0.16	-0.02	-0.12
O R.	-7.321	0.52*	0.02	0.10	-0.13
Male					
CD (P=0.05)	12.34	0.48	0.59	0.18	0.32
CD (P=0.01)	21.68	0.85	1.04	0.33	0.87
Testers					
Varuna	-64.92**	0.10	-1.70**	0.03	0.23
Pusa Bold	-55.88**	-0.20	-2.31**	-0.06	-0.13
Vardan	21.00*	0.00	0.48	0.01	-0.41*
RH-8812	-2.34	-0.02	-0.17	0.06	0.43*
RH-8813	9.08	-0.42	0.05	0.14	-0.43*
RH-8814	-18.50*	-0.40	0.21	0.13	0.25
Rohini	47.68**	1.10*	1.13**	-0.07	0.09
Kranti	22.70*	-0.24	0.95**	-0.26*	-0.05
NDR-8501	31.02*	-0.46	0.77**	-0.09	0.03
RLM-1359	10.12	0.52	0.58	0.05	0.03
Female					
CD (P=0.05)	15.00	0.59	0.72	0.26	0.39
CD (P=0.01)	23.08	0.91	1.11	0.46	0.60

*, ** Significant at 5% and 1% level, respectively; O R = Ornamental Rai

Table 3 Superior general combiners for different characters in Indian mustard

Character	Lines (Males)	Testers (Females)
No. of siliquae/Plant	MCN-75	Rohini, NDR-8501, Kranti, Vardan
No. of seeds/Siliqua	Ornamental Rai	Rohini
Seed yield/Plant	MCN-75	Rohini, Kranti, NDR-8501
Length of siliqua	-	-
1000-seed weight	-	RH-8812

Table 4 Estimates of specific combining ability effects in line x tester analysis in Indian mustard

Crosse	No. of siliquae/plant	No. of seeds/siliqua	Seed yield/plant	Length of siliqua	1000-seed weight
O. R. x Varuna	11.01	2.44**	-0.12	-0.07	-0.28
O. R. x Pusa Bold	14.16	0.22	0.32	0.07	-0.55
O. R. x Vardan	-13.79	2.09**	0.69	0.31	-0.38
O. R. x RH-8812	-10.12	-2.96**	0.60	-0.26	0.26
O. R. x RH-8813	-1.24	-1.78**	-0.29	-0.03	0.17
O. R. x RH-8814	-8.13	-1.26*	0.07	-0.03	0.08
O. R. x Rohini	-9.48	-1.48*	-0.99	-0.64*	0.21
O. R. x Kranti	-24.23	-0.61	0.27	-0.24	-0.06
O. R. x NDR-8501	49.34**	2.24**	0.71	0.33	-0.28
O. R. x RLM-1359	-7.48	1.12	-0.07	0.56*	0.03
MCN-129 x Varuna	0.49	0.04	0.85	0.15	0.66
MCN-129 x Pusa Bold	-41.36*	0.42	-1.16*	0.09	-0.57
MCN-129 x Vardan	38.49*	-0.21	0.63	-0.22	0.02
MCN-129 x RH-8812	11.46	0.24	-0.16	0.11	0.10
MCN-129 x RH-8813	-9.06	-0.48	-0.16	-0.11	-0.29
MCN-129 x RH-8814	49.73**	0.36	0.67	-0.10	0.08
MCN-129 x Rohini	-48.42**	-0.56	-0.44	-0.26	-0.19
MCN-129 x Kranti	-37.87**	-0.69	-0.52	0.18	-0.36
MCN-129 x NDR-8501	34.10*	0.36	0.77	0.11	0.02
MCN-129 x RLM-1359	2.48	0.54	-0.48	0.09	0.43
MCN-70 x Varuna	21.18	1.26*	-0.81	0.17	0.12
MCN-70 x Pusa Bold	62.26**	-0.36	0.24	-0.09	-0.35
MCN-70 x Vardan	-3.69	0.21	0.91	0.00	0.38
MCN-70 x RH-8812	-65.72**	-1.14	-1.16*	0.13	0.46
MCN-70 x RH-8813	-14.64	0.04	0.81	-0.19	-0.63
MCN-70 x RH-8814	0.59	0.94	-0.53	0.28	-0.40
MCN-70 x Rohini	2.84	0.22	1.39*	0.27	0.23
MCN-70 x Kranti	3.19	-2.51**	-0.93	-0.44*	0.06
MCN-70 x NDR- 8501	-37.64**	0.54	-1.16*	-0.01	-0.36
MCN -70 x RLM-1359	31.04*	0.82	-1.23*	-0.08	0.45
MCN-73 x Varuna	-13.89	-0.86	0.05	0.18	0.16
MCN-73 x Pusa Bold	68.46**	0.82	0.29	0.12	0.89*
MCN-73 x Vardan	-36.69*	0.39	-0.51	-0.04	-1.08*
MCN-73 x RH-8812	-23.32	-0.66	-0.07	-0.06	-0.40
MCN-73 x RH-8813	5.46	0.32	0.24	-0.18	0.41
MCN-73 x RH-8814	18.39	-1.72**	-0.60	-0.40	0.20
MCN-73 x Rohini	-34.46**	1.36*	0.24	0.04	-0.17
MCN-73 x Kranti	21.99	0.63	-0.08	0.28	0.26
MCN-73 x NDR-8501	23.06	0.08	0.57	-0.09	0.04
MCN-73 x RLM 1359	-28.96	-0.34	-0.12	0.19	-0.35
MCN-75 x Varuna	-49.73**	-0.90	-0.13	-0.10	-0.48
MCN-75 x Pusa Bold	-12.68	-0.42	0.19	0.19	0.25
MCN-75 x Vardan	47.97*	-0.35	0.37	0.08	-0.02
MCN-75 x RH-8812	12.14	2.91**	0.37	0.01	0.16
MCN-75 x RH-8813	2.32	-1.22*	-0.80	-0.16	0.07
MCN-75 x RH-8814	-30.23*	-0.28	0.55	-0.04	-0.18
MCN-75 x Rohini	-1.28	-0.20	-0.09	0.25	0.15
MCN-75 x Kranti	4.67	1.07	-0.84	0.09	0.38
MCN-75 x NDR-8501	6.74	-1.58*	0.73	-0.23	-0.04
MCN-75 x RLM-1359	20.12	1.00	-0.35	-0.05	-0.33
CD (P=0.05)	30.10	1.19	1.12	0.40	0.79
CD (P=0.01)	42.56	1.68	2.05	0.65	1.12

Crosses with significant and desirable better parent heterosis (BPH) and mid parent heterosis (MPH) for different characters, were computed to identify the superior cross combinations for their potential use in hybrid breeding (Table 5). This experiment showed the presence of significant desirable better parent (BPH) and mid parent heterosis (MPH) for a good number of crosses for different characters. For seed yield, MCN-75 x NDR-8501 expressed the highest better parent heterosis (BPH) of 31.81% and cross MCN-75 x Rohini showed the highest mid parent heterosis (MPH) of 55.20%. For number of siliquae/plant cross MCN-73 x Rohini expressed the highest better parent heterosis (BPH) of 41.99% and cross MCN-73 x Vardan expressed the highest mid parent heterosis (MPH) of 39.08%. Thakur *et al.* (1997) and Satwinder *et al.* (2000) reported that F_1 generations expressed significant heterosis for number of siliquae/plant. Cross MCN-73 x Kranti expressed the highest better parent heterosis (BPH) of 15.29% for number of seeds/siliqua and cross Ornamental Rai x Vardan expressed the highest mid parent heterosis (MPH) of 33.66%. For length of siliqua none of the cross expressed the better parent heterosis (BPH) but cross Ornamental Rai x NDR-8501 expressed the highest mid parent heterosis (MPH) of 16.85%. The positive heterosis is desirable for length of siliqua was reported by Dharmendra and Mishra (2001) and Kumar *et al.* (2002). Cross MCN-73 x Vardan and Ornamental Rai x Vardan expressed the highest better (BP) parent and mid parent (MP) heterosis of 43.90% and 24.70% for 1000-seed weight In brassica positive heterosis is desirable for 1000-seed weigh was reported by Yadav *et al.* (2004).

In most of the crosses had very low *sca* effects but one of the parents had high *gca*. Hence, in these crosses heterosis for seed yield may be due to predominance of additive gene action and better selection advance can be expected in subsequent generations. Therefore, it may be possible to utilize heterobeltious in hybrid breeding as well as heterosis may be fixed in subsequent generations.

For the major yield contributing characters namely, number of siliquae/plant, number of seeds/siliqua, length of siliqua and 1000-seed weight the better parent heterosis was either due to high *gca* effects of the parents or due to high *sca* effects of the respective cross. The role of both additive as well as non-additive gene action for better parent heterosis expression was evident suggesting the development of heterotic combination for use in hybrid breeding programme. Results of the present study suggested some concept on breeding methodology to be followed in mustard and cross combination to be followed for further improvement. Seed yield and yield contributing traits showed the significant of additive and non-additive type of gene action in different cross combinations for different characters. The presence of additive gene action suggested that a part of the heterosis can be fixed in subsequent generations to take advantages in further selection. The predominance of non-additive gene action, however brought out that heterosis component could be exploited in hybrid development in Indian mustard.

Table 5 Heterotic effects for number of siliquae/plant, number of seeds/siliqua, length of siliqua, 1000 seed weight and seed yield/plant in *Brassica juncea* L. genotypes

Trait	Number of crosses with				Crosses with	
	Heterosis over		Significant heterosis over		The highest heterosis in rank order over	
	MP* (% range)	BP * (% range)	MP	BP	MP	BP
No. of siliquae/plant	29 (1.31 to 39.08)	25 (0.93 to 41.99)	16	13	MCN-73 x Vardan	MCN-73 x Rohini
No. of seeds/ siliqua	26 (1.63 to 33.66)	16 (2.90 to 15.29)	16	14	O.R. x Vardan	MCN-73 x Kranti'
Length of siliqua	18 (0.00 to 16.85)	0	8	00	O.R. x NDR-8501	None
1000-seed weight	38 (2.17 to 24.70)	45 (2.44 to 43.90)	12	08	O.R. x Vardan	MCN-75 x Vardan
Seed yield/plant	39 (0.74 to 55.20)	17 (0.00 to 31.81)	19	05	MCN-75 x Rohini	MCN-75 x NDR-8501

MP = mid-parent, BP = Better parent, O.R.=Ornamental Rai

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Fertility restoration, combining ability effects and heterosis in sunflower (*Helianthus annuus* L.) using different CMS sources

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ABSTRACT

Combining ability studies were made in sunflower (*Helianthus annuus* L.) using line x tester analysis with two diverse CMS lines PET-1 and ARG-1 and 12 testers. Analysis of variance revealed significant differences among the genotypes i.e., parents and hybrids. Non-additive type of gene action was found important for expression of all the characters studied. Studies on identification of effective restorer lines revealed that out of 12 inbreds, four turned out to be restorers for both PET-1 and ARG-1, while eight behaved as maintainers. Among the lines, PET-1 was found to be good general combiner for seed yield and oil content. Testers HAM-161, RHA-273 and HAM-174 have also exhibited desirable general combining ability effect for seed yield and several other characters. The cross combination ARG-1 x RHA-273 and ARG-1 x RHA-274 were found to be promising for most of the characters such as seed yield, plant height, number of leaves, capitulum diameter, stem girth and 100-seed weight. Besides PET-1 source, other source *viz*., ARG-1 used in the present investigation was equally efficient in expressing their fullest potential of yield and yield contributing characters. Most of the crosses involving high x low general combining parents, exhibited high *sca* effects for various traits.

Key words: Fertility restoration, *gca* effects, Heterobeltiosis, *sca* effects, Sunflower

Commercial cultivation of sunflower (*Helianthus annuus* L.) in India started with open pollinated varieties. The discovery of cytoplasmic male sterility in sunflower has resulted in the development of hybrids for commercial cultivation. Development of hybrids with diverse cytoplasmic background has been one of the priorities in the sunflower breeding programme in India. Studies on the genetics of fertility restoration have been very much limited and restricted mostly to the traditional CMS sources. It is therefore essential to identify the effective restorers for each of the sources and elucidate the inheritance pattern of fertility restoration in the respective fertility restorer lines. It is also being observed that the yield levels have stagnated in sunflower with the presently used parental lines. Thus, a diversification of parental lines to use them in heterosis breeding to develop hybrids with high heterosis, in order to raise the yield ceiling in sunflower is necessary. The present study was undertaken to identify effective restorer lines to the CMS sources and estimate the extent of heterosis of the hybrids developed in comparison with the existing commercial hybrids and general and specific combining ability variances and effects in sunflower.

Two diverse cytoplasmic male sterile (CMS) lines were crossed with 12 inbreds in a Line x Tester design during winter season at the College Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. Based on the fertility restoration on the diversified cytoplasmic male sterile (CMS) [L_1 PET -1 (*Helianthus petiolaris* L.) and L_2 ARG -1 (*Helianthus argophyllus* L.)] sources with 12 inbred lines (T_1 RHA -273, T_2 RHA -274, T_3 RHA -348, T_4 7-1B, T_5 234B, T_6 851B, T_7 HAM -161, T_8 HAM -174, T_9 GP -290, T_{10} GP -2008, T_{11} DRM -34-2 and T_{12} DRM -70-1 and 2 checks KBSH-1 and Morden) were studied. The F_1s obtained from the above crosses were planted in a randomized block design with two replications. Each entry was sown in a single row of 4.5 m length (with a spacing of 60cm x 30cm). Recommended package of practices for sunflower were adopted to raise a healthy crop. All the F_1s were studied for maintainer/restorer behaviour of the inbreds. The plants were classified as male fertile or male sterile at growth stage of 5.3 (Schneiter and Miller, 1981), based on anther exertion and pollen production during flowering period. The fertility of the pollen was confirmed in the laboratory by using 1% Acetocaramine staining (Chaudhary *et al*., 1981). If no pollen production was noticed along with conspicuous stigma projection, and the disc appeared pale yellow in colour, the plant was concluded to be sterile. Segregation for fertility was noted during rainy season, the number of fertile and sterile plants were counted and considered as partially fertile. Five competitive plants were selected randomly from each plot for recording observations on seed yield/plant, days to 50% flowering, plant height (cm), number of leaves/plant, stem girth (cm), capitulum diameter (cm), number of filled seed/capitulum, oil content (%) and for 100-seed weight. The data were subjected to

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analysis of variance. Combining ability was estimated based on the method of Kempthorne (1957). The estimate of heterosis over the mid-parent and better-parent was calculated using the procedure of Matzingar *et al*. (1962).

The analysis of variance revealed significant differences among the parents and hybrids for their general and specific combining ability effects respectively for all characters (Table 1). It indicates the importance of both additive and non-additive gene actions in controlling these characters. The female (Line) exhibited highly significant differences for all the traits except stem girth, seed yield/plant and 100-seed weight, while the male (testers) exhibited highly significant differences for plant height stem girth and number of filled seeds/capitulum. The Lines vs Testers exhibited significant difference for all the traits.

The F_1 hybrids synthesized by crossing the 12 inbreds with two different CMS lines were tested for male sterility/fertility reaction for different CMS sources, results are presented in table 2. Studies on identification of effective restorer lines revealed that out of 12 inbreds, four turned out to be restorers for both PET-1 and ARG-1, while eight behaved as maintainers. The newly identified restorers for the different CMS sources will be useful for exploiting heterosis and combining ability and these hybrids may compete with already existing hybrids based on PET-1 cytoplasm. The maintainers identified for the new sources of male sterility can be converted into new CMS lines, which will serve the purpose of broadening the genetic base of the Helianthus species.

Table 1 Analysis of variance for seed yield and yield contributing characters in sunflower

Source of variation	d.f.	Days to 50% flowering	Plant height (cm)	Number of leaves	Stem girth (cm)	Capitulum diameter (cm)	Number of filled seeds/ capitulum	100 Seed weight (g)	Seed yield/plant (g)	Oil content (%)
Replication	2	4.08	2.82	3.98	0.16	2.80	315.62	0.08	1.82	8.07
Treatment	13	18.23**	746.12**	47.82**	3.82**	68.94**	36687.34**	2.61**	112.69**	56.88**
Parents	5	17.53**	516.68**	38.61**	3.37**	15.97**	8360.24**	0.85**	15.14**	12.45**
Parents Vs. Crosses	1	23.80**	21623.67**	1664.74**	115.03**	2515.20**	1338543.50**	126.72**	7039.34**	2340.10**
Crosses	7	18.49**	487.51**	23.28**	2.04**	52.39**	27952.94**	1.29**	38.18**	38.80**
Lines	1	72.01*	2002.33*	150.48**	0.37NS	733.34**	445270.09**	1.11NS	65.72 NS	460.02**
Testers	7	19.01NS	646.14*	26.91NS	2.82*	48.15NS	27449.28*	1.46NS	34.98NS	32.88 NS
Lines x Testers	7	15.99**	272.76**	14.93**	1.33**	31.41**	13000.46**	1.12**	40.36**	29.122**
Error	26	1.67	10.40	1.42	0.10	1.23	165.88	0.03	1.10	3.53
SEd		1.05	2.63	0.97	0.26	0.90	10.51	0.14	0.86	1.53
CD(P= 0.05)		2.07	5.16	1.90	0.51	1.77	20.61	0.29	1.68	3.01
CD(P=0.01)		2.72	6.78	2.50	0.67	2.33	27.09	0.38	2.21	3.95
CV (%)		2.40	2.77	5.68	4.94	5.64	2.56	3.26	4.44	6.42

Table 2 Identification of maintainers and restorers from two different CMS sources in sunflower

Tester	PET 1 (L_1)	ARG (L_2)
T_1 RHA 273	R	R
T_2 RHA 274	R	R
T_3 RHA 348	M	M
T_4 7-1B	M	M
T_5 234B	M	M
T_6 851B	M	M
T_7 HAM 161	R	R
T_8 HAM 174	R	R
T_9 GP 290	M	M
T_{10} GP 2008	M	M
T_{11} DRM 34-2	M	M
T_{12} DRM 70-1	M	M

PET 1 *Helianthus petiolaris*; ARG *Helianthus argophyllus*
M = Maintainer; R = Restorer

A perusal of general combining ability (*gca*) effects of parents indicated that one of the parent PET-1 was found to be good general combiner for all the traits (Table 3). The desirable highest negative *gca* effect for days to 50% flowering was recorded for the line ARG-1. However, one of the parents HAM-161 was found to be a good general combiner for three characters *viz*., 100-seed weight, seed yield/plant and for plant height by exhibiting desirable significant positive *gca* effect. Whereas the tester, RHA-273; proved to be good combiner for days to 50% flowering. HAM-174 is a good combiner for stem girth and number of filled seeds/capitulum. It can be concluded that parent PET-1, HAM-161, RHA-273 and HAM-174 possess desirable alleles for most of the characters. Hence, these parents could be used in future breeding programme for improvement of respective characters.

None of the cross combination was found to be a common combiner for all the characters under study (Table

3). The *sca* effects were found to be significant for seed yield and yield components. Similar results were also observed by Giriraj *et al.* (1987) and Rudranaik *et al.* (1998). The cross, ARG-1 x RHA-274 was found to exhibited high *sca* effects in the favourable direction for four characters *viz*., plant height, stem girth, capitulum diameter and seed yield/plant, whereas the cross, PET-1 x HAM-161 exhibited high *sca* effects in the favourable direction for days to 50% flowering. Some of the hybrids showed high and significant *sca* effects in desired direction along with seed yield/plant such as ARG-1 x RHA-273; for days to 50% flowering, ARG-1 x HAM-161; for plant height ; ARG-1 x RHA-273 for number of leaves; ARG-1 x RHA 273 for capitulum diameter; PET-1 x HAM-161 for number of filled seeds/capitulum; ARG-1 x RHA-273 for 100-seed weight and seed yield/plant. Earlier crosses with high *gca* effects involving low x low by Kadkol *et al.* (1984) and high x high *gca* effects were also reported by Limbore *et al.* (1997).

All the hybrids exhibited significant positive heterosis for more than one character (Table 4). All hybrids also exhibited significant positive heterobeltiosis but no hybrid expresses standard positive heterosis over commercial checks, KBSH-1 and Morden. Significant positive heterosis for plant height, number of leaves/plant, stem girth (cm), capitulum diameter, filled seeds/capitulum, 100-seed weight (g), seed yield/plant (g) and oil content was also reported by Goksoy *et al.* (2000). Significant negative heterosis for days to 50% flowering was observed by in some studies. Heterobeltiosis for days to 50% flowering was found to be significant in negative direction for PET-1 x RHA-273 and PET-1 x HAM-161.

Maximum negative heterosis for plant height is exhibited by ARG-1 x HAM-161. These results are in conformity with the findings of Satyanarayana (2000) Gill and Sheoran. (2002). High significant positive heterosis was recorded for stem girth by ARG-1 x HAM-174, capitulum diameter by ARG-1 x HAM-161, and 100-seed weight by PET-1 x RHA-274.

Heterobeltiosis for seed yield/plant was found to be highest significant in positive direction by ARG-1 x RHA-274. Similar results were observed by Radhika *et al.* (2001) and Trinadh Kumar *et al.* (2001). For the trait oil content, PET-1 x HAM0-161 recorded positive significant heterobeltiosis. Similar results also reported by Rajanna *et al.* (2001). Combining ability analysis showed that the hybrids with significant *sca* effects in the desired direction involved parents with either high x high or high x low or low x low *gca* effects, indicating that high performance of these crosses was due to additive, dominance or epistatic gene interactions. The good combining parents for different traits may be utilized in constituting a dynamic population which could be improved through recurrent selection.

Table 3 Combining ability effects (*gca* and *sca*) of parents and crosses for yield and yield contributing characters in sunflower

Line/tester/cross	Days to 50 % flowering	Plant height (cm)	Number of leaves	Stem girth (cm)	Capitulum diameter (cm)	Number of filled seeds/capitulum	100-Seed weight (g)	Seed yield/plant (g)	Oil content (%)
PET-1	3.45**	3.45**	0.95**	0.05	2.09**	51.48**	0.08**	0.63**	1.65**
ARG-1	-0.65**	-3.45**	-0.95**	-0.05	-2.09**	-51.48**	-0.08**	-0.63**	-1.65**
RHA 273	-2.61**	3.04*	-2.86**	0.09	-4.10**	-82.20**	0.09	-2.30**	-2.29**
RHA274	0.23	3.37*	-0.53	-0.74**	-3.93**	-78.53**	1.22**	-0.49	0.71
HAM 161	-0.61	-10.80**	0.64	0.11	1.73**	8.97	0.29**	1.80**	0.71
HAM 174	1.73**	3.54**	-3.53**	1.12**	0.07	28.47**	-0.68**	1.58**	-0.29
PET-1 x RHA 273	-0.65	-2.29	-2.61**	-0.47*	-1.92**	1.85	-0.58**	-3.44**	1.51
PET-1 x RHA274	-1.49*	-6.95**	-0.95	-0.40*	-4.09**	-7.15	-0.15	-5.66**	-0.49
PET-1 x HAM 161	-2.65**	5.55**	1.22	0.39*	-0.09	52.35**	-0.08	0.66	0. 18
PET-1 x HAM 174	-0.65	2.88	-2.61**	-0.47*	3.58**	-52.82**	0.05	-0.13	0.18
ARG-1 x RHA 273	0.65	2.29	2.61**	0.47*	1.92**	-1.85	0.58**	3.44**	-1.51
ARG-1 x RHA274	1.49*	6.95**	0.95	0.40*	4.09**	7.15	0.15	5.66**	0.49
ARG-1 x HAM 161	2.65**	-5.55**	-1.22	-0.39*	0.09	-52.35**	0.08	-0.66	-0.18
ARG-1 x HAM 174	0.65	-2.88	2.61**	0.47*	-3.58**	52.82**	-0.05	0.13	-0.18

*,** significant at 5% and 1% level

Table 4 Heterosis for yield and yield contributing characters in sunflower

Crosse	Days to 50% flowering			Plant height (cm)			Number of leaves		
	HB	SH		HB	SH		HB	SH	
		KBSH 1	Morden		KBSH 1	Morden		KBSH 1	Morden
PET-1 x RHA 273	-4.97*	-3.77	6.25**	19.75**	1.87	31.27**	-26.67**	-23.61**	-23.61**
PET-1 x RHA274	-2.45	0	10.42**	27.68**	-1.6	26.80**	-10.67**	-6.94	-6.94
PET-1 x HAM 161	-6.71**	-3.77	6.25**	4.90*	-2.93	25.09**	2.67	6.94	6.94
PET-1 x HAM 174	1.22	4.40*	15.28**	16.33**	6.40**	37.11**	-29.33**	-26.39**	-26.39**
ARG-1 x RHA 273	6.25**	-3.77	6.25**	17.55**	0	28.87**	-9.72*	-9.72*	-9.72*
ARG-1 x RHA274	13.89**	3.14	13.89**	36.36**	4	34.02**	3.08	-6.94	-6.94
ARG-1 x HAM 161	14.58**	3.77	14.58**	-10.66**	-17.33**	6.53*	-1.54	-11.11**	-11.11**
ARG-1 x HAM 174	15.28**	4.40*	15.28**	5.25*	-3.73	24.05**	-3.08	-12.50**	-12.50**

Crosse	Stem girth (cm)			Capitulum diameter (cm)			Number of filled seeds/capitulum		
	HB	SH		HB	SH		HB	SH	
		KBSH 1	Morden		KBSH 1	Morden		KBSH 1	Morden
PET-1 x RHA 273	2.44	-12.61**	16.18**	3.85	-22.86**	36.71**	26.54**	-48.57**	-38.17**
PET-1 x RHA274	-9.23*	-22.57**	2.94	-7.69	-31.43**	21.52**	35.24**	-49.09**	-38.79**
PET-1 x HAM 161	16.18**	-0.88	31.76**	36.28**	10.00**	94.94**	47.82**	-34.71**	-21.51**
PET-1 x HAM 174	18.52**	1.11	34.41**	50.91**	18.57**	110.13**	51.96**	-43.09**	-31.58**
ARG-1 x RHA 273	20.54**	-1.33	31.18**	26.19**	-24.29**	34.18**	0.88	-59.00**	-50.71**
ARG-1 x RHA274	17.15**	-13.27**	15.29**	42.86**	-14.29**	51.90**	12.21**	-57.76**	-49.22**
ARG-1 x HAM 161	18.35**	-12.39**	16.47**	15.04**	-7.14	64.56**	1.85	-55.02**	-45.92**
ARG-1 x HAM 174	39.56**	12.39**	49.41**	-10.91*	-30.00**	24.05**	52.65**	-42.83**	-31.27**

Crosse	100-Seed weight (g)			Seed yield / plant (g)			Oil content (%)		
	HB	SH		HB	SH		HB	SH	
		KBSH 1	Morden		KBSH 1	Morden		KBSH 1	Morden
PET-1 x RHA 273	8.40**	-11.29**	-16.75**	20.86**	-54.29**	-42.56**	18.29**	-11.01**	18.29**
PET-1 x RHA274	38.54**	13.23**	6.26**	51.72**	-55.10**	-43.59**	21.95**	-8.26	21.95**
PET-1 x HAM 161	43.79**	-0.37	-6.50**	58.00**	-37.55**	-21.54**	22.89**	-6.42	24.39**
PET-1 x HAM 174	11.93**	-13.33**	-18.67**	62.34**	-39.59**	-24.10**	20.73**	-9.17*	20.73**
ARG-1 x RHA 273	27.65**	4.46	-1.97	51.26**	-42.79**	-28.12**	1.3	-28.44**	-4.88
ARG-1 x RHA274	41.30**	15.49**	8.37**	121.15**	-34.56**	-17.78**	20.78**	-14.68**	13.41*
ARG-1 x HAM 161	32.68**	-0.26	-6.40**	44.75**	-42.79**	-28.12**	9.64	-16.51**	10.98
ARG-1 x HAM 174	6.44*	-17.59**	-22.66**	56.86**	-41.63**	-26.67**	14.29*	-19.27**	7.32

* Significant at 5% level; ** Significant at 1% level; HB= Heterobeltiosis; SH = Standard heterosis

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Character association and path analysis in sunflower (*Helianthus annuus* L.)

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ABSTRACT

Association and path coefficient analysis was computed on 64 genotypes of sunflower (*Helianthus annuus* L.). Seed yield was positively correlated with number of filled seeds/head, total number of seeds/head, seed filling per cent, plant height and 100 seed weight. Selection based on number of filed seeds/head, total seeds/head and seed filling percent would increase seed yield. Path analysis indicated that number of filled seeds/head had the maximum direct effect followed by 100 seed weight, total seeds/head and seed filling per cent.

Key words: Association, Path analysis, Sunflower

The cultivated sunflower (*Helianthus annuus* L.) has emerged as one of the major edible vegetable oilseeds crop in the world. To initiate any breeding programme, information on association yield component of attributes with seed yield and among themselves and the extent by which these are influenced by the environment, are essential. The various yield components often exhibit considerable degree of association which maybe due to linkage, pleiotrophy or physiological association. Path co-efficient analysis measures the direct influence of a variable upon yield and permits the partitioning of the correlation coefficient into components of direct and indirect effects. The present study was therefore conducted to investigate the nature of correlations by path analysis for seed yield.

The material for the present study comprised of 64 germplasm accessions of sunflower. The experiment was conducted at Directorate of Oilseeds Research, Hyderabad during the winter season of 2007. Each accession was sown in two rows of 4 m length with spacing of 60 cm between rows and 30 cm between plants. The experiment laid out in simple lattice design with two replications. In each accession, five plants were randomly selected and used for collection of data on yield and yield related characters. The correlations were computed. The path co-efficient analysis at genotypic level was computed by Deway and Lu, (1959) procedure.

The correlation coefficients between all parts of eleven traits are presented table 1. Seed yield was significantly associated with plant height, head diameter, number of filled seeds/head, total seeds/head, seed filling per cent and 100 seed weight, while negative and significant association with stem diameter and hull content. This indicated that seed yield can be improved by making selection on the basis of number of filled seeds/head, total number of filled seeds/head, seed filling and 100 seed weight. Similar results were reported by Chikkadevaiah *et al*. (2002), Madhavi Latha *et al*. (2004) and Sridhar *et al*. (2005).

Total number of filled seeds/head was positively and significantly correlated with plant height, head diameter, and number of filled seeds/head. Seed filling per cent positively and significantly with plant height, head diameter, number of filled seeds/head and total number of seeds/head. Stem diameter had negative association with days to maturity. Hull content positively and significant association with stem diameter, head diameter and negative association with days to 50% flowering, days to maturity, number of filled seeds/head, total number of seeds/head and seed filling per cent.

A path coefficient analysis that portions the correlation coefficient into direct and indirect effect was computed and presented in table 2. Among the 12 characters the maximum direct effect on seed yield /plant was number of filled seeds/head, followed by 100 seed weight, total seeds/head, seed filing per cent, head diameter and days to maturity while hull content and stem diameter recorded negative direct effect on seed yield/plant.

Days to 50% flowering recorded indirect positive effect through plant height and seed filling, while it exhibited indirect negative effect through head diameter, hull content, days to maturity. Days to maturity recorded indirect positive effect through seed filling per cent, head diameter, filled seeds/head and it exhibited indirect negative effect with stem diameter and 100 seed weight. Plant had recorded indirect positive effect through filled seeds/head, total seeds/head and seed filling per cent. Stem diameter exhibited indirect positive effect through 100 seed weight, days to maturity and filled seeds/head while it exhibited indirect negative effect through hull content and plant height. Head diameter recorded indirect positive effect through total seeds/head, seed filling per cent and filled seeds/head and it exhibited indirect negative effect through days to 50% flowering, 100 seed weight.

Filled seeds/head exhibited indirect positive effect through total seeds/head, seed filling, head diameter and days to maturity and it exhibited indirect negative effect through stem diameter, 100 seed weight. Hull content showed indirect positive effect through days to 50% flowering and seed filling per cent and it exhibited indirect negative effect through head diameter, stem diameter and plant height. Total seeds/head recorded indirect positive effect through filed seeds/head, seed filling per cent and head diameter while it exhibited indirect negative effects through stem diameter and 100 seed weight.

Seed filling per cent exhibited indirect positive effect through filled seeds/head, total seeds/head while it exhibited indirect negative effects through 100 seed weight and hull content. 100 seed weight recorded indirect positive through hull content and plant height it exhibited indirect negative effect through seed filing per cent, stem diameter. Similar results were reported by Ayub Khan (2001) and Vidhyavathi *et al*. (2005).

In conclusion, the selection for higher yield in sunflower should be based on number of filled seeds/head higher number of total seeds/head, 100 seed weight, seed filling per cent and seed yield/plant.

Table 1 Estimation of phenotypic correlation between seed yield and its component characters in sunflower genotypes

Character	Days to 50% flowering	Days to maturity	Plant height (cm)	Stem diameter (cm)	Head diameter (cm)	No. of filled seeds/ head	Total no of seeds/ head	Seed filling/ cent	100-seed weight (g)	Oil content (%)	Hull content (%)	Seed yield/ plant
Days to 50% flowering	1.000	-0.095	0.123	0.009	-0.165	0.001	-0.017	0.022	-0.009	-0.021	-0.127	0.025
Days to maturity		1.000	0.083	-0.147	0.085	0.093	0.095	0.101	-0.110	0.038	-0.004	0.107
Plant height (cm)			1.000	0.083	0.136	0.259**	0.258**	0.187*	0.070	0.124	0.107	0.296**
Stem diameter (cm)				1.000	0.046	-0.131	-0.100	-0.086	-0.132	-0.060	0.202*	-0.173
Head diameter (cm)					1.000	0.262**	0.277**	0.265**	-0.084	-0.073	0.254**	0.302**
No. of filled seeds/head						1.000	0.975**	0.759**	-0.104	0.064	-0.105	0.837**
Total no of seeds/head							1.000	0.630**	-0.098	-0.083	-0.057	0.820**
Seed filling (%)								1.000	-0163	-0.044	-0.144	0.629**
100 seed weight (g)									1.000	-0.010	0.086	0.269**
Oil content (%)										1.000	0.100	0.040
Hull content (%)											1.000	-0.056

*, ** significant at 5% and 1% level, respectively

Table 2 Estimation of path coefficient between seed yield and yield component characters in sunflower genotypes

Character	Days to 50% flowering	Days to maturity	Plant height (cm)	Stem diameter (cm)	Head diameter (cm)	Filled seeds/ head	Total No. of seeds / head	Seed filling (%)	100-seed weight (gm)	Oil content (%)	Hull content (%)	Seed yield /plant (g)
Days to 50% flowering	**0.046**	-0.004	0.005	-0.000	-0.008	0.000	-0.000	0.001	-0.000	-0.001	-0.006	0.025
Days to maturity	-0.005	**-0.056**	0.005	-0.008	0.005	0.005	-0.005	0.006	-0.006	0.002	-0.000	0.107
Plant height (cm)	0.004	0.003	**0.034**	-0.002	0.005	0.009	0.009	0.006	0.002	0.004	0.004	0.296
Stem diameter (cm)	-0.000	0.003	-0.002	**-0.019**	0.000	0.002	0.001	0.002	0.003	0.001	-0.004	-0.173
Head diameter (cm)	-0.018	-0.009	0.015	0.005	**0.109**	0.029	0.030	0.029	-0.009	-0.008	0.028	0.302
Filled seeds/head	0.000	0.037	0.103	-0.052	0.104	**0.397**	0.387	0.302	-0.042	0.026	-0.042	0.837
Total no. of seeds/head	-0.005	0.033	0.089	-0.035	0.096	0.336	**0.344**	0.217	-0.034	0.029	-0.020	0.820**
Seed filling (%)	0.003	0.013	0.023	-0.011	0.033	0.095	0.079	**0.125**	-0.020	-0.006	-0.014	0.629**
100 seed weight (g)	-0.003	-0.042	0.027	-0.050	-0.032	-0.040	-0.037	-0.062	**0.380**	-0.004	0.033	0.269**
Oil content (%)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.000**	0.000	0.040
Hull content (%)	0.004	0.000	-0.003	-0.007	-0.008	0.003	0.002	-0.004	-0.003	-0.004	**-0.035**	0.056

*, ** significant at 5% and 1% level, respectively

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Heterosis studies in sunflower (*Helianthus annuus* L.)

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ABSTRACT

Thirty single cross sunflower (*Helianthus annuus* L.) hybrids produced were subjected to mid parent, better parent and standard heterosis studies using three checks, *viz*., KBSH 1, KBSH 44 and GK 2002. The cross CMS 234 A x RHA-95-C-1 recorded the highest heterosis of 104.01% over better parent for seed yield which was followed by CMS 234 A x RHA-6D-1 and CMS 234 A x RHA-271 with 86.06 and 85.15%, respectively. None of the experimental hybrids could surpass the standard heterosis over checks KBSH-1 and GK 2002 for seed yield and oil content. However, three hybrids CMS 17 A x RHA-6D-1 (13.82), DCMS 51 A x R-298 (12.85), DCMS 51 A x RHA-272 (9.81) and 18 crosses where RHA-6D-1 and RHA-271 were used as male parents in combination with CMS 234 A, CMS 4546 A and DCMS 51 A showed significant heterosis over the check KBSH-44 for seed yield and oil content, respectively. The highest heterosis in the cross CMS 234 A x RHA-95-C-1 can be assigned to contribution of heterosis from component characters such as hull content, per cent seed filling and number of filled seeds/head.

Key words: Heterosis, Single cross hybrids, Sunflower

Of the various genetic approaches to break yield barrier in sunflower (*Helianthus annuus* L.), heterosis breeding is the most powerful one. Information on the importance of heterosis for different traits existing in cross combinations is a prerequisite for identifying superior crosses. Heterotic crosses suggest productive transgressive segregants and the extent of heterosis gives an idea of genetic control. Heterosis estimates may help in deciding whether the hybrids are of economic value and worth exploiting. The present study was attempted to know heterotic behaviour of single cross hybrids over mid parent, better parent and check hybrids.

The experimental material consists of 44 entries comprising 30 single cross hybrids, 11 parents (five maintainer lines of corresponding CMS lines and six restorer lines) with three checks KBSH-1, KBSH-44 and GK-2002 were evaluated during rainy season of 2006 at MARS, Dharwad. All the genotypes were sown in a randomized complete block design with three replications, in which each replication was represented by three rows of 3 m length for each entry. A spacing of 60 cm between rows and 30 cm within a row was provided. Two to three seeds of each entry were dibbled/hill in furrows at a depth of 2-3 cm. After 15 days, only one healthy seedling/hill was kept by removing remaining seedlings. Recommended dose of fertilizers at the rate of 60:90:60 kg NPK/ha was adopted. The entire quantity of phosphorous and potash and 50% of nitrogen was applied at sowing while the remaining dose of nitrogen was top-dressed when the crop was 30 days old. All other recommended agronomic practices were followed to grow the experimental crop. The observations were recorded for head diameter, 100 seed weight, per cent seed filling, number of filled seeds/head, volume weight, hull content, oil content and seed yield/plant from 10 random plants and the data was subjected to genetic analysis.

The results of heterosis over mid parent showed the prevalence of heterosis to an extent of 183% for seed yield/plant (Table 1) and majority of the crosses were observed to be positive and significant in their expression. A similar trend was observed for better parent heterosis for which as many as 28 crosses showed significant heterosis. The cross CMS 234 A x RHA-95-C-1 recorded the highest heterosis of 104.01%, which was followed by CMS 234 A x RHA-6D-1 and CMS 234 A x RHA-271 with 86.06 and 85.15%, respectively. Manivannan *et al*. (2005); Singh and Singh (2003) and Rajeswari *et al.* (2005) also reported the prevalence of substantial importance of heterosis over better parent and seed yield is governed by non-additive gene action. Thus, the present study offers ample scope to isolate superior hybrids for seed yield. Although, most of the hybrids revealed heterobeltiosis, the standard heterosis over the leading checks assumes importance to decide whether an experimental hybrid is worth consideration for replacement. The results obtained on standard heterosis over three check hybrids revealed none of the experimental hybrids were superior over the checks KBSH-1 and GK-2002, however, three hybrids CMS 17 A x RHA-6D-1 (31.99), DCMS 51 A x R-298 (30.86), DCMS 51 A x RHA-272 (27.34) excelled check hybrid KBSH-44. At the same time, these three hybrids also recorded positive but non-significant heterosis for seed yield over KBSH-1 and GK-2002 (more than 9.5%). Thus, these serve as potential hybrids for large-scale testing over locations.

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In this study, the number of hybrids recording standard heterosis with relative magnitude of heterobeltiosis was low. This is because of exploitation of available variability leading to better hybrid combinations and their release. Thus, this would attract attention of the breeder to look into potentiality of parental lines per se performance and nicking ability whether A, B or R lines to have altered genetic constitution. The approaches may be to look for CMS sources other than petiolaris or improvement of B and R lines, the latter being most commonly adopted by the plant breeders in the genetic improvement of sunflower. The best try would be to subject crosses showing standard heterosis for pedigree breeding by delaying selection until the genotypes are stabilized on selfing, leading to improved version of inbred for conversion as A line and to derive improved version of R lines. However, selective intermating among the genotypes in the segregating generations would offer better scope to increase opportunity for crossing over to occur for the traits concerned as has been reported only in inbreds developed by sunflower workers (Parameswari *et al*., 2004). The extent of mid, better parent and standard heterosis for oil content was low, in general. None of the experimental hybrids has been able to surpass standard heterosis over check KBSH-1, the hybrid known for its high oil content. A similar trend has also been observed over the leading private check hybrid GK-2002. Several workers (Kumar *et al*., 1999 and Alone *et al*., 2003) also reported the lack of heterosis for oil content in sunflower. However, as many as 18 hybrids have shown standard heterosis over recently released public hybrid KBSH-44, the oil content of which is known to be low when compared to other hybrids. In spite of low standard heterosis for oil content, existence of better parent heterosis in some crosses suggest that oil content is governed mainly by non-additive component of genetic variance (Radhika *et al*., 2001). The crosses wherever RHA-6D-1 and RHA-271 were used as male parents in combination with CMS 234 A, CMS 4546 A and DCMS 51 A able to yield significant standard heterosis over KBSH-44. So, these crosses can be subjected to changed pedigree selection where intermating among selected genotypes may exploit non-additive portion of genetic variance leading to selection of inbreds with high oil content.

Table 1 Per cent heterosis over mid parent (MP), better parent (BP) and check hybrids for oil content and seed yield/plant in sunflower

Cross	Oil content					Seed yield/ plant				
	MP	BP	KBSH-1	KBSH-44	GK- 2002	MP	BP	KBSH-1	KBSH-44	GK- 2002
CMS 234A x RHA-6D-1	-2.07	-3.66	-5.54 *	6.04 *	-4.77 *	154.55 **	86.06 **	-2.30	13.97	-1.72
CMS 234A x RHA-95-C-1	2.53	0.58	-0.81	11.34 **	0.00	183.57 **	104.01 **	7.13	24.96	7.76
CMS 234A x R-298	7.06 **	-2.32	-7.33 **	4.03	-6.57 **	82.56 **	80.49 **	-3.02	13.12	-2.45
CMS 234 A x R-64	1.19	0.17	-3.02	8.87 **	-2.22	107.32 **	82.22 **	-4.32	11.61	-3.75
CMS 234 A x RHA-271	8.02 **	4.73 *	-0.65	11.53 **	0.16	172.61 **	85.15 **	-2.78	13.41	-2.2
CMS 234 A x RHA-272	0.98	-2.15	-7.17 **	4.21	-6.41 **	94.27 **	42.12 **	-25.37 *	-12.95	-24.93 *
CMS 4546A x RHA-6D-1	3.84 *	-2.24	-4.16	7.59 **	-3.37	91.75 **	34.22 **	-18.6	-5.05	-18.12
CMS 4546A x RHA-95-C-1	7.22 **	0.66	-0.73	11.44 **	0.08	113.95 **	47.62 **	-10.47	4.43	-9.94
CMS 4546A x R-298	8.61 **	3.39	-10.51 **	0.46	-9.78 **	59.37 **	50.28 **	-8.86	6.31	-8.32
CMS 4546A x R-64	0.27	-5.05 *	-8.07 **	3.20	-7.31 **	70.67 **	41.33 **	-14.29	-0.02	-13.78
CMS 4546 A x RHA-271	9.51 **	7.96 **	-3.83	7.96 **	-3.04	139.16 **	56.69 **	-4.98	10.84	-4.41
CMS 4546 A x RHA-272	9.19 **	7.69 **	-4.16	7.59 **	-3.37	118.46 **	53.03 **	-7.19	8.25	-6.64
CMS 17 A x RHA-6D-1	7.10 **	-1.00	-2.93	8.97 **	-2.14	132.85 **	55.14 **	13.15	31.99 *	13.82
CMS 17 A x RHA-95-C-1	-3.18	-10.74 **	-11.98 **	-1.19	-11.26 **	116.60 **	42.52 **	3.95	21.25	4.57
CMS 17 A x R-298	14.39 **	10.97 **	-7.66 **	3.66	-6.90 **	69.74 **	47.39 **	7.50	25.39	8.14
CMS 17 A x R-64	-14.08 **	-20.12 **	-22.66 **	-13.17 **	-22.02 **	52.88 **	18.14 *	-13.83	0.51	-13.32
CMS 17 A x RHA-271	7.47 **	3.93	-7.42 **	3.93	-6.66 **	130.83 **	45.19 **	5.90	23.53	6.53
CMS 17 A x RHA-272	-0.05	-3.3	-13.94 **	-3.39	-13.23 **	102.13 **	34.77 **	-1.71	14.65	-1.12
CMS 103 A x RHA-6D-1	6.27 **	2.08	0.08	12.35 **	0.90	91.58 **	27.09 **	-5.67	10.03	-5.11
CMS 103 A x RHA-95-C-1	-3.02	-7.11 **	-8.39 **	2.84	-7.64 **	72.84 **	13.25	-15.94	-1.95	-15.44
CMS 103 A x R-298	7.06 **	-0.09	-9.78 **	1.28	-9.04 **	61.43 **	39.14 **	3.27	20.46	3.89
CMS 103 A x R-64	2.35	-1.09	-4.24 *	7.50 **	-3.45	47.59 **	13.36	-15.87	-1.86	-15.37
CMS 103 A x RHA-271	2.59	1.90	-7.99 **	3.29	-7.23 **	91.48 **	20.01 *	-10.93	3.90	-10.4
CMS 103 A x RHA-272	11.27 **	10.47 **	-0.24	11.99 **	0.58	95.97 **	30.09 **	-3.45	12.63	-2.87
DCMS 51 A x RHA-6D-1	3.96 *	3.28	2.61	15.19 **	3.45	81.91 **	19.34 *	-7.25	8.19	-6.70
DCMS 51 A x RHA-95-C-1	-1.93	-2.30	-2.93	8.97 **	-2.14	89.70 **	22.97 **	-4.42	11.49	-3.86
DCMS 51 A x R-298	8.31 **	-3.20	-3.83	7.96 **	-3.04	70.69 **	44.34 **	12.18	30.86 *	12.85
DCMS 51 A x R-64	4.45 **	3.12	2.44	15.00 **	3.29	55.51 **	17.56 *	-8.63	6.58	-8.09
DCMS 51 A x RHA-271	4.58 *	-0.82	-1.47	10.61 **	-0.66	111.51 **	31.36 **	2.10	19.09	2.70
DCMS 51 A x RHA-272	5.84 **	0.33	-0.33	11.89 **	0.49	113.97 **	40.46 **	9.17	27.34 *	9.81
SE(Sij)	0.67	0.78	0.62	0.61	0.61	3.61	4.17	3.30	5.49	3.52

*, ** significant at 5% and 1% level, respectively

Newly developed sunflower hybrids must have higher yield and oil content than the existing popular hybrid KBSH-1. The low oil content in KBSH-44 hybrid is a limitation in its cultivation in spite of its high seed yield potential. Therefore, any hybrid in future must almost have seed yield at par or more than KBSH-44 and oil content as that of KBSH-1 or more. Although, none of the hybrids revealed standard heterosis for seed yield over KBSH-1, the hybrids CMS 234 A x RHA-271(85.15,4.73), CMS 4546 A x RHA-271 (56.69,7.96), CMS 4546 A x RHA-272 (53.03,7.69), CMS 17 A x R-298 (47.39,10.97) and CMS 103 A x RHA-272 (30.09,10.47) showed significant better parent heterosis for both seed yield and oil content (Nehru *et al*., 2000). Negative association between hull content and oil has been well proved in sunflower. seven hybrids showed significant negative heterosis over better parent for hull content (Table 2), highest being in the crosses CMS 234 A x RHA-272 (-20.73), CMS 234 A x R-64 (-15.98) and DCMS 51 A x R 298 (-15.87).

The range of heterosis for volume weight over mid parent was from -15.40 (DCMS 51 A x RHA-271) to 19.84% (CMS 4546 A x R-298) and over better parent from -25.21 (CMS 17 A x R-64) to 14.96% (CMS 4546 A x R-298). Only a few number of hybrids showed heterosis over mid and better parents. None of the hybrids registered significant positive heterosis over all the three standard checks for volume weight.

The per cent filled seeds in sunflower can be considered as one of the limiting causes in its production. Although, environments like high temperature and humidity influence this trait during flowering, the existence of genetic differences cannot be ruled out as could be seen from the present studies where there was lack of better parent heterosis in cross combinations of CMS 103 A and to certain extent in DCMS 51 A with all restorer lines. This is because of certain degree of incompatibility in hybrid combinations hindering self-fertility without pollinators. Therefore, it is necessary to exploit desirable cross combinations with higher percentage of seed filling. Considerable amount of heterosis is noted in the present investigation for per cent seed filling. The crosses CMS 234 A x RHA-95 C-1 (36.32, 30.86) and CMS 4546 A x RHA-95 C-1 (30.63, 20.97) were rated high for manifestation of heterosis over mid and better parents (Table 3). Prevalence of significant heterosis for this trait agrees with the studies of Burli and Jadhav (2001) and Manivannan *et al*. (2003). Only six hybrids over better parent and eleven hybrids over KBSH-1 and GK-2002 had significant positive heterosis, which infers existence of sufficient amount of heterosis for per cent seed filling in the experimental material.

Table 2 Per cent heterosis over mid parent (MP), better parent (BP) and check hybrids for volume weight and hull content in sunflower

Crosses	Volume weight (g/100cc)					Hull content (%)				
	MP	BP	KBSH-1	KBSH-44	GK- 2002	MP	BP	KBSH-1	KBSH-44	GK- 2002
CMS 234A x RHA-6D-1	-8.42 *	-12.84 **	-11.98 **	-17.05 **	-18.07 **	-0.20	-12.67 **	2.48	-23.50 **	-13.28 **
CMS 234A x RHA-95-C-1	1.46	-2.77	-3.21	-8.78 *	-9.90 *	19.06 **	8.87 **	27.76 **	-4.62 **	8.11 **
CMS 234A x R-298	9.87 *	3.33	-5.70	-11.13 **	-12.23 **	8.17 **	7.92 **	26.65 **	-5.46 **	7.16 **
CMS 234 A x R-64	10.43 *	-6.66	-14.82 **	-19.73 **	-20.72 **	-12.96 **	-15.89 **	-1.30	-26.32 **	-16.48 **
CMS 234 A x RHA-271	-4.82	-8.63	-9.36 *	-14.57 **	-15.63 **	-4.95 **	-5.42 **	10.99 **	-17.14 **	-6.08 **
CMS 234 A x RHA-272	4.23	1.89	-7.02	-12.37 **	-13.45 **	-20.36 **	-20.73 **	-6.98 **	-30.56 **	-21.29 **
CMS 4546A x RHA-6D-1	4.47	-9.56 *	-8.68	-13.93 **	-14.99 **	26.82 **	12.60 **	27.77 **	-4.62 **	8.12 **
CMS 4546A x RHA-95-C-1	-0.43	-13.28 **	-13.67 **	-18.64 **	-19.65 **	25.58 **	16.62 **	32.33 **	-1.21	11.98 **
CMS 4546A x R-298	19.84 **	14.96 **	-7.57	-12.89 **	-13.97 **	4.14 **	2.66	19.92 **	-10.48 **	1.47
CMS 4546A x R-64	-1.62	-8.84	-32.68 **	-36.56 **	-37.34 **	-2.70	-4.43 *	8.46 **	-19.04 **	-8.23 **
CMS 4546 A x RHA-271	4.44	-8.91 *	-9.63 *	-14.84 **	-15.88 **	-13.87 **	-14.88 **	-1.09	-26.16 **	-16.31 **
CMS 4546 A x RHA-272	10.62 *	2.17	-10.95 *	-16.08 **	-17.11 **	-0.04	-1.23	14.81 **	-14.29 **	-2.85
CMS 17 A x RHA-6D-1	0.09	-0.46	0.51	-5.27	-6.44	31.22 **	12.28 **	38.94 **	3.72 *	17.56 **
CMS 17 A x RHA-95-C-1	-3.29	-3.44	-3.57	-9.12 *	-10.24 *	29.51 **	15.66 **	43.12 **	6.84 **	21.10 **
CMS 17 A x R-298	12.11 **	1.19	1.05	-4.77	-5.94	-3.27 *	-5.97 **	16.34 **	-13.15 **	-1.55
CMS 17 A x R-64	-8.28	-25.21 **	-25.31 **	-29.61 **	-30.48 **	21.13 **	14.13 **	41.22 **	5.42 **	19.50 **
CMS 17 A x RHA-271	3.14	2.80	2.65	-3.26	-4.45	7.62 **	4.33 **	29.10 **	-3.62 *	9.24 **
CMS 17 A x RHA-272	3.87	-2.74	-2.88	-8.47 *	-9.59 *	25.83 **	22.02 **	50.98 **	12.71 **	27.75 **
CMS 103 A x RHA-6D-1	-10.13 *	-21.07 **	-20.29 **	-24.88 **	-25.80 **	54.56 **	43.46 **	47.46 **	10.08 **	24.78 **
CMS 103 A x RHA-95-C-1	-8.14	-18.82 **	-19.19 **	-23.84 **	-24.78 **	35.53 **	31.90 **	35.58 **	1.21	14.72 **
CMS 103 A x R-298	0.02	-2.47	-21.59 **	-26.10 **	-27.01 **	7.06 **	0.63	17.55 **	-12.25 **	-0.53
CMS 103 A x R-64	3.30	-5.76	-28.00 **	-32.14 **	-32.98 **	5.36 **	2.16	11.81 **	-16.53 **	-5.39 **
CMS 103 A x RHA-271	-10.27 *	-20.59 **	-21.22 **	-25.75 **	-26.67 **	3.04	-2.90	12.82 **	-15.78 **	-4.54 *
CMS 103 A x RHA-272	-0.95	-7.06	-19.00 **	-23.66 **	-24.60 **	9.09 **	2.78	19.48 **	-10.81 **	1.10
DCMS 51 A x RHA-6D-1	-5.76	-6.91	-6.00	-11.41 **	-12.50 **	6.20 **	4.70 *	-7.84 **	-31.20 **	-22.02 **
DCMS 51 A x RHA-95-C-1	-3.11	-3.61	-4.05	-9.57 *	-10.69 *	9.96 **	3.33	0.52	-24.96 **	-14.95 **
DCMS 51 A x R-298	8.74 *	-1.26	-2.73	-8.33 *	-9.45 *	-2.87	-15.87 **	-1.73	-26.64 **	-16.84 **
DCMS 51 A x R-64	8.27	-11.24 *	-12.56 **	-17.59 **	-18.61 **	27.37 **	13.46 **	24.17 **	-7.30 **	5.07 **
DCMS 51 A x RHA-271	-15.40 **	-15.69 **	-16.36 **	-21.18 **	-22.15 **	-0.58	-13.69	0.28	-25.14	-15.14
DCMS 51 A x RHA-272	-3.09	-8.68	-10.03 *	-15.21 **	-16.25 **	16.86 **	1.43	17.90 **	-11.99 **	-0.24
SE(Sij)	1.58	1.82	1..30	1..30	1.35	0.44	0.51	0.35	0.39	0.38

*, ** significant at 5% and 1% level, respectively

Table 3 Per cent heterosis over mid parent (MP), better parent (BP) and check hybrids for per cent seed filling and number of filled seeds/head in sunflower

Cross	% cent seed filling					No. of filled seeds/head				
	MP	BP	KBSH-1	KBSH-44	GK- 2002	MP	BP	KBSH-1	KBSH-44	GK- 2002
CMS 234A x RHA-6D-1	18.85 **	15.10 *	6.14	-2.7	6.11	180.01 **	73.23 **	-17.79 *	-36.37 **	-14.92
CMS 234A x RHA-95-C-1	36.32 **	30.68 **	12.91 **	3.51	12.88 **	232.60 **	94.24 **	-7.82	-28.65 **	-4.61
CMS 234A x R-298	7.19	-3.95	4.76	-3.97	4.72	66.78 **	62.11 **	-18.51 *	-36.92 **	-15.67
CMS 234 A x R-64	24.67 **	21.79 **	10.34 *	1.14	10.30 *	104.19 **	63.68 **	-22.32 *	-39.87 **	-19.62 *
CMS 234 A x RHA-271	13.87 *	12.45 *	-0.35	-8.65 *	-0.38	160.96 **	56.20 **	-25.87 **	-42.62 **	-23.29 *
CMS 234 A x RHA-272	15.49 **	10.63	-4.41	-12.37 **	-4.44	113.62 **	36.82 *	-35.07 **	-49.74 **	-32.81 **
CMS 4546A x RHA-6D-1	18.07 **	17.56 **	9.36 *	0.25	9.33 *	137.67 **	45.94 **	-27.93 **	-44.22 **	-25.42 **
CMS 4546A x RHA-95-C-1	30.63 **	20.97 **	12.53 **	3.15	12.50 **	173.89 **	59.05 **	-21.45 *	-39.20 **	-18.72 *
CMS 4546A x R-298	8.89	0.88	10.02 *	0.86	9.99 *	74.83 **	73.29 **	-12.89	-32.57 **	-9.85
CMS 4546A x R-64	10.11 *	8.67	1.09	-7.33	1.06	73.95 **	37.39 *	-32.15 **	-47.48 **	-29.79 **
CMS 4546 A x RHA-271	2.70	0.27	-6.73	-14.50 **	-6.76	172.12 **	61.83 **	-20.08 *	-38.14 **	-17.29
CMS 4546 A x RHA-272	13.51 *	5.04	-2.29	-10.43 *	-2.32	180.44 **	78.08 **	-12.06	-31.93 **	-8.99
CMS 17 A x RHA-6D-1	14.70 **	9.19	11.41 *	2.12	11.37 *	243.04 **	101.74 **	28.99 **	-0.16	33.48 **
CMS 17 A x RHA-95-C-1	13.85 **	1.14	3.2	-5.4	3.16	211.59 **	75.22 **	12.03	-13.28 *	15.94
CMS 17 A x R-298	-0.76	-3.96	4.74	-3.99	4.71	104.23 **	82.40 **	16.62	-9.73	20.69 *
CMS 17 A x R-64	6.31	0.35	2.39	-6.14	2.36	89.79 **	37.39 **	-12.16	-32.01 **	-9.1
CMS 17 A x RHA-271	5.79	-1.16	0.84	-7.56	0.81	187.01 **	64.50 **	5.18	-18.58 **	8.85
CMS 17 A x RHA-272	16.67 **	3.58	5.68	-3.12	5.65	172.17 **	64.46 **	5.16	-18.61 **	8.82
CMS 103 A x RHA-6D-1	10.96 *	5.37	8.07	-0.94	8.04	128.77 **	32.57 **	-6.09	-27.31 **	-2.82
CMS 103 A x RHA-95-C-1	11.89 *	-0.82	1.72	-6.75	1.69	51.33 **	-15.82	-40.37 **	-53.84 **	-38.29 **
CMS 103 A x R-298	0.26	-2.73	6.08	-2.76	6.05	30.43 **	11.49	-21.02 *	-38.87 **	-18.27 *
CMS 103 A x R-64	-1.76	-7.49	-5.12	-13.02 **	-5.15	41.86 **	-0.41	-29.45 **	-45.39 **	-26.99 **
CMS 103 A x RHA-271	17.47 **	9.49	12.29 **	2.93	12.26 *	81.11 **	2.51	-27.38 **	-43.79 **	-24.85 **
CMS 103 A x RHA-272	12.45 *	-0.39	2.17	-6.35	2.13	74.63 **	3.75	-26.51 **	-43.11 **	-23.95 **
DCMS 51 A x RHA-6D-1	9.58 *	-2.03	14.65 **	5.1	14.62 **	81.44 **	2.86	-13.40	-32.97 **	-10.38
DCMS 51 A x RHA-95-C-1	11.20 *	-6.75	9.13	0.04	9.1	101.96 **	10.54	-6.93	-27.96 **	-3.69
DCMS 51 A x R-298	3.11	-0.4	16.56 **	6.85	16.53 **	80.98 **	44.52 **	21.68 *	-5.82	25.92 **
DCMS 51 A x R-64	4.4	-7.39	8.38	-0.65	8.35	68.35 **	12.79	-5.03	-26.49 **	-1.72
DCMS 51 A x RHA-271	7.46	-5.58	10.50 *	1.29	10.46 *	92.50 **	6.95	-9.96	-30.30 **	-6.82
DCMS 51 A x RHA-272	17.13 **	-1.83	14.88 **	5.31	14.85 **	131.20 **	33.91 **	12.74	-12.73	16.67
SE(Sij)	3.82	4.42	2.75	2.73	2.79	26.30	30.37	22.71	22.70	24.16

*, ** significant at 5% and 1% level, respectively

Number of filled seeds/head forms an important yield component that varies among genotypes. All the 30 hybrids over mid parent and only 21 hybrids over better parent showed significant heterosis showing the presence of non-additive gene actions. The results were in conformity with the findings of Manivannan *et al*. (2003). The crosses CMS 17 A x RHA-6D-1 and CMS 234 A x RHA-95-C-1, recorded heterosis to the extent of 101.74 and 94.24. The same cross CMS 17 A x RHA-6D-1 also had significant heterosis over KBSH-1 and GK-2002 28.99 and 33.48.

Only six hybrids were noticed to have significant positive heterosis over better parent for 100 seed weight (Table 4) which was an important yield contributing character. Considering the per se performance, CMS 17 A had high hull part and by being better combiner it contributes for high part of hull content in the hybrid combinations also resulting in the increased seed weight. The higher hull part of this line no doubt contributes towards seed yield through seed weight and thus naturally results decrease in oil content since they are inversely related. The increased seed weight in hybrids is considered as undesirable as it mainly contributes for low oil content. The seed weight is known to be influenced by dominance gene action as suggested by higher magnitude of heterosis. Therefore, one must be cautious to decide about better seed weight in hybrids, which lead to high yield but not the oil content. Under these circumstances, it would be desirable to opt for negative heterosis for seed weight in hybrids. However, the derived heterosis for seed yields needs to be compensated through heterosis for per cent filled seeds and number of seeds/head. The latter is decided by head diameter in which the medium sized head with better seed arrangement within it are most desirable for a genotype.

Capitulum or head diameter is another important yield contributing trait attracting attention of the workers for better head size. In this study, only one hybrid DCMS 51 A x R-298 excelled the check hybrid KBSH-1 with a limited heterosis of 8.97% and none of the experimental hybrids excelled KBSH-44 and GK-2002. All the hybrids expressed significant heterosis over mid parent and as many as 24 hybrids over better parent suggesting that it is possible to combine better head size compared to commercial hybrids. However, mere increase in head size may not be helpful to get more number of seeds/head that again is dependent on per cent seed filling and orientation of seeds in the heads in such a way to hold more number of seeds in a unit area. It can be noted that KBSH-1 has moderate head size with excellent arrangement of seeds in the whorls of the head.

The present investigation on the heterotic performance of the developed single cross hybrids revealed the highest magnitude of heterosis for seed yield/plant followed by number of filled seeds/head and lowest magnitude of heterosis for oil content. None of the hybrids were significantly superior over KBSH-44 for seed yield/plant, volume weight, number of filled seeds/head, per cent seed filling and 100 seed weight. The highest heterosis to the extent of 104% for seed yield over better parent in the cross CMS 234 A x RHA-95-C-1 can be attributed to contribution of heterosis from component characters such as, number of filled seeds/head (94.24), per cent seed filling (30.68) and hull content (8.87).

Table 4 Per cent heterosis over mid parent (MP), better parent (BP) and check hybrids for head diameter and 100 seed weight in sunflower

Cross	Head diameter (cm)					100 seed weight (g)				
	MP	BP	KBSH-1	KBSH-44	GK- 2002	MP	BP	KBSH-1	KBSH-44	GK- 2002
CMS 234A x RHA-6D-1	31.02 **	9.38	-13.80 **	-18.67 **	-22.05 **	23.02 **	-6.84	-15.85 **	-25.05 **	-13.01 *
CMS 234A x RHA-95-C-1	48.26 **	21.08 **	-4.59	-9.97 **	-13.72 **	38.47 **	-4.24	-13.50 *	-22.95 **	-10.58
CMS 234A x R-298	16.32 **	11.77 *	-4.45	-9.84 **	-13.59 **	-8.56	-10.17	-15.89 **	-25.08 **	-13.05 *
CMS 234 A x R-64	17.90 **	12.54 *	-2.44	-7.95 *	-11.79 **	0.00	-10.16	-18.85 **	-27.72 **	-16.11 **
CMS 234 A x RHA-271	46.24 **	22.54 **	-3.44	-8.88 *	-12.68 **	9.18	-15.37 *	-23.55 **	-31.90 **	-20.97 **
CMS 234 A x RHA-272	39.78 **	21.67 **	-4.12	-9.53 **	-13.30 **	19.69 **	-3.62	-12.94 *	-22.45 **	-10.00
CMS 4546A x RHA-6D-1	37.18 **	16.62 *	-12.10 **	-17.06 **	-20.52 **	38.50 **	8.75	-11.39 *	-21.07 **	-8.40
CMS 4546A x RHA-95-C-1	41.19 **	17.35 **	-11.56 **	-16.55 **	-20.03 **	51.01 **	7.58	-12.35 *	-21.93 **	-9.39
CMS 4546A x R-298	12.37 *	5.72	-9.62 *	-14.72 **	-18.27 **	9.41	2.31	-4.20	-14.67 **	-0.96
CMS 4546A x R-64	13.27 *	5.87	-8.22 *	-13.40 **	-17.01 **	3.38	-2.66	-20.69 **	-29.35 **	-18.01 **
CMS 4546 A x RHA-271	45.11 **	23.83 **	-6.67	-11.94 **	-15.60 **	28.33 **	3.32	-15.82 **	-25.02 **	-12.98 *
CMS 4546 A x RHA-272	44.52 **	28.23 **	-3.35	-8.81 *	-12.61 **	37.02 **	14.88 *	-6.4	-16.63 **	-3.24
CMS 17 A x RHA-6D-1	48.31 **	19.55 **	3.07	-2.75	-6.80 *	69.68 **	29.79 **	13.86 *	1.42	17.71 **
CMS 17 A x RHA-95-C-1	52.95 **	20.74 **	4.10	-1.77	-5.87	76.04 **	22.75 **	7.68	-4.08	11.32 *
CMS 17 A x R-298	16.62 **	16.12 **	0.12	-5.53	-9.46 **	19.98 **	16.19 *	8.80	-3.09	12.47 *
CMS 17 A x R-64	21.00 **	20.68 **	4.61	-1.30	-5.41	27.54 **	16.08 *	1.83	-9.30	5.27
CMS 17 A x RHA-271	48.78 **	20.34 **	3.76	-2.10	-6.18	44.45 **	13.15	-0.73	-11.58 *	2.62
CMS 17 A x RHA-272	42.29 **	19.31 **	2.87	-2.94	-6.98 *	49.81 **	22.00 **	7.02	-4.67	10.64
CMS 103 A x RHA-6D-1	47.50 **	17.78 **	4.12	-1.75	-5.85	40.95 **	4.84	-0.07	-10.99 *	3.30
CMS 103 A x RHA-95-C-1	52.43 **	19.25 **	5.42	-0.53	-4.68	9.16	-25.60 **	-29.09 **	-36.83 **	-26.69 **
CMS 103 A x R-298	18.34 **	16.39 **	2.89	-2.92	-6.96 *	-18.90 **	-19.61 **	-23.38 **	-31.75 **	-20.79 **
CMS 103 A x R-64	18.38 **	17.23 **	3.64	-2.21	-6.29	0.09	-12.17	-16.29 **	-25.44 **	-13.46 *
CMS 103 A x RHA-271	30.05 **	4.21	-7.88 *	-13.08 **	-16.70 **	11.59	-15.10 *	-19.08 **	-27.92 **	-16.35 **
CMS 103 A x RHA-272	27.37 **	5.74	-6.53	-11.80 **	-15.48 **	1.29	-20.05 **	-23.80 **	-32.12 **	-21.22 **
DCMS 51 A x RHA-6D-1	42.48 **	11.76 *	3.70	-2.15	-6.23	20.33 **	-14.05 *	-6.79	-16.97 **	-3.64
DCMS 51 A x RHA-95-C-1	45.71 **	12.04 *	3.96	-1.91	-5.99	35.91 **	-10.36	-2.78	-13.41 **	0.50
DCMS 51 A x R-298	22.25 **	17.44 **	8.97 *	2.82	-1.46	7.36	0.03	8.48	-3.38	12.14 *
DCMS 51 A x R-64	19.64 **	15.70 **	7.36	1.30	-2.92	15.21 *	-4.17	3.93	-7.43	7.44
DCMS 51 A x RHA-271	43.64 **	13.04 *	4.89	-1.03	-5.15	11.15	-18.95 **	-12.10 *	-21.71 **	-9.13
DCMS 51 A x RHA-272	36.37 **	11.08 *	3.07	-2.75	-6.80 *	26.23 **	-4.79	3.25	-8.03	6.74
SE(Sij)	0.68	0.79	0.43	0.42	0.43	0.31	0.35	0.21	0.22	0.22

*, ** significant at 5% and 1% level, respectively

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Character association and path analysis among yield components in castor (*Ricinus communis* L.)

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ABSTRACT

The analysis of the nature and magnitude of associations among 10 quantitative traits and their contribution towards seed yield was carried out in 30 genotypes of castor (*Ricinus communis* L.) during the winter season of 2009 at Regional Agricultural Research Station, Tirupati. The results revealed that 1200 seed weight, oil yield/plant, effective length of main spike, oil content and number of spikes/plant had significant positive association with seed yield/plant. Path analysis revealed that oil yield/plant, 100 seed weight, number of capsules on main spike, number of nodes upto main spike, plant height up to main spike and days to 50% flowering are the direct contributors for seed yield in castor.

Key words: Castor, Character association, Oil yield, Path analysis, Seed yield

Castor (*Ricinus communis* L.) yield is a complex character depends on a number of component characters. Direct selection for yield is not a reliable approach since it is highly influenced by the environment. Hence, knowledge of association of the yield component traits with each other would be of great help in formulating a selection criterion useful in crop improvement. Correlation, which is the primary tool of a plant breeding programme only provides the degree of association of the characters while path coefficient analysis which is a standard partial regression coefficient, measures the direct influence of one variable upon another and permits the separation of correlation coefficient into components of direct and indirect effects (Dewey and Lu, 1959). Therefore, it is essential to identify the component characters through which yield can be improved. Thus, correlation in conjunction with path analysis would give better insight into the cause and effect relationship between different character pairs.

The experimental material comprised of 21 hybrids and nine parents derived out of a Line x Tester mating system. The experiment was conducted in a randomized block design with three replications at Regional Agricultural Research Station, Tirupati during the winter season of 2009. Each genotype was sown in three rows of 6m length by adopting inter and intra row spacing of 90 cm x 60 cm. Observations were recorded on five competitive plants selected at random in the central row of plot on days to 50% flowering, plant height upto main spike, number of nodes upto main spike, effective length of main spike, number of spikes/plant, number of capsules on main spike, 100 seed weight, oil content, oil yield/plant and seed yield/plant. The oil content was estimated by following Nuclear Magnetic Resonance Spectroscopy method (Grami *et al.,* 1977). The phenotypic and genotypic correlation coefficients were calculated using the method given by Johnson *et al.* (1955). The direct and indirect effects both at genotypic and phenotypic level were estimated by taking seed yield as dependent variable using path coefficient analysis suggested by Wright (1921) and Dewey and Lu (1959).

The nature and magnitude of genotypic and phenotypic correlation coefficients (Table 1) obtained among 10 characters in 30 genotypes of castor revealed that seed yield/plant exhibited a significant positive correlation with effective length of main spike, number of spikes/plant, 100 seed weight, oil content and oil yield/plant, indicating that genotypes possessing these characters always result in higher seed yield. The earlier studies also indicate the importance of effective length of main spike, number of spikes/plant and 100 seed weight (Manivel and Manivannan, 2006). Hundred seed weight, an index of seed size had significant positive correlation with seed yield, which is in accordance with earlier studies made by Manivel and Manivannan (2006). Therefore, the positively correlated yield attributes *viz.,* effective length of main spike, number of spikes/plant, 100 seed weight, oil content and oil yield/plant should be considered as crucial parameters for selection in breeding programme targeted to high yield in castor.

Days to 50% flowering registered positive significant genotypic correlation with plant height upto main spike and number of nodes upto main spike and negative significant genotypic association with oil content. Plant height upto main spike exhibited significant positive phenotypic and genotypic correlation with number of nodes upto primary spike and effective length of main spike whereas negative significant genotypic correlation with number of capsules on main spike. Number of nodes upto primary spike recorded significant positive phenotypic and genotypic correlations

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with effective length of main spike, significant negative phenotypic correlation with number of spikes/plant, significant negative genotypic correlation with number of capsules on main spike and positive significant genotypic correlation with oil content. Effective length of main spike exhibited significant negative phenotypic and genotypic correlations with number of spikes/plant and positive significant phenotypic and genotypic correlations with 100 seed weight and significant positive genotypic correlation with number of capsules on main spike, oil content and oil yield/plant. Number of spikes/plant had significant negative genotypic correlation with number of capsules on main spike and significant positive genotypic correlation with oil yield/plant. Hundred seed weight recorded significant positive phenotypic and genotypic correlation with oil content and oil yield/plant. Oil content exhibited significant positive phenotypic and genotypic correlation with oil yield/plant.

From the foregoing, it is to conclude that seed yield/plant exhibited significant positive correlation with 100 seed weight, oil yield/plant, effective length of main spike, oil content and number of spikes/plant indicating the importance of these characters in selection of elite castor genotypes.

The observed correlation between yield and a particular yield component is not only the result of direct effect of that component but also due to its indirect effects through the other yield attributes. The direct effects may be different from the observed correlations. The total correlation between yield and a component character may sometimes be misleading since it may be over estimated or under estimated because of its association with other characters. Hence, direct selection by correlated response may sometimes be misleading when many characters are affecting a given trait. Hence, the correlation has to be partitioned into direct and indirect effects as devised by Wright (1921).

Among all the characters, oil yield/plant had exerted the highest positive direct effect on seed yield, followed by characters plant height upto main spike, number of capsules on main spike, 100 seed weight, days to 50% flowering and number of nodes upto main spike, respectively (Table 2). These results were in accordance with the reports for oil yield/plant (Ramesh *et al*., 2001), plant height upto main spike (Manivel and Manivannan, 2006), number of capsules on main spike (Khorgade *et al*., 1994), days to 50% flowering (Manivel and Manivannan, 2006) and number of nodes upto main spike (Yadav *et al*., 2004). Hundred seed weight, effective length of main spike and oil content influenced seed yield through their high indirect effects via oil yield/plant to register significant positive association with seed yield. These results were in accordance with 100 seed weight (Manivel and Manivannan, 2006), oil content and effective length of main spike (Khorgade *et al*., 1994).

Table 1 Phenotypic (r_p) and genotypic (r_g) correlation coefficients among seed yield and yield components in 30 genotypes of castor

Source		Days to 50% flowering	Plant height upto main spike	No. of nodes upto main spike	Effective length of main spike	No. of spikes/plant	No. of capsules on main spike	100 seed weight	Oil content	Oil yield/plant	Seed yield/plant
Days to 50% flowering	r_p	1.0000	0.0888	0.1828	-0.0428	-0.1113	-0.1865	-0.0540	-0.1134	-0.0573	-0.0472
	r_g	1.0000	0.4379*	0.3888*	0.2124	-0.0659	-0.2773	-0.0289	-0.2547*	-0.1264	-0.1093
Plant height upto main spike	r_p		1.0000	0.6464**	0.6097**	-0.0924	0.1512	0.1607	0.1091	0.1310	0.1161
	r_g		1.0000	0.9705**	0.6488**	-0.3610*	-0.3661*	0.2867*	0.2336*	0.1962	0.1740
No. of nodes upto main spike	r_p			1.0000	0.3486*	-0.0711	-0.1217	0.1205	0.1755	0.1267	0.1014
	r_g			1.0000	0.6293**	-0.0464	-0.3300*	0.1254	0.2962*	0.1735	0.1377
Effective length of main spike	r_p				1.0000	-0.3850*	0.2655	0..2575*	0.0755	0.2195	0.2138
	r_g				1.0000	-0.6215**	0.4191*	0.7357**	0.3267**	0.5064**	0.5017**
No. of spikes/plant	r_p					1.0000	-0.1307	0.0149	0.1271	0.1568	0.1432
	r_g					1.0000	-0.6394**	-0.1630	0.2312	0.3389*	0.3176*
No. of capsules on main spike	r_p						1.0000	-0.0264	-0.1028	-0.0766	-0.0668
	r_g						1.0000	-0.0977	-0.1698	-0.1578	-0.1495
100 seed weight	r_p							1.0000	0.2924*	0.6017**	0.5889**
	r_g							1.0000	0.5012**	0.9723**	1.0686**
Oil content	r_p								1.0000	0.4444**	0.3238
	r_g								1.0000	0.5184**	0.4072*
Oil yield/plant	r_p									1.0000	0.9901**
	r_g									1.0000	0.9916**
Seed yield/plant	r_p										1.0000
	r_g										1.0000

*,** Significant at 5% and 1% level, respectively

Table 2 Phenotypic (P) and genotypic (G) path coefficients for seed yield and yield components in 30 genotypes of castor

Source		Days to 50% flowering	Plant height upto main spike	No. of nodes upto main spike	Effective length of main spike	No. of spikes/plant	No. of capsules on main spike	100 seed weight	Oil content	Oil yield/plant	Seed yield/plant
Days to 50% flowering	P	-0.0039	0.0003	-0.0011	0.0005	0.0010	0.0002	0.0002	0.0163	-0.0608	-0.0472
	G	0.0038	0.0254	0.0007	-0.0224	0.0018	-0.0145	-0.0008	0.0347	-0.1379	-0.1093
Plant height upto main spike	P	-0.0003	0.0034	-0.0038	-0.0064	0.0009	-0.0001	-0.0007	-0.0157	0.1390	0.1161
	G	0.0017	0.0580	0.0019	-0.0684	0.0096	-0.0192	0.0083	-0.0319	0.2140	0.1740
No. of nodes upto main spike	P	-0.0007	0.0022	-0.0059	-0.0037	0.0007	0.0001	-0.0005	-0.0253	0.1345	0.1014
	G	0.0015	0.0644	0.0018	-0.0664	0.0012	-0.0173	0.0036	-0.0404	0.1893	0.1377
Effective length of main spike	P	0.0002	0.0021	-0.0020	-0.0106	0.0036	-0.0002	-0.0011	-0.0109	0.2328	0.2138
	G	0.0008	0.0376	0.0011	-0.1055	0.0165	0.0219	0.0214	-0.0446	0.5523	0.5017**
No. of spikes/plant	P	0.0004	-0.0003	0.0004	0.0041	-0.0094	0.0001	-0.0001	-0.0183	0.1663	0.1432
	G	-0.0003	-0.0209	-0.0001	0.0655	-0.0266	-0.0335	-0.0047	-0.0315	0.3696	0.3176
No. of capsules on main spike	P	0.0007	0.0005	0.0007	-0.0028	0.0012	-0.0008	0.0001	0.0148	-0.0812	-0.0668
	G	-0.0011	-0.0212	-0.0006	-0.0442	0.0170	0.0523	-0.0028	0.0232	-0.1721	-0.1495
100 seed weight	P	0.0002	0.0005	-0.0007	-0.0027	-0.0001	0.0000	-0.0043	-0.0421	0.6381	0.5889**
	G	-0.0001	0.0166	0.0002	-0.0776	0.0043	-0.0051	0.0290	-0.0684	1.1696	1.0686**
Oil content	P	0.0004	0.0004	-0.0010	0.0008	-0.0012	0.0001	-0.0013	-0.1441	0.4713	0.3238
	G	-0.0010	0.0135	0.0005	-0.0345	-0.0062	-0.0089	0.0145	-0.1364	0.5654	0.4072
Oil yield/plant	P	0.0002	0.0004	-0.0007	-0.0023	-0.0015	0.0001	-0.0026	-0.0641	1.0605	0.9901**
	G	-0.0005	0.0114	0.0003	-0.0534	-0.0090	-0.0083	0.0311	-0.0707	1.0907	0.9916**

Bold : Direct effect; Normal : Indirect effect; Phenotypic residual effect : 0.00562; Genotypic residual effect : 0.00437

Plant height upto main spike influenced seed yield through its low indirect effects via number of spikes/plant followed by 100 seed weight, number of nodes upto main spike and days to 50% flowering and number of nodes upto main spike via oil yield/plant, plant height upto main spike, 100 seed weight, days to 50% flowering and number of spikes/plant. These results were in accordance with the reports of Sachli (1986) for plant height upto main spike and Yadav *et al.* (2004) for number of nodes upto main spike. Days to 50% flowering and number of capsules on main spike though expressed positive direct effects, but, their indirect negative effects were exerted through effective length of main spike, 100 seed weight and oil yield/plant. Number of capsules on main spike and days to 50% flowering characters though expressed direct positive effects, their indirect effects through effective length of main spike and 100 seed weight were negative resulting in negative non-significant correlation with seed yield. The negative direct effects were exerted by effective length of main spike, number of spikes/plant and oil content.

The path coefficient analysis revealed that oil yield/plant, 100 seed weight, number of capsules on main spike, number of nodes upto main spike, plant height upto main spike and days to 50% flowering are the direct contributors for seed yield in castor. Hence, emphasis should be laid out on these yield determinants in order to improve the seed yield in castor.

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Combining ability studies in castor (*Ricinus communis* L.) under irrigated and un-irrigated environments

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ABSTRACT

Forty eight hybrids developed through L x T design (four females and 12 males) were evaluated under irrigated and unirrigated environments for computing estimates of general and specific combining ability effects for 14 quantitative and qualitative characters including castor (*Ricinus communis* L.) seed yield. Combining ability analysis revealed that *gca* variances were significant, only for few characters, under both environments; whereas *sca* variances were significant for all the characters in both the environments, reiterating the preponderance of non-additive gene action in the inheritance of these characters. The female parents, SKP-84 and SKP-49 and male parents *viz*., JI-224, JI-244, JI-260, SKI-160, SKI-202 and SKI-232 were superior and consistent general combiners for seed yield and other yield contributing characters. For oil content, the parents SKP-49, SKI-202, SKI 232 and JI-260 were superior general combiners under irrigated environment, whereas under the un-irrigated situation, SKP-84, JP-82, JI 263 and JI-258 were the good general combiners. The hybrids which recorded high *sca* effects for seed yield were Geetha x JI-224 and SKP-49 x JI-227 under irrigated and un-irrigated environments, respectively. Looking to the importance of both additive and non-additive gene action in the inheritance of various characters, a breeding strategy involving biparental matings coupled with reciprocal recurrent selection may be employed for simultaneous improvement of the characters.

Key words: Castor, General combining ability, Oil content, Specific combining ability, Yield

Castor (*Ricinus communis* L.), an important non-edible commercial crop grown under both irrigated and unirrigated situations. About 50% of the castor growing area (14.69 l. ha) is cultivated under unirrigated conditions while the major area under irrigated conditions is concentrated in western India *viz.,* Gujarat, Rajasthan, etc. The wide disparity in productivity levels (nearly 1000 kg/ha) between irrigated and unirrigated conditions is mainly due to the lack of genotypes suitable for different situations. There is a need to identify parents with good general combining ability for seed yield and yield components under different environments.

Further, it is observed that the performance and the behaviour of castor genotypes vastly vary under different environmental situations. Therefore, it was necessary to identify genotypes combining well under different environmental conditions producing superior hybrids which can perform well under each situation. With this view, the present study was conducted to identify genotypes possessing good general combining ability and cross combinations displaying high specific combining ability, under two environments i.e., irrigated and un-irrigated .

The experimental material was developed by crossing four females (pistillate lines), *viz*., Geetha (P_1), SKP-84 (P_2), SKP-49 (P_3) and JP-82 (P_4) with twelve males(testers), *viz*., SKI-215 (P_5), SKI-202 (P_6), SKI-232 (P_7), GC-2 (P_8), DCS-47 (P_9), JI-244 (P_{10}), JI-227 (P_{11}), JI-224 (P_{12}), JI-263 (P_{13}), JI-260 (P_{14}), SKI-258 (P_{15}) and SKI-160 (P_{16}) in a Line x Tester mating system. The resultant 48 hybrids, their 16 parents and 2 standard hybrids (GCH-5 and GCH-6) were grown in randomized complete block design, with three replications during the rainy season of 2003 at plant breeding farm, GAU, Anand. Each plot consisted of a single row of 6.0 m length with 120 cm x 60 cm spacing. Two environmental situations were created for evaluating the 66 genotypes. In experiment under irrigated condition (E_1), 50 kg P_2O_5/ha as a basal dose and 30 kg N/ha was applied at the time of first irrigation. Another experiment was conducted entirely under un-irrigated situation (E_2) with the application of fertilizer at the time of sowing only. Observations were recorded from a minimum of five randomly selected plants for each treatment in each replication for seed yield/plant, plant height, length of the primary raceme, number of effective branches/plant, number of nodes up to the primary raceme, number of capsules on the primary raceme, days to 50% flowering, days to 50% maturity of the primary raceme, shelling out turn, 100 seed weight, volume weight, oil content, ricinoleic acid and un-saturated fatty acid. The combining ability analysis was done following the statistical procedure proposed by Kempthorne (1957).

The analysis of variance for combining ability for various characters under irrigated and un-irrigated environments is given in table 1. The variance due to *gca* was significant for four characters *viz*., plant height, primary spike length, days to 50% maturity of primary raceme and 100 seed weight both in E_1 and E_2. The significant of *gca* for seven characters varied with the environments. The variance due to specific combining ability (*sca*) was found to be highly significant for all the characters in both the environments, indicating the predominance of non-additive gene action. Further, partitioning of the total variance into additive and non-additive components, confirmed the latter's role in the total variance makeup. Similar observations were earlier reported by Ramu *et al.* (2002) and Lavanya and Chandramohan (2003). The estimates of *gca* effects are presented in table 2. The *gca* effects revealed that none of the parents had good *gca* for all the characters in both the environments. The female parents SKP-84 and SKP-49 were found to be good general combiners for seed yield and many yield contributing characters under irrigated and non irrigated environments, respectively. Among the male parents, JI-260 and JI-227 exhibited high *gca* effects for seed yield under irrigated and unirrigated environments, respectively. However, barring few, they were not found to be good general combiners for other yield contributing characters. For oil content, SKP-84, SKP-49, SKP-232 and JI-260 were found to have good *gca* effects under irrigated environment whereas SKP-84, JI-263 and JI-258 exhibited good *gca* under un-irrigated condition. For ricinoleic acid content, JP-82, GC-2, DCS-47 and JI-244 in irrigated environment and SKI-232 and JI-244 in un-irrigated environment exhibited significant *gca* effects. In most of these cases, the inverse relationship between oil and principal fatty acid content (ricinoleic acid) was reported by Moshkin (1986) and Nagaraj (1996).

Table 1 Analysis of variance and variance estimates for combining ability for various characters in castor under irrigated (E_1) and un-irrigated (E_2) environments

Source	Seed yield/ plant (g)		Plant height (cm)		Length of primary raceme (cm)		No. of effective branches/ plant		No. of nodes upto primary raceme		No. of capsules on the primary raceme		Days to 50% flowering		Days to 50% maturity of primary raceme	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
Replication	270.50	46.42	16.44	326.89	24.92	18.14	0.98**	8.01**	0.26	25.68**	6.74	552.80	2.53	1.02	4.47	1.72
Lines(L)	56703.31**	5810.62	3555.33**	251.61	614.51**	411.74*	12.48**	7.05	12.74	38.96**	2403.37**	1104.02	62.84	329.47**	8.79	329.46**
Testers(T)	17108.44	1850.63	580.82*	443.62*	51.07	80.07	3.14**	2.26	11.21	20.52**	918.78**	572.94	93.13	151.11*	201.85**	174.67
L x T	18889.84**	2138.20**	271.53**	191.93**	56.33**	124.14**	0.98**	2.94**	6.88**	5.95**	261.02**	607.32**	80.83**	54.37**	31.84**	112.22**
Error	287.07	47.62	19.04	10.61	10.31	22.49	0.18	0.32	0.36	0.80	5.88	184.07	1.69	1.68	2.48	6.62
σ^2*gca* (L)	1050.37*	102.02	91.22**	1.66	15.50**	7.99*	0.32**	0.11	0.16	0.92**	59.51**	13.80	-0.50	7.64**	-0.64	6.03*
σ^2*gca* (T)	-148.45	-23.96	25.77*	20.97*	-0.44	-3.67	0.18**	-0.06	0.36	1.21**	54.84**	-2.87	1.02	8.06*	14.17**	5.20**
σ^2*gca*	750.67*	70.52	74.85*	6.49*	11.59*	5.07*	0.28**	0.07	0.21	0.91*	58.34**	9.63	-0.12	7.74**	3.06*	5.83*
σ^2*sca*	6200.93**	696.86**	84.04**	60.44**	15.34**	33.88**	0.27**	0.87**	2.17**	1.72**	85.05**	141.08**	26.38**	17.56**	9.78**	35.20**
σ^2A	3002.67	282.08	299.42	25.95	46.08	20.29	1.14	0.29	0.85	3.97	233.34	38.53	-0.47	30.99	12.25	23.30
σ^2D	2403.70	2787.44	336.44	241.76	61.36	135.53	1.07	3.49	8.69	6.87	340.19	564.35	105.52	70.26	39.13	140.81
σ^2A/σ^2D	0.12	0.10	0.89	0.11	0.75	0.15	1.06	0.08	0.09	0.58	0.69	0.08	-	0.44	0.31	0.17
Degree of Dominance	2.87	3.14	1.06	3.05	1.15	2.58	0.97	3.49	3.20	1.32	1.21	3.85	14.92	1.50	1.78	2.46

Table 1 (contd...)

Source	Shelling out turn (%)		100 seed weight (g)		Volume weight (g/100 ml)		Oil content (%)		Ricinoleic acid (%)		Unsaturated fatty acids (%)	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
Replication	12.19	27.14	0.38	3.31	1.60	2.45	2.09**	6.83	0.40	0.24	1.05	0.37
Lines(L)	235.21	88.38	68.30**	159.21**	19.11	7.57	8.87*	8.24	7.46	3.45	10.38	6.66
Testers(T)	165.65	88.41	18.98**	13.57	14.58	18.40	5.25	8.49	11.91*	4.52	11.22	3.03
L x T	96.39**	106.24**	6.17**	10.64**	24.42**	22.39**	3.01**	4.69**	5.38**	7.25**	6.76**	7.66**
Error	9.03	6.98	2.12	3.19	1.16	0.64	0.17	0.15	0.30	0.83	0.08	0.12
σ^2*gca* (L)	3.86	-0.50	1.73**	4.12**	-0.15	-0.41	0.16*	0.09	0.06	-0.10	0.10	-0.03
σ^2*gca* (T)	5.77	-1.49	1.07**	0.24	-0.82	-0.33	0.19	0.32	0.54*	-0.23	0.37	-0.38
σ^2*gca*	4.33	-0.74	1.56**	3.16*	-0.32	-0.39	0.17*	0.15	0.18*	-0.14	0.17	-0.12
σ^2*sca*	29.12**	33.09**	1.35**	2.48**	7.76**	7.24**	0.95**	1.51**	1.69**	2.14**	0.22**	2.51**
σ^2A	17.34	-2.97	6.24	12.63	-1.26	-1.57	0.67	0.62	0.72	-0.54	0.67	-0.47
σ^2D	116.49	132.34	5.40	9.93	31.02	29.00	3.79	6.06	6.78	8.56	8.89	10.06
σ^2A/σ^2D	0.15	-	1.16	1.27	-	-	0.18	0.10	0.11	-	0.08	-
Degree of Dominance	2.59	6.67	0.93	0.89	4.96	4.30	2.37	3.15	3.08	3.97	3.63	4.63

*,** significant at 5% and 1% levels of probability, respectively E_1 = Irrigated, E_2 = Unirrigated

Table 2 Estimates of general combining ability effects (*gca*) for various characters in castor under irrigated (E_1) and un-irrigated (E_2) environments

Source	Seed yield/plant (g)		Plant height (cm)		Length of primary raceme (cm)		Number of effective branches/plant		Number of nodes upto primary raceme		Number of capsules on the primary raceme		Days to 50 % flowering		Days to 50 % maturity of primary raceme	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
Female (Line)																
Geetha (P_1)	4.03	-0.87	13.89**	1.99**	5.09**	0.16	0.35**	0.18*	-0.35**	1.14**	-4.44**	-0.09	0.88**	1.92**	0.60*	-0.17
SKP 84 (P_2)	23.40**+	-3.19**	-6.33**	2.21**	-2.24**	-0.52	-0.11	-0.24**	-0.38**	-0.49**	-7.05**	1.94	-1.37**	1.81**	-0.10	-4.03**
SKP 49 (P_3)	29.78**	17.28**	0.39	-0.81	1.42**	4.30**	0.54**	0.53**	0.88**	0.55**	0.05	5.65**	1.35**	-4.47**	-0.60*	3.19**
JP 82 (P_4)	-57.22**	-13.22**	-7.94**	-3.39**	-4.27**	-3.93**	-0.78**	-0.47**	-0.16	-1.19**	11.44**	-7.50**	-0.87**	0.73**	0.10	1.00*
S.E. (g_i)	2.82	1.15	0.73	0.54	0.54	0.79	0.07	0.09	0.10	0.15	0.40	2.26	0.22	0.22	0.26	0.43
S.E. (g_i-g_j)	3.99	1.63	1.04	0.77	0.76	1.12	0.10	0.13	0.14	0.21	0.57	3.20	0.31	0.31	0.37	0.61
Male (Tester)																
SKI-215(P_5)	5.23	-8.86**	7.22**	2.17*	-0.30	3.83**	0.54**	0.78**	0.82**	1.37**	2.49**	12.42**	1.99**	3.40**	1.35**	-0.44
SKI-202(P_6)	-24.69**	6.26**	-1.03	1.35	0.12	1.18	-0.32**	-0.47**	0.91**	-0.40	-5.23**	-0.30	-4.92**	1.23**	-3.82**	-1.28
SKI-232(P_7)	34.42**	-6.64**	-6.19**	-4.17**	-2.47**	-2.84*	0.27	-0.50**	-0.35*	0.06	-6.62**	-12.16**	-1.84**	-1.10**	-6.32**	-0.69
GC-2 (P_8)	-41.07**	10.35**	-7.28**	1.66	-2.72**	2.04	-0.17	0.34*	-1.07**	-0.78**	-12.78**	0.29	-1.67**	-5.94**	-3.15**	0.22
DCS-47(P_9)	-19.91**	-11.64**	-1.86	-1.68	-1.22	-1.62	-0.24*	0.05	-0.57**	1.12**	6.27**	0.65	2.41**	4.15**	5.60**	-7.11**
JI-244 (P_{10})	27.96**	5.93**	-13.11**	-4.59**	3.12**	-2.94*	-0.28**	0.03	0.09	-1.23**	3.49**	2.54	-2.51**	0.06	2.51**	1.47*
JI-227 (P_{11})	-85.83**	27.17**	4.72**	-3.12**	1.70	4.62**	0.41**	-0.32*	-0.87**	-1.28**	-14.41**	-7.51	3.16**	-2.85**	6.85**	-6.03**
JI-224 P_{12})	21.42**	11.31**	3.31**	-5.50**	3.79**	0.22	-0.27*	-0.26	-0.52**	-0.08	12.02**	5.40	1.99**	-0.27	0.01	1.22
JI-263 (P_{13})	22.32**	-13.27**	2.14	-1.29	0.37	0.58	-0.32**	-0.72**	0.95**	0.57*	12.10**	-9.97*	1.41**	6.81**	1.60**	7.06**
JI-260 (P_{14})	48.02**	-1.89	13.06**	16.41**	-0.38	-3.23*	-0.49**	-0.13	1.70**	2.91**	-2.81**	3.13	2.83**	-3.77**	-0.65	2.31**
JI-258 (P_{15})	-4.68	-5.11	-1.86	-5.30**	-2.13*	-0.92	-0.38**	-0.40*	-1.44**	-1.62**	-1.04	4.49	0.91	-0.27	1.43**	-0.19
SKI-160(P_{16})	17.36**	-13.60**	0.89	4.10**	0.12	-0.91	1.24**	0.16	0.53**	0.64*	6.52**	1.03	-3.76**	-1.57**	-5.40**	3.47**
S.E.(g_j)	4.89	1.99	1.27	0.94	0.93	1.37	0.12	0.16	0.17	0.26	0.70	3.92	0.38	0.37	0.46	0.74
S.E. (g_i-g_j)	6.91	2.82	1.80	1.33	1.31	1.94	0.34	0.23	0.25	0.36	0.99	5.54	0.53	0.53	0.64	1.05

Table 2 (contd...)

Source	Shelling out turn (%)		100 seed weight (g)		Volume weight (g/100 ml)		Oil content (%)		Ricinoleic acid (%)		Unsaturated fatty acids (%)	
	E_1@	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
Female (Line)												
Geetha (P_1)	1.94**+	-0.98*	0.49*	0.60	0.60**	-0.002	0.19**	-0.25**	0.19*	0.28	-0.11*	-0.53**
SKP 84 (P_2)	2.31**	-0.93*	1.37**	2.12**	0.29	-0.25*	-0.34**	0.57**	-0.47**	-0.17	0.66**	0.36**
SKP 49 (P_3)	-1.27*	2.32**	0.03	0.19	-1.06**	0.64**	0.62**	-0.51**	-0.26**	-0.35*	0.09	0.34**
JP 82 (P_4)	-2.98**	-0.42	-1.89**	-2.90**	0.18	-0.39**	-0.46**	0.19**	0.54**	0.24	-0.64**	-0.17**
S.E. (g_i)	0.50	0.44	0.24	0.30	0.18	0.13	0.07	0.07	0.09	0.16	0.05	0.06
S.E. (g_i-g_j)	0.71	0.62	0.34	0.42	0.25	0.38	0.10	0.18	0.13	0.42	0.07	0.08
Male (Tester)												
SKI-215(P_5)	6.08**	-0.23	0.83	1.49**	-2.07**	-0.81**	0.18	0.02	-0.74**	-1.03**	0.75**	0.41**
SKI-202(P_6)	-1.18	2.52**	1.14**	-0.51	0.60	0.09	0.36**	-0.42**	-0.14	-0.58*	0.24**	0.73**
SKI-232(P_7)	1.60	1.05	-0.17	0.99	0.14	-0.15	1.16**	-0.47**	-2.00**	0.50	1.97**	-0.76**
GC-2 (P_8)	-4.49**	3.80**	-1.05*	0.34	-0.10	2.03**	-0.87**	-0.48**	1.04**	0.58*	-1.20**	-0.45**
DCS-47(P_9)	-0.89	-5.12**	-1.20**	-2.04**	-1.93**	0.21	-0.38**	-1.53**	1.31**	0.48	-1.20**	-0.54**
JI-244 (P_{10})	-0.06	1.97**	0.34	-0.79	-0.79*	0.56*	-0.17	-0.31**	0.02	0.27	0.43**	0.38**
JI-227 (P_{11})	-8.08**	-1.71*	-2.76**	-0.43	-0.12	-1.57**	-0.18	-0.02	1.10**	0.24	-1.09**	-0.05
JI-224 (P_{12})	3.76**	1.57*	1.78**	1.37**	0.95**	0.14	-1.11**	-0.15	-0.85**	0.83**	0.63**	-0.40**
JI-263 (P_{13})	-1.35	1.96*	-0.55	-0.91	1.32**	-2.73**	-0.10	1.57**	-0.21	-0.72**	0.07	0.51**
JI-260 (P_{14})	2.49**	-1.35	1.25**	-0.53	1.18**	0.57*	1.03**	0.05	-0.84**	0.39	0.59**	-0.49**
JI-258 (P_{15})	1.44	-0.21	0.09	0.05	0.45	1.02**	-0.08	1.47**	0.74**	-0.50	-0.45**	-0.31**
SKI-160 (P_{16})	0.69	-4.24**	0.30	0.97	0.37	0.65*	0.16	0.27*	0.58**	-0.44	-0.79**	0.34**
S.E.(g_j)	0.87	0.76	0.42	0.52	0.31	0.23	0.12	0.11	0.16	0.26	0.09	0.10
S.E. (g_i-g_j)	1.23	1.08	0.59	0.73	0.44	0.65	0.17	0.32	0.22	0.74	0.12	0.14

*,** significant at 5% and 1% levels of probability, respectively E_1 = Irrigated, E_2 = Unirrigated, Figures in bold are at par values

Table 3 Three best hybrids on the basis of *sca* estimates for different characters under irrigated (E1) and un-irrigated (E2) environments

Rank	Seed yield/plant (g)		Plant height (cm)		Length of the primary raceme (cm)	
	E1@	E2	E1	E2	E1	E2
1.	P1 x P12 (143.12)	P3 x P11 (91.65)	P1 x P10 (- 14.56)	P4 x P14 (- 19.54)	P1 x P12 (7.16)	P3 x P11 (10.78)
2.	P3 x P16 (126.63)	P1 x P10 (51.27)	P1 x P12 (- 12.64)	P2 x P12 (- 11.20)	P4 x P9 (6.19)	P3 x P13 (10.12)
3.	P2 x P7 (106.81)	P3 x P8 (32.84)	P1 x P15 (- 11.47)	P1 x P13 (- 8.72)	P4 x P6 (4.52)	P1 x P5 (8.87)
Rank	Number of effective branches/plant		Number of nodes upto the primary raceme		Number of capsules on the primary raceme	
	E1	E2	E1	E2	E1	E2
1.	P1 x P16 (0.99)	P3 x P14 (1.84)	P1 x P14 (- 2.67)	P2 x P13 (- 1.77)	P2 x P13 (16.32)	P1 x P6 (26.67)
2.	P1 x P5 (0.88)	P3 x P13 (1.73)	P2 x P5 (- 2.43)	P4 x P14 (- 1.71)	P3 x P16 (15.95)	P1 x P5 (21.91)
3.	P2 x P9 (0.85)	P1 x P9 , P1 x P16 (1.32)	P2 x P6 (- 1.86)	P1 x P12 (- 1.42)	P4 x P7 (15.85)	P3 x P11 (21.11)
Rank	Days to 50 % flowering		Days to 50 % maturity of the primary raceme		Shelling out turn (%)	
	E1	E2	E1	E2	E1	E2
1.	P2 x P14 (- 1.13)	P1 x P5 (- 8.76)	P2 x P14 (- 6.07)	P1 x P12 (- 12.75)	P2 x P14 (9.46)	P4 x P9 (10.38)
2.	P2 x P15 (- 8.95)	P4 x P11 (- 5.90)	P1 x P8 (- 4.92)	P2 x P5 (- 9.89)	P4 x P16 (8.80)	P3 x P10 (10.02)
3.	P3 x P13 (- 6.44)	P1 x P10 (- 5.01)	P4 x P15 (- 4.68)	P4 x P12 (1.08)	P1 x P13 (7.17)	P2 x P14 (- 3.83)
Rank	100 seed weight (g)		Volume weight (g/100 ml)		Oil content (%)	
	E1	E2	E1	E2	E1	E2
1.	P1 x P12 (3.50)	P4 x P13 (3.63)	P3 x P10 (5.12)	P2 x P9 (6.65)	P1 x P12 (2.21)	P4 x P8 (2.54)
2.	P3 x P5 (2.11)	P3 x P14 (2.74)	P4 x P5 (4.55)	P4 x P13 (3.31)	P4 x P6 (1.51)	P1 x P14 (2.29)
3.	P1 x P8 (2.01)	P1 x P6 (2.03)	P2 x P16 (3.08)	P2 x P10 (3.17)	P3 x P12 (1.33)	P3 x P10 (1.64)

Rank	Ricinoleic acid (%)		Unsaturated fatty acid (%)	
	E1	E2	E1	E2
1.	P4 x P14 (1.84)	P4 x P5 (2.94)	P2 x P13 (-1.97)	P3 x P16 (-2.67)
2.	P1 x P10 (1.75)	P2 x P10 ,P3 x P16 (1.95)	P4 x P12 (-1.94)	P4 x P5 (-2.49)
3.	P2 x P13 (1.53)	P3 x P11 (1.80)	P1 x P5 (-1.79)	P2 x P14 (-1.89)

Three best hybrids on the basis of *sca* estimates for different characters are presented in table 3.The highest *sca* effect was observed in the crosses, Geetha x JI224 and SKP-49 x JI 227 under irrigated and un-irrigated environments, respectively. The cross, Geetha x JI 224 was also one of three best crosses under irrigated environment for the characters *viz.,* plant height, length of the primary raceme, 100 seed weight and oil content. However, no such relationship could be established under un-irrigated environment for high specific combiners of seed yield. Nevertheless, it was observed that presence of at least one good general combiner in the cross lead to good *sca* effects indicating additive x dominance type of gene action which could produce desirable transgressive segregants in subsequent generations. However, considering the importance of both additive and non-additive gene action observed for various characters in this study, a breeding strategy involving biparental matings coupled with reciprocal recurrent selection may be employed for simultaneous improvement of the characters. The importance of additive and non additive gene action for character expression in castor can be corroborated from the earlier studies of Lavanya and Chandramohan (2003) and Lavanya *et al.* (2006).

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Combining ability analysis for seed yield and yield components in castor (*Ricinus communis* L.)

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ABSTRACT

The genetic analysis was done through a line x tester design involving 70 castor (*Ricinus communis* L.) hybrids generated by crossing 5 pistillate lines with 14 pollen parents. The combining ability analysis for yield and its components revealed that both additive and non-additive genetic variance were significantly influenced by environment. The preponderance of additive gene action was observed for the control of days to 50 % flowering and days to 50 % maturity of main raceme as well as number of nodes up to main raceme. Non-additive gene effect was predominant for the characters, plant height and oil content. The parents SKP-8, 103745, 1379, SKP-93, TMV-5, Aruna, SH-72 and SK2-8A were good general combiners for imparting earliness, former three as well as VP-1 were good general combiner for short plant stature. The parents SH-72, SK 2-BA, SKP-82, JH-128, SH-41 and 48-1 were good general combiners for oil content. The estimates of *gca* effects suggested that parents SKP-93, SKP-82, 48-1, Aruna, SPS-35-9B, JI-77 and JH-128 were good general combiners for seed yield and several yield components viz., 100 seed weight, effective branches/plant, number of capsules in main raceme and length of main raceme. The good specific cross combinations for yield *viz*., SKP-8 x TMV-5, VP-l x SKI-41 and SKP 25 x 1379 were also identified as superior hybrids for earliness, high oil content and short plant stature, respectively and may be exploited for commercial cultivation. The hybrids SKP-8 x TMV-5, SKP-25 x JH- 128 and SKP-82 x 48-1 with significant positive *sca* effect for seed yield could be exploited for development of hybrids and new inbred as well as pistilate lines in castor. The potence ratio of genetic variance suggested preponderance of non-additive gene effect for inheritance of the seed yield/plant, number of capsules in main raceme and number of effective branches.

Key words: Castor, Combining ability, Oil content, Seed yield

Heterosis breeding is the major breeding strategy for castor (*Ricinus communis* L.) crop in present era. However, the extent of success in improving one or more economic characters depends on the judicious selection of parents and subsequent handling of segregating generations. The availability of pistillate lines has permitted large scale exploitation of heterosis in castor. The choice of appropriate parents to be incorporated in hybridization programme is a crucial step for the breeders. Use of known superior general combiners ensures much better success. Information of combining ability of pistillate lines and staminate lines would be useful to formulate breeding programme for development of new hybrids. Hence, a Line x Tester analysis was under taken to obtain information on combining ability for yield and its attributes.

Five pistillate lines (SKP-8, SKP-25, SKP-82, SKP-93 and VP-l) and 14 pollen parents (Table 2) were crossed in Line x Tester mating design. Seventy hybrids along with their 19 parents were evaluated in randomized block design with four replications. Each entry was represented by a single row of 9.60 m length with 90 cm x 60 cm spacing. Ten competitive plants/plot were randomly selected for recording observations of 11 quantitative traits. The combining ability analysis was done as suggested by Kempthrone (1957). The analysis of variance for combining ability (Table 1) revealed that the variance due to females, males and hybrids were significant for all the characters except variance due to female for the traits, seed yield/main raceme and oil content, which suggest that the females, males and hybrids differed statistically among themselves. The contrast comparisons due to parent v/s hybrid were also significant for all the attributes indicating for the presence of heterotic effects.

Both the components of genetic variance were significant for all the character revealing importance of both additive and non-additive genetic variances. However, the large estimates of variance due to general combining ability for the days to 50% flowering of main raceme, days to 50% maturity of main raceme and number of nodes up to the main raceme suggested preponderance of additive genetic variance. However, for the plant height, both the components were of equal importance. The variance due to specific combining ability was of larger magnitude for seed yield/plant indicating greater influence of non-additive genetic variance for the inheritance of these traits. The results are in conformity with reports of Ramu *et al.* (2002); Lavanya and Mohan (2003) and Patel *et al.* (2003).

The lines and testers also differed statistically among themselves for all characters except lines for the trait seed

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yield/main raceme. The variance component due to hybrids was significant for all the characters suggesting existence of differences among the hybrids. The variance due to contrast comparisons of parents *viz*., hybrids were also significant for all the characters except effective branches/plant indicating the possibility of heterosis for these traits. The variance components due to male (σ^2m) were higher than those due to females (σ^2f) for number of capsules in main raceme, effective branches/plant and seed yield/main raceme. However, females contributed largely in comparison to males for total genetic variance for the traits *viz*., length of main raceme, hundred seed weight and seed yield/plant. Both additive and non-additive genetic variances were important for all the characters. However, the estimates of *sca* variances were considerably higher than those of *gca* variances for number of capsules in main raceme, effective branches/plant, hundred seed weight and seed yield/plant, indicating preponderance of non-additive genetic variance for the inheritance of these traits. However, for length of main raceme and seed yield/main raceme additive genetic variance influenced predominantly. The results confirm the findings of Gondalia *et al.* (2001); Ramu *et al.* (2002) and Solanki *et al.* (2003).

The estimates of *gca* effects (Table 2) revealed that the female parents SKP-93 and SKP-8 were good general combiners for days to 50% flowering as well as days to 50% maturity of main raceme and seed yield. The lines SKP-25 and SKP-82 were good general combiners for oil content' and VP-I for short plant height. In case of pollen parents, SH-41, SH-72, SKI-41, Aruna, 103745 and 1379 were good general combiners for imparting earliness. Among them, SH-41, SH-72, SKI-41 were good combiners for oil content, while, 103745 and 1379 were good general combiners for short plant stature.

The female lines SKP-82 and SKP-93 were good general combiners for seed yield/plant, seed yield/main raceme hundred seed weight, number of capsules in main raceme and length of main raceme (Table 2). Among male parents JH-128, JI-77, 48-1, SPS-35-9B, 1379 and Aruna were good general combiners for seed yield/plant and at least for two important yield attributes *viz*., 100 seed weight, effective branches/plant, number of capsules in main raceme and length of main raceme. The male parents 48-1 and Aruna were good general combiners for effective branches/plant, while, pollen parents SH-72, 48-1 and 1379 for length of main raceme and number of capsules in main raceme. The male parents SH-72 and 48-1 showed significant desirable *gca* effects for test weight.

About 33% of the total number of hybrids depicted significant *sca* effects for seed yield of which, the hybrids SKP-8 x TMV-5 and VP-l x SKI-41 were good specific combiners for seed yield/plant in addition to high oil content and for imparting earliness (Table 3). The cross SKP-25 x 1379 had significant *sca* effect in desired direction for earliness, short plant stature and seed yield/plant. These hybrids involved one or both poor general combining parents; hence these may be directly exploited for commercial cultivation. The hybrid SKP-82 x JI- 77 had significant *sca* effects for seed yield and also involved both good general combining parents. This hybrid may be advanced in addition to commercial exploitation for production of desirable transgressive segregants for development of improved male inbred and female lines.

Table 1 Analysis of variance for combining ability in 89 castor genotypes

Source	d.f.	Days to 50% flowering of main raceme	Days to 50% maturity of main raceme	Number of nodes up to main raceme	Plant height (cm)	Length of main raceme (cm)	Number of capsules in main raceme	Effective branches/ plant	100 seed weight (g)	Seed yield/ main raceme (g)	Oil content (%)	Seed yield/plant (g)
Replication/ season	6	7.10	31.64	15.34	22.8	8.64	14.35	2.18	1.57	20.10	0.54	149.09
Parents	18	368.20 **	3094.96**	40.94	150.9**	501.13**	380.99**	50.80 **	86.15**	227.84 **	4.67**	11018.40**
Females	4	210.78 **	1631.53**	7.62**	58.59**	795.90 **	282.72**	34.91*	105.93**	97.84	6.04	12693.34**
Males	13	423.54 **	3678.59**	48.80**	158.9**	385.72 **	407.99**	59.45**	86.34**	246.52*	4.04*	5590.32**
Females Vs Males	1	278.37**	1361.50**	72.01**	511.19**	822.40 **	423.08**	2.00	0.50	506.45**	7.42**	74883.75**
Hybrids	69	248.72**	1227.19**	37.48**	544.2**	299.23 **	558.70**	17.04*	26.73**	417.91**	5.03**	8749.33**
Parents Vs Hybrids	1	50.88 **	2277.75**	7.87**	277.2**	1149.53**	4770.32**	3.17	259.87**	8873.67**	52.8**	72987.75**
Error	528	2.78	5.13	1.77	15.94	10.492	14.953	1.350	1.562	14.47	0.16	67.86
Variance components												
σ^2 *gca*	-	9.15	37.77	1.74	17.81	18.26	10.17	0.26	1.18	17.13	0.10	321.86
σ^2 *sca*	-	1.99	28.05	0.55	17.90	11.07	46.62	0.66	1.25	12.72	0.90	540.99
2 σ^2 *gca*/ 2σ^2 *sca*	-	0.22	0.74	0.32	1.01	0.61	4.58	2.62	1.06	0.75	3.03	1.68

*, ** = 5% and 1% level of probability, respectively

Table 2 General combining ability effects of 19 parents for eleven characters in castor

Parent	Days to 50% flowering of main raceme	Days to 50% maturity of main raceme	Number of nodes up to main raceme	Plant height (cm)	Length of main raceme (cm)	Number of capsules in main raceme	Effective branches/ plant	100 seed weight (g)	Seed yield/main raceme (g)	Oil content (%)	Seed yield/plant (g)
Female											
SKP- 8	-1.30**	-2.48**	-1.85**	-0.97	-5.05**	-3.45**	0.19*	-1.60**	-5.74**	-0.37**	-14.85**
SKP-25	-1.26**	1.34**	-0.50**	0.47	-4.98**	-1.70**	0.33**	-0.46**	-2.80**	0.42**	-16.93**
SKP- 82	3.08**	6.30**	1.32**	-5.31**	5.74**	7.47**	-0.66**	0.89**	8.02**	0.62**	16.04**
SKP- 93	-1.12 **	-5.72**	0.58**	0.52	0.55 **	0.48	0.02	1.57**	2.22	0.08**	30.73**
VP -1	0.61**	0.57**	0.45**	5.33**	3.74**	-2.80**	0.11	-0.40**	-1.63**	0.39**	-15.00**
SE (gi) ±	0.12	0.17	0.10	0.55	0.24	0.28	0.09	0.09	0.28	0.03	0.62
Male											
JH- 128	2.51**	1.34**	0.15	-0.79**	1.46 **	-1.15*	-0.13	-0.08	1.69**	0.19**	5.61**
JI -77	7.06**	15.19**	1.08**	2.23**	-0.26	-0.14	0.72**	0.91	0.39	-0.50**	24.33**
SH-66	-0.16**	3.43**	0.72**	10.55**	-0.53	3.50**	-1.12**	0.26	2.81**	0.46**	1.81
SH-72	2.56**	-2.39**	0.10	-1.91**	1.10**	2.05**	-0.71**	1.58**	2.97**	-0.19**	-16.57**
SK2-8A	-2.09**	-6.33**	0.14	5.13**	2.54**	-1.99**	-0.59**	-0.39*	-1.57**	0.42**	-12.99**
SKI-41	-0.51**	0.89**	1.27**	-4.22**	-1.99**	1.26*	0.48**	0.32	1.23*	0.11*	-17.32**
SA-2	-2.24**	-4.78	0.24	4.54**	0.17	1.05*	0.61**	-0.95**	0.60	0.35**	-12.17**
48-1	-1.71 **	-0.61*	0.66**	-2.02**	3.85 **	1.49**	1.26**	0.58**	5.16**	-0.09*	16.98**
TMV-5	7.56 **	-9.29**	1.16**	5.29**	-0.19	0.71	-0.26	-1.35**	-0.59	0.13**	-23.89**
SPS -35-9B	-0.74**	-3.38**	0.58**	0.12	2.69**	-2.41**	0.24	0.61**	-3.74**	0.07	12.13**
103745	-8.31**	-14.33**	-3.73**	-12.86**	1.09*	0.14	0.22	0.60**	0.41	-0.30**	-5.74**
1379	-9.14**	-17.36**	-4.14**	-11.13**	4.15**	1.50**	-1.35**	-0.68	-0.77	-0.37**	2.68
Aruna	-2.34**	-4.36**	1.06**	3.43**	0.39	6.83**	2.86**	-2.41**	2.19**	-0.08	15.46**
S.E. (gi) ±	0.22	0.31	0.18	0.31	0.43	0.51	0.15	0.17	0.51	0.05	1.12

*, ** = 5% and 1% level of probability, respectively

Table 3 Estimates of specific combining ability (*sca*) effects of best eight crosses for six characters in 70 hybrids of castor

Selected cross	Days to 50 % flowering of main raceme	Days to 50 % maturity of main raceme	Number of nodes up to main raceme	Plant height (cm)	Oil content (%)	Seed yield/plant (g)
SKP- 8 x JH-128	-1.45**	-10.19**	4.62**	0.25	-1.77**	9.97**
SKP- 8 x TMV-5	-2.73**	-5.69**	2.09	0.17	0.21*	7.95**
SKP- 25 x SH-41	-1.94**	-4.61**	-5.86**	-0.44	-0.24*	0.55
SKP- 25 x SH-72	-1.14**	-8.59**	-0.21	0.44	0.51*	18.52**
SKP- 25 x 1379	-1.59**	-3.69**	-2.79*	0.58	-0.70**	33.48**
SKP-82 x JI-77	-1.62**	-2.45**	7.94**	0.55	0.07	50.78**
SKP- 82 x 1379	-2.42**	-4.05**	-1.49	-1.70*	0.91**	2.26
VP- 1 x SKI-41	-1.99**	-6.37**	-2.14	-0.62	0.68**	29.30**
S.E. (gi) ±	0.44	0.63	1.11	0.37	0.05	1.12

*, ** = 5% and 1% level of probability, respectively

The *sca* effects revealed that hybrids SKP-25 x JH-128, SKP-82 x 48-1, SKP-82 x JI -77, SPK-93 x SPS 35-9B; SPK-8 x TMV-5 and VP-l x SH-72 for grain yield/plant, SKP-8 x 103745, SKP-82 x SH-66; SKP-82 x JI- 77 and SKP-8 x SA-2 for length of main raceme; SKP-82 x SH-66, SKP-93 x Aruna; SKP-8 x 103745 and SKP-82 x SH-41 for number of capsules in main raceme; VP-1 x 48-1; SKP-93 x 103745; SKP-93 x Aruna and SKP-25 x JH-128 for effective branches/plant; SKP-8 x SA-2, SKP-25 x TMV-5; SKP-82 x 103745 and SKP-82 x SH-72 for hundred seed weight; SKP 82 x SH-41, SKP-8 x 103745; SKP-82 x JH-77 and VP-l x SH-72 for seed yield per main raceme were good specific combiners. The hybrids SKP-93 x Aruna, SKP-82 x JH- 77 and SKP-93 x TMV-5 were good specific combiners for seed yield and majority of the yield contributing characters.

The hybrids which had high *sca* effects and involved both good general combiner parents suggest the involvement of additive x additive and additive x dominance type of interallelic interactions. However, hybrids which involved poor general combiner parents and higher estimates of *sca* effects suggest the presence of dominance and pseudo dominance gene effects. The crosses, which had both the good general combiner parents, may be advanced for development of improved female and male lines, in addition to commercial exploitation of hybrids. Thus, the hybrids which involved both the parents as poor general combiners like SKP-8 x TMV-5, VP-1 and SKI-41 may be exploited for commercial cultivation.

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Genetic variability for root, shoot and water use efficiency traits in castor (*Ricinus communis* L.)

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ABSTRACT

A study was conducted to identify castor (*Ricinus communis* L.) genotypes with good root growth for water mining, high total drymatter (TDM) and high water use efficiency (WUE). Sixty four genotypes including germplasm lines and advanced varietal/hybrid trial (AVT/AVHT) entries were sown during rainy season of 2008 in two specially constructed root structures (32 in each structure) replicating twice with four plants/replication after attaining the bulk density of the structure as that of field . Data on root (length, volume, dry weight), shoot (leaf area index, TDM, stem girth) and WUE traits (SPAD chlorophyll meter reading, specific leaf area, ^{13}C, ^{18}O) were recorded at 90 DAS. Efficient genotypes were selected based on a composite index using principal component analysis (PCA) and top 10 genotypes were selected for root and shoot growth traits. These genotypes include RG 1437, RG 1463, RG 1494, RG 1614, RG 1645, RG 1941, RG 2058, RG 2113, RG 2127 and RG 2139.

Key words: Castor, Root traits, Total drymatter, Water use efficiency

Castor (*Ricinus communis* L.) is generally considered as drought tolerant crop. But, there is an enormous yield gap between irrigated and rainfed situations. In Gujarat, it is grown in fertile soils with irrigation and good management practices and average yield is 14 q/ha but in Andhra Pradesh it is grown as rainfed crop in poor and marginal soils with very low inputs and average yield varies 4-6 q/ha. Though, it has higher realizable yield (potential yield is 1989 kg/ha and realizable yield is 1078 kg/ha), it shows fairly high per cent reduction under stress over the potential yield (86% reduction) (Hegde and Damodaram,1998). There is scope to increase realizable yield by improving the drought tolerance of the crop which has greater adaptation in drought prone conditions.

At Directorate of Oilseeds Research, 4307 Castor germplasm lines with wide variability for various morphological characters are being maintained. It is very essential to study the genetic differences for yield potential and drought tolerance among the promising germplasm lines for pest and disease tolerance. Among many traits associated with drought tolerance, root characters play a major role for water acquisition from the soil. A well developed root system is essential for crop plants to grow under moisture deficit conditions. This in turn influences the performance of the shoot growth and yield potential of that genotype. Yield is also determined by water use efficiency (WUE) and it has shown significant genetic variability and also has heritability (Wright *et al.,* 1988, Farquhar *et al.,* 1989). Alternate approaches for measuring WUE are measuring specific leaf area (SLA), SPAD chlorophyll meter reading (SCMR) and relating it with specific leaf nitrogen (SLN) and mineral ash content, etc. (Nageshwar Rao *et al.,* 1995; Sheshashayee *et al*., 2001). High ^{18}O, which acts as surrogate for transpiration and stomatal conductance (Bindu Madhava *et al*., 1999) and low ^{13}C which shows mesophyll capacity to fix carbon (Farquhar and Richards, 1984) also are used as surrogates for WUE. Identifying these traits with total drymatter (TDM) helps in improving the productivity in water limited environments. Hence, a study was conducted to identify genotypes for root, shoot, TDM and WUE traits.

Sixty four castor genotypes including 55 germplasm lines with tolerance to wilt or leaf hopper and nine advanced varietal/hybrid trial (AVT/AVHT) entries along with 48-1 were grown during rainy season of 2008 in two specially constructed root structures (32 genotypes in each structure) replicating twice with four plants/replication in randomized block design. Each root structure was of 30 m length, 1.5 m height and 2.4 m width on either side of central 30 cm permanent wall (Fig. 1). Once the structure was filled with red soil representing the field, it was watered regularly to allow compaction. When the bulk density of the structure reached the bulk density of that of the field, crop was grown. The spacing adopted was 90 cm x 60 cm. Recommended dose of fertilizers (40 kg N : 40 kg P_2O_5; 20 kg K_2O/ha) were applied. Plants were allowed to grow for 90 days which coincide with its maximum root growth, the side walls were carefully removed, with a jet of water the roots were washed and observations on growth parameters *viz*., plant height (cm), branches, leaf number, stem girth (cm), leaf area index (LAI), water use efficiency (WUE) traits like SPAD chlorophyll meter reading (SCMR), specific leaf area (SLA), ^{13}C, ^{18}O and root characters i.e., root length, fresh weight and dry weight, root volume and total drymatter which include root and shoot (stem, leaf and spike) dry weight were recorded. Data were analyzed to test the significance in RBD (Panse and Sukhatme, 1985). Genotypes were selected using principal component analysis (PCA) with high performance in terms of shoot and root characters (Dunteman, 1994). In the first stage indices were developed separately for shoot and root characters using principal component analysis based on the correlation matrices. Thus, developed indices were utilized as variables for second stage principal component analysis to develop a composite index for selecting the castor genotypes. The genotypes were ranked based on the index in ascending order to select the efficient genotypes with high ranks.

Range of variability for different growth characters in the genotypes studied is presented in table 1. Plant height showed wide variability ranging from 15-225 cm. Total drymatter ranged from 66-629 g/plant with an average of 254 g/pl.

Among root characters, root volume and dry weight showed more variability in different genotypes studied and showed strong positive correlation (>0.90) compared to root length (0.37) with TDM (Table 2). Stem girth, LAI and shoot weight also showed strong positive correlation (>0.80) with TDM. The genotypes with relatively more root (>270ml volume, >45g dry weight) and shoot (LAI >2.5, TDM >350g) growth characters among the genotypes studied are presented in table 3.

Fig. 1. Crop growth and dismantling of root structures

Though SCMR and SLA act as surrogates for WUE in other crops, these traits did not show strong correlation with TDM in castor (Lakshmamma *et al*., 2010). The genotypes with good root and shoot root growth recorded high ^{18}O (surrogate for transpiration and stomatal conductance) and low ^{13}C (mesophyll capacity to fix carbon) which are also are used as alternate approaches for measuring WUE (Bindu Madhava *et al*., 1999; Farquhar and Richards, 1984). Among the genotypes screened, top 10 genotypes were selected based on index using PCA as best genotypes for root (volume, dry weight) and shoot (LAI, TDM, stem girth) growth traits. These genotypes include RG 1437, RG 1463, RG 1494, RG 1614, RG 1645, RG 1941, RG 2058, RG 2113, RG 2127 and RG 2139. Growth in terms of shoot and root characters along with WUE traits (SCMR, SLA, $d^{13}C$, $d^{18}O$) and index value of selected lines is presented in tables 4a and 4b.

Thus, genotypes with more root and shoot growth along with WUE traits are selected for developing productive genotypes for water mining and high WUE. Improvement in productivity through enhanced root (Li *et al*., 2005) and WUE traits (Condon *et al*., 2004) have been demonstrated implying the relevance of these traits in breeding for stress tolerance as well as improved productivity.

Table 1 Mean and range for different characters among the genotypes

Character (per plant)	Mean	Range
Plant height (cm)	75	15 - 225
Leaf number	23	11 - 40
Node number	15	7 - 25
Secondary branch number	3	0 - 6
Tertiary branch number	1	0 - 5
LAI	2.1	0.6 - 4.6
Stem girth (cm)	8.2	4.9 - 12.2
SLA (dm^2/g)	2.0	1.5 - 3.3
SCMR	44.1	38.1 - 52.4
Shoot weight (g)	174	35 - 448
TDM (g)	254	66 - 629
Root length (cm)	215	166 - 293
Root volume (ml)	215	49 - 574
Root dry wt. (g)	36.7	8.2 - 122
Root/shoot wt.	0.22	0.12 - 0.36
TDM/LA	239	120 - 499

Table 2 Correlation coefficients of different characters with TDM

Character	Correlation coefficient
Root length vs TDM	0.37
Root volume vs TDM	0.92
Root dry weight vs TDM	0.90
LAI vs TDM	0.80
Shoot weight vs TDM	0.97
Plant height vs TDM	0.62
Leaf number vs TDM	0.72
Stem girth vs TDM	0.91
SCMR vs TDM	-0.36
SLA vs TDM	0.44
SCMR vs SLA	-0.42

Table 3 Genotypes selected for root, shoot and WUE traits

Character	Per plant	Germplasm line
Root length	> 230cm	RG 1197, 1404, 1452, 1463, 1922, 1941, 1993, 2058, 2127, 2140, 2712, 2813, 2829, 2847, 3088, RHC-199, DCS-106 , 48-1
Root volume	> 270 ml	RG87, 1404, 1437, 1463, 1471, 1488, 1494, 1614, 1631, 1645, 1922, 1941, 1993, 2058, 2113, 2127, 2139, 2847
Root dry weight	> 45g	RG72, 87, 964, 1337, 1437, 1463, 1488, 1494, 1614, 1645, 1922, 1941, 1993, 2113, 2125, 2127, 2139, 2140
LAI	> 2.5	RG77, 87, 964, 1369, 1437, 1463, 1471, 1488, 1494, 1614, 1631, 1645, 1941, 2058, 2113, 2127, 2136, 2139
TDM	> 350g	RG87, 964, 1437, 1463, 1488, 1494, 1614, 1631, 1645, 1922, 1941, 1993, 2058, 2113, 2127, 2139
SCMR	> 47	RG575, 1403, 1432, 1452, 2829, 2847, 2855, 3088, DCH-177, DCS-106, 48-1
SLA	< 1.60	RG575, 1337, 1404, 1432, 1479, 2473, 2777, 2813, 2847, 2855, DCS-106, DCS-9
TDM/LA	> 270	RG72, 1337, 1433, 1437, 1443, 1494, 1645, 1922, 1929, 1941, 1993, 2125, 2127, RHC-199, SKI-307
Root/shoot ratio	> 0.24	RG1406, 1197, 1433, 1494, 1929, 2127, 2139, 2140,2473, 2777, 2855, 3088, RHC-199, DSP-222, SKI-307

Table 4a Physiological characters in selected lines

Genotype	Plant height (cm)	Leaf No.	Stem girth (cm)	SCMR	SLA	LAI	TDM (g)	Index value (PCA)
RG 1614	225	20	11.1	46.1	1.92	3.7	500	1.72
RG 1941	161	40	11.5	42.3	2.21	2.6	629	1.67
RG 2139	154	25	11.0	41.2	2.07	4.6	502	1.58
RG 2058	88	37	10.0	42.3	6.40	4.6	497	1.52
RG 2127	105	31	11.7	44.3	2.09	3.2	501	1.49
RG 2113	152	25	12.2	44.8	1.96	3.3	409	1.22
RG 1494	70	35	10.4	42.2	2.21	2.5	465	1.19
RG 1437	130	30	11.9	39.7	2.29	2.8	448	0.98
RG 1645	179	20	10.0	46.3	2.06	3.1	429	0.97
RG 1463	63	39	10.4	40.8	3.14	4.5	421	0.92
48-1	47.5	23	8.6	45.2	1.967	1.64	291	-0.17
SEm±	10.1	3.7	0.75	1.3	0.24	0.37	29.1	
CD (P=0.05)	28.5	10.6	2.1	3.6	0.67	1.03	82.3	
CV(%)	19	22.8	12.9	4.1	16.5	25.2	16.3	

Table 4b Root characters, $d^{13}C$ and $d^{18}O$ in selected lines

Genotype	Root character			$d^{13}C$	$d^{18}O$
	Length (cm)	Volume (ml)	Dry weight (g)		
RG 1614	210	584	89	-28.563	21.5539
RG 1941	254	487	85	-28.937	20.6259
RG 2139	222	557	93	-29.873	21.4674
RG 2058	261	276	45	-29.568	20.0254
RG 2127	252	546	95	-29.228	19.9054
RG 2113	223	429	71	-28.990	19.1654
RG 1494	215	310	122	-28.481	24.0459
RG 1437	201	355	64	-29.818	19.8065
RG 1645	182	380	64	-29.010	20.1254
RG 1463	241	314	55	-28.813	20.3105
48-1	204	184	26.4	-28.744	18.4466
SEm±	16.5	29.3	5.2		
CD (P=0.05)	46.5	82.7	14.6		
CV(%)	10.9	19.3	20.0		

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Crop coefficients for prediction of evapotranspiration and irrigation requirements of drip irrigated castor (*Ricinus communis* L.)

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ABSTRACT

A study was conducted on castor (*Ricinus communis* L.) in winter 2009-10 at Agricultural College Farm, Rajendranagar, Hyderabad with different drip irrigation schedules at 40, 60 and 80% pan evaporation replenishment levels either kept constant throughout the crop life or combinations at vegetative, flowering and development stages were compared with surface check basin method, irrigated at 0.8 IW/CPE ratio to derive crop coefficients (Kc) for drip irrigated castor. The Kc values were also used to suggest methodology for determination of periodic and peak irrigation requirements of castor for field application. The Kc values worked out varied between 0.345 to 0.822 and the average Kc values for different phenological phases of germination and establishment, vegetative, flowering, capsule development, seed filling and maturity periods were 0.449, 0.626,0.771, 0.940, 0.677 and 0.38, respectively. The peak irrigation, net irrigation and gross irrigation water requirements worked out were 808.7 m^3, 32.11cm and 3567.4 m^3, respectively for drip irrigated castor.

Key words: Castor, Crop coefficient, Drip irrigation, Net irrigation, Reference evapotranspiration

Crop evapotranspiration (ETc) estimates are extensively used for determining irrigation requirements and for scheduling irrigations to crops. Experimentally derived crop coefficients facilitate prediction of crop ETc at progressive stages of crop growth for a given location from the estimates of reference crop evapotranspiration (Praveen Rao and Raikhelkar, 1994). The values of Kc and water requirement (ETc) for drip irrigated castor (*Ricinus communis* L.) were not reported by Allen *et al.* (1998) or Doorenbos and Pruitt (1977). However, Patel *et al.* (2004) reported that the amount of water applied varied between 200 to 400 mm for drip irrigated castor and 530 mm for surface irrigated castor under Gujarat agro-climatic conditions. Hence, the present study was to derive crop coefficients of drip irrigated castor at different crop growth stages under variable water supply levels assumes significance and help complete the FAO list of crop coefficients. Also, methodology for determination of periodic and peak irrigation requirements was suggested.

A field experiment was conducted at College Farm, College of Agriculture, Acharya N.G. Ranga Agricultural University, Hyderabad (17.19° N, 78.23° E and 543 m altitude) in winter season of 2009-10 on a sandy clay soil. The soil was low in N, medium in P and high in K status and alkaline in reaction (pH 8.03). The soil water retention capacity at -0.03 and -1.5 MPa was 0.254 and 0.130 cm^3/cm^3. The available water was 12.4 cm/m depth of soil. Soil bulk density was 1.43 g/cm^3. The source of irrigation water of bore well with C_3S_1 water quality. There were seven irrigation treatments based on surface drip method of irrigation and irrigation scheduling levels in the form of pan evaporation replenishment. The evaporation replenishment factor *viz*., 0.4, 0.6 and 0.8 was either kept constant throughout the crop life or was combinations of the above at vegetative, flowering and capsule development stages besides a treatment of surface check basin irrigated crop at 0.8 IW/CPE ratio with IW = 50 mm (Table 1). The eight irrigation treatments were laid out in randomized block design with three replications. The dripper lines of 16 mm diameter were laid out along the crop rows at 1.2 m spacing with emitters spaced at 0.5 m having a flow rate of 4 l/h. The application rate was 6.66 mm/h. Flow meters were used to measure flow rates to each individual treatment according to designated pan evaporation (Epan) replenishment factor. The total depth of irrigation water applied in drip irrigated treatments varied between 227 mm (0.4 Epan) to 453 mm (0.8 Epan), whereas in surface check basin irrigated crop it was 450 mm. Hybrid, PCH 111 was planted on 7th November, 2009 by adopting a row-to-row spacing of 1.2 m and plant to plant distance of 0.5 m in plots of 18.0 m x 7.2 m. A fertilizer dose of 60 kg N, 40 kg P_2O_5 and 30 kg K_2O ha were applied through fertigation at weekly intervals up to 100 days after sowing. The crop was harvested on 5th April, 2010.

For determination of crop ETc the soil moisture was monitored by delta probe at four locations and various depths before and after each irrigation and on intermediate dates in case of incident precipitation. Effective rainfall received during experimental period was 46.8 mm (Dastane, 1974). The reference crop evapotranspiration (ETo) was estimated at specific crop growth sub-periods based on Penman Monteith equation (Allen *et al*., 1998). Thus, the data obtained on ETc of castor and ETo at specific crop growth sub-periods were used to calculate the crop coefficient (Kc) as follows:

$$Kc = ETc \div ETo$$

For constructing the crop coefficient curve (Fig. 1) the crop life of castor was divided in to germination and establishment, vegetative, flowering, capsule development, seed filling and maturity periods. To use Kc values for predicting crop ETc (ETc = Kc.ETo) throughout the crop season, only ETo estimates on Penman Monteith method from the new planting site are needed.

As an application of this study in irrigation water management, the estimates of ETc for castor crop from the Kc values of highest yielding irrigation treatment I_6 (Drip irrigation at 0.6 Epan up to flowering (81 DAS) and 0.8 Epan later on) were used to determine the actual irrigation requirements for a given design as follows:

$$In = ETc \times \text{Growth period in days}$$

In which, In, net irrigation requirement (cm) for the growth period considered and ETc, crop evapotranspiration (mm/day).

$$V \text{ at field inlet} = (10 \div Ea) \times (A.In \div 1 - LR)\ m^3$$

In which, V, gross irrigation requirement for the period considered (m^3); Ea, field application efficiency (0.9); A, area (1.0 ha); In, net irrigation requirement (cm); LR, leaching requirement (nil); and Ep, project efficiency under groundwater irrigation through bore wells (0.9).

Data on crop coefficients (K_c) calculated based on castor crop ET_c and ET_o derived from Penman Monteith method are presented in table 1. The Kc values in the germination and establishment period were not markedly different from each other owing to uniform water application, since the crop was subjected to variable water supply levels only from 15 DAS. The highest value of the Kc was 1.233, and was exhibited by the crop in I_8 treatment with irrigation at all the crop growth sub-periods equivalent to 0.8 IW/CPE ratio. Likewise the Kc values in I_3 and I_6 were comparable to I_8. Whereas, for I_1 treatment irrigation at only 0.4 Epan at all the crop growth sub-periods (15 to 150 days), the maximum value of the Kc was 0.579. Thus, the K_c values were primarily a function of evaporation replenishment factor during a given crop growth sub-period in different irrigation treatments. Higher the replenishment factor i.e., higher the water application level, higher were the K_c values.

Table 1 Castor crop coefficients as influenced by different drip irrigation schedules

Irrigation treatment	Crop growth sub-periods						Total season
	Germination & establishment	Vegetative	Flowering	Capsule development	Seed filling	Maturity	
I_1 = Drip irrigation at 0.4Epan throughout crop life	0.431	0.479	0.552	0.579	0.386	0.291	0.456
I_2 = Drip irrigation at 0.6Epan throughout crop life	0.446	0.724	0.802	0.822	0.558	0.345	0.637
I_3 = Drip irrigation at 0.8Epan throughout crop life	0.508	0.843	1.032	1.134	0.760	0.406	0.816
I_4 = Drip irrigation at 0.4Epan up to flowering and 0.6Epan later on	0.411	0.479	0.544	0.766	0.588	0.365	0.544
I_5 = Drip irrigation at 0.4Epan up to flowering and 0.8Epan later on	0.422	0.489	0.549	0.951	0.776	0.397	0.629
I_6 = Drip irrigation at 0.6Epan up to flowering and 0.8Epan later on	0.462	0.724	0.829	1.120	0.805	0.402	0.762
I_7 = Drip irrigation at 0.4Epan up to 50 DAS, 0.6Epan from 51-95 DAS and 0.8Epan 96 – maturity	0.446	0.486	0.762	0.920	0.762	0.345	0.653
I_8 = Surface check basin irrigation at 0.8 IW/CPE ratio with an IW of 50 mm throughout crop life	0.473	0.790	1.098	1.233	0.786	0.503	0.850
Average	0.449	0.626	0.771	0.940	0.677	0.381	0.668

The crop coefficient curve shown in Fig. 1 was derived from Kc values of I_2 treatment registering optimal bean yield, maximum net returns with higher water productivity. The Kc values for I_2 treatment varied between 0.345 to 0.822. The Kc value from sowing to establishment was small in view of very little (incomplete) canopy cover (LAI = <0.06) and majority of the water loss may be attributed to evaporation from the soil. Thereafter the Kc value increased linearly from 0.446 to 0.822 due to increase in crop ETc as the crop grew rapidly and developed more leaf area (LAI = 0.067 to 2.05) from establishment through vegetative to flowering period. From flowering to capsule development period the Kc almost remained constant at 0.82. This could be attributed to full leaf canopy cover (LAI = 2.6) and its persistence (Leaf area duration = 42.3 m^2 days) intercepting maximum photosynthetically active radiation. During the final 33-days of crop life the Kc value decreased precipitously reaching a low value of 0.345. This could be due to reduction in crop ETc owing to unproductive/senescence of leaves (LAI = 1.95) and partly due to reduced root activity.

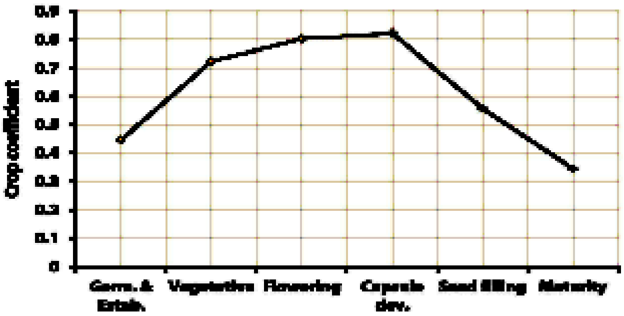

Fig. 1. Crop coefficient curve for drip irrigated castor

Irrigation requirements

Table 2 presents the irrigation requirements of castor. The net irrigation requirement (In) was low (2.115 cm) in the germination and establishment period, increased linearly during vegetative period to 7.105 cm, through flowering (6.011 cm) and capsule development period (7.2 cm) to attain peak value of 7.279 cm in seed filling period. Thereafter In decreased towards maturity period reaching a value of 2.4 cm. The seasonal In was 32.11 cm/ha exclusive of effective precipitation of 1.3 cm. The gross irrigation requirements (V) showed trend similar to In with crop ontogeny (Table 2). The V at field inlet varied from 235.0 to 808.7 m^3 during different crop growth sub-periods. The seasonal V at field inlet and V peak amounted to 3567.4 m^3/ha and 808.7 m^3, respectively. However, while determining irrigation requirements of castor in advance at a new planting site, if historical rainfall and groundwater data indicates any dependable (with 75% probability) contribution to crop ETc during crop growing season accordingly adjustments have to be made (Table 2) in irrigation scheduling.

Thus, it is concluded that the crop Kc values derived in the present study for drip irrigated castor facilitate estimation of crop ETc, which in turn can be used in determining net and gross irrigation requirements for scheduling irrigation at proper time with optimum quantity for optimal castor production and higher water productivity.

Table 2 Irrigation requirements of drip irrigated castor
(variety PCH 111)

Particulars	Crop growth sub-periods						Total season
	Germination & Establishment (0-15 days)	Vegetative (16-50 days)	Flowering (51-81 days)	Capsule development (82-106 days)	Seed filling (107-135 days)	Maturity (136-150 days)	
Reference crop evapotranspiration (cm/day)	0.317	0.281	0.294	0.350	0.449	0.463	0.349
Crop coefficient	0.446	0.724	0.802	0.822	0.558	0.345	0.637
Crop evapotranspiration (mm/day)	0.141	0.203	0.236	0.288	0.251	0.160	0.223
Effective precipitation (cm/period)	0.0	0.0	1.305	0.0	0.0	0.0	0.0
Ground water contribution (cm/period)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net irrigation requirement (cm/period)	2.115	7.105	6.011	7.200	7.279	2.400	32.11
Gross irrigation requirement at field inlet (m^3/period/ha)	235.0	789.4	667.8	799.9	808.7	266.6	3567.4
Peak gross irrigation requirement (m^3/ha)							808.7

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Nutrient rich karanja (*Pongamia pinnata* L.) Pierre genotypes for diversified uses : An inventory

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ABSTRACT

A study was conducted to quantify the content of major nutrients nitrogen (N), phosphorus (P) and potassium (K) in recently matured leaves (RML) of 66 genotypes of *Pongamia pinnata* (L) Pierre, which were grown under same soil fertility and management conditions at the Rajendranagar Research Farm of the Directorate of Oilseeds Research, Hyderabad. Classification of the accessions on the basis of their nutrient content indicted that majority of the genotypes have medium N, P and K content in the RML while two genotypes *viz*., DORPP 27 and 67 recorded high N content. Present investigation indicates that leaves of *P. pinnata* genotypes, DORPP 27 and 67 have shown better nutrient composition to use as manure as well as feed. Further, the index developed may be useful in assessing the nutrient status of recently matured leaves for deficiency, sufficiency and toxicity in various crops.

Key words: Diversified uses, Karanja, Nitrogen, Phosphorus, Potassium

Crop genotypes vary in their nutrient requirements as well as their contents. Both these factors form important components of growth and use of the species. *Pongamia pinnata* (L) Pierre. (Karanja) is a multipurpose species, which has attracted much attention for the seed oil, which can be used as a source of biodiesel (Vigya Kesari *et al*., 2010; Biswas *et al.,* 2011). The karanja leaves have been used as a source of green manure, mulch or live stock fodder (WOI, 1969; Vadivel and Hans, 2011) since long. Out of a rating on 1 to 10 (maximum) scale, the species has recorded a rating of 6 for its use as fodder compared to 10 for *Leucaena leucocephala* and *Prosopis cineraria* (Hocking, 1993). In this study, an attempt was made to identify some *Pongamia pinnata* (L) Pierre (karanj) genotypes having efficient nutrient composition *vis-a-vis* its use as manure as well as feed.

Nutrient content in the leaf is a good index of indicating whether the crop/plant is healthy or not. Knowledge of nutrient content in the leaf of different genotypes will not only help in selecting genotype(s) to suit a particular soil fertility condition but also in rectification of deficiency or toxicity problems. An exploration trip was conducted during March, 2006 and 70 plus trees were identified from four districts of Andhra Pradesh. Nursery was raised and seedlings of 66 *Pongamia pinnata* (karanj) accessions were transplanted into the field during September, 2007. Pongamia plant height varied from 41.5 cm to 91.5 cm with a mean value of 62.4 cm. Fully matured leaf samples from one and half year old plants of 66 accessions raised under same fertility and management condition were collected from the experimental field (DOR farm, Rajendranagar) having the following characteristics; pH 7.2, EC(dS/m) 0.25, organic carbon 3.4 g/kg, available phosphorus 16 kg/ha, available potassium 275 kg/ha. The collected leaf samples were dried, powdered and analysed for N, P and K by following the recommended procedures. Based on the nutrient concentration (%) data (Table 1), the genotypes were classified in terms of low (<u-1p), medium (u-1p to u+1p) and high (>u+1p), where u and p are mean and standard deviation, respectively (Sarkar and Deb, 1984). Crude protein per cent in the leaves was also computed.

Variation in the nitrogen, phosphorus and potassium content in the recently matured leaves was noticed among the *P. pinnata* genotypes (Table 1) although they were grown under similar soil fertility conditions. This could be due to the genotypic ability of extracting nutrients from the soil. As per the classification out of 66 *P. pinnata* genotypes, nitrogen content was low and high in seven each and medium in 52 genotypes (Table 1). Phosphorus content was found to be low in seven, medium in 56 and high in three genotypes whereas potassium content was low and high in 10 each and medium in 46 genotypes (Table 1). Thus, it was observed that majority of the genotypes have medium N, P and K content in the recently matured leaves while genotypes DORPP 27 (17° 03' N 79° 16' E) and 67 (17° 19' N 78° 24'E) have shown high N content. However, these values are much higher for N and K in comparison to earlier report (WOI, 1969) where it was 1.16 and 0.49%, respectively. The role of tree legume leaf as a green manure in increasing the N status of soils has been widely recognized. Crude protein content in the leaves varied from 14.6 to 26.3% (Table 1). Highest crude protein content was noticed in the leaves of PP 27 (26.2%) followed by 67 (26.0%). Dinesh Kumar *et al.* (2011) recently reported variation in the crude protein content in karanja seeds collected from different places in Karnataka as 14.46 to 23.09%. Present investigation further indicates that the leaves of *P. pinnata* genotypes PP 27 and 67 have shown better nutrient content for using leaves as a manure as well as feed.

Extensive studies have been undertaken by many researchers on the chemical compounds present in the leaves of karanja (Bringi and Mukerjee, 1987), however, information on the content of major nutrients is scanty. Singh (1982) reported that leaves of karanja contain 44% dry matter and 18% crude protein. Out of the 66 genotypes studies, 61 exhibited values higher than the reported value. The information generated in this study indicates the existence of variability for major nutrients among leaves of different karanja accessions. Based on better nutrient composition, DORPP 27 and 67 have been identified as the most suitable genotypes for use as green manure and livestock feed.

Table 1 Nutrient content in the recently matured leave of *Pongamia pinnata* genotypes

DOR PP genotype	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Protein (%)
26	3.52	0.12	1.45	22.0
27	**4.20**	0.10	1.29	**26.2**
29	*2.76*	*0.07*	1.37	*17.3*
30	*2.80*	0.11	**1.87**	*17.5*
31	3.19	0.08	**1.61**	19.9
32	3.27	0.12	**2.09**	20.4
33	*2.91*	0.14	1.49	*18.2*
34	3.20	0.09	1.55	20.0
35	3.54	0.18	1.47	22.1
36	3.33	0.10	1.51	20.8
37	3.38	0.09	**1.84**	21.1
38	3.31	0.12	1.27	20.7
39	**3.68**	0.09	1.55	**23.0**
40	*2.96*	0.15	1.13	*18.5*
41	3.12	0.08	1.21	19.5
42	3.31	0.12	1.42	20.7
42-1	3.45	0.11	1.31	21.5
43	3.46	0.10	1.33	21.6
44	3.25	*0.07*	1.66	20.3
45	3.49	0.13	1.41	21.8
47	3.44	0.23	**1.89**	21.5
48	3.33	*0.01*	1.46	20.8
49	**4.00**	0.08	1.33	**25.0**
50	3.36	0.13	1.19	21.0
51	3.27	0.10	1.43	20.5
52	3.34	0.10	1.01	20.9
53	*2.34*	0.09	1.26	*14.7*
54	*2.78*	0.14	1.09	*17.4*
55	3.36	0.14	1.10	21.0
57	3.29	0.16	1.48	20.6
58	3.59	0.18	1.13	22.4
59	3.54	0.15	1.12	22.1
60	3.37	0.16	1.19	21.1
61	3.60	0.14	1.24	22.5
62	3.32	0.16	1.14	20.8
63	3.45	0.15	1.31	21.6

Table 1 Contd...

DOR PP genotype	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Protein (%)
64	3.17	0.11	1.36	19.8
66	3.45	0.10	1.33	21.6
67	**4.16**	0.15	**1.65**	**26.0**
69	3.49	0.15	1.27	21.8
70	3.36	0.15	1.18	21.0
71	3.13	0.15	1.16	19.6
73	3.18	*0.06*	1.21	19.9
74	**3.78**	0.11	**1.69**	**23.6**
75	3.50	*0.07*	1.46	21.9
76	3.40	0.12	*1.06*	21.3
77	3.37	0.10	1.51	21.0
78	3.43	0.15	**1.61**	21.4
79	3.14	0.15	1.33	19.6
80	3.42	0.14	1.44	21.4
81	3.27	0.15	1.29	20.4
82	3.13	0.15	**1.73**	19.6
83	3.44	0.11	1.17	21.5
85	**3.69**	0.15	1.25	**23.1**
86	3.45	0.09	1.46	21.6
88	3.25	0.12	*0.94*	20.3
89	3.49	0.16	*1.03*	21.8
90	**3.75**	0.16	*0.94*	**23.4**
91	3.63	0.10	*0.88*	22.7
92	3.60	*0.07*	*0.99*	22.5
93	3.39	*0.07*	*1.05*	21.2
94	*2.94*	0.13	*0.99*	*18.4*
95	3.26	0.08	1.07	20.4
96	3.46	0.08	*0.99*	21.6
97	3.26	0.15	*1.05*	20.4
98	3.60	0.11	1.43	22.5
Mean	**3.37**	**0.12**	**1.33**	**21.04**
S.D	**0.30**	**0.04**	**0.26**	**1.87**
Range	**2.34-4.20**	**0.01-0.23**	**0.88-2.09**	**14.6-26.3**
Low	***< 3.07 (7)***	***< 0.08 (7)***	***< 1.07 (10)***	***< 19.17 (7)***
Medium	**3.07-3.67 (52)**	**0.08-0.16 (56)**	**1.07-1.59 (46)**	**19.17-22.91 (52)**
High	**>3.67 (7)**	**> 0.16 (3)**	**> 1.59 (10)**	**> 22.91(7)**

Nutrient per cent values of low range was shown in `italics' medium in `normal' and high in `bold'. Total number of samples in each category was shown in parenthesis.

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Biology of *Gesonia gemma* (Swinhoe) on soybean

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ABSTRACT

Studies on the biology of grey semilooper, *Gesonia gemma* were carried out in the laboratory during the rainy season of 2012. A female laid eggs from 149 to 247 (average 182 ± 36.97) on the upper surface of the soybean (*Glycine max* L.) leaves. Most of the eggs were deposited near midrib and basal part of the leaves. There were 5 larval instars, differing in colouration. Fully grown larvae measured 18.0-22.0 mm in length and 2.0-2.5 mm in width. Prolegs were present on 4th, 5th, 6th and last abdominal segment. The duration of the egg, larval and pupal periods was 2-3, 9-17 and 7-8 days, respectively. The total duration from egg to adult emergence was completed in 18-28 days. The size of the pupa was 8-9 mm in length and 1.9 to 2.1 mm in width. Female pupa was comparatively long in size than male. Medium sized moth measuring 6.0-8.0 mm body length 15.0-17.0 mm wing expanse. The longevity of adult male and female was 3 to 6 and 2 to 8 days, respectively.

Key words: Biology, Grey semilooper, Laboratory studies, Soybean

Soybean (*Glycine max* L.) is one of the most important pulse crops in Madhya Pradesh. Among the various factors responsible for the low yield, the insect pests have been considered to be of prime importance. The grey semilooper, *Gesonia gemma* (Swinhoe) was observed for the first time during the rainy season of 1984 (Singh, 1987). It has become a serious and regular defoliator of soybean in Madhya Pradesh and causes maximum damage in the month of September, which inflicts significant reduction in pod number, pod weight, grain number and grain weight, resulting loss of grain 3.94 q/ha (Singh and Singh, 1989). Owing to the lack of detailed information on the life cycle of this pest and to obtain basic ecological information which might prove useful for the integrated pest management programme against this pest on soybean.

The study was conducted during August to October 1st week, 2012, when the average maximum and minimum temperature and relative humidity were 28.02ºC and 21.08ºC and 95.48%, respectively in the laboratory of entomology department, RAK College of Agriculture, Sehore. For the study of biology mass collection of larvae of *Gesonia gemma* was made from the untreated fields of soybean and reared in laboratory. Ten pairs of newly emerged adults were released into glass chimneys containing cotton swabs soaked with 10% sucrose solution and a fresh twig of JS-335 variety having tender leaves for egg laying. Observations were recorded on pre-oviposition, oviposition, fecundity of female and longevity of moths. The egg laying was observed within 3-5 days. The eggs were transferred in to petridishes having tender leaves of soybean with the help of brush. After hatching the eggs, larvae were reared individually in petridishes with food. Observation on developmental period and feeding behaviour of larvae and general character of larval instars, pupa and adult was recorded.

Biology

Egg: Pre-oviposition period ranged from 3-4 days with an average of 2.5±0.61 days. Egg laying was observed at night but some times it was observed during day time also. A female laid eggs from 149 to 247 (average 182 ± 36.97) on the upper surface of the leaves. Some times egg laying was also noted on the dorsal surface of the leaves. Most of the eggs were deposited near midrib and basal part of the leaves. Female moth preferred upper leaves which are green and very succulent. Freshly laid eggs are creamy white, spherical and measured 0.30 to 0.40 mm in diameter. Before hatching eggs changed into light brown. The incubation period was 2-3 days with an average of 2.8±0.42 days. Earlier Singh and Singh (1990) also reported that the female moth of *Rivula* species invariably oviposited eggs individually on ventral surface of leaves. They also reported that the preference for oviposition for middle portion may be attributed to highly green and succulent leaves in this portion in comparison with the apical and basal portions.

Larval instars and their duration: The larvae moulted four times and five larval instars were observed. First instar larvae pale white and within 2nd day change to light green. Thoracic and abdominal legs are formed but not developed well. No newly hatched larvae feed on green matter of leaves. The length and width of 1st instar larvae measured 0.9-2 mm (average 0.94±0.041 mm) and 0.03-0.05 mm (average 0.03 ± 0.008 mm). The larval duration of first instar ranged from 1-2 days (average 1.7±0.48 days). Second instar larvae was light yellow green measuring about 3-7 mm in length (average 6.5±1.17 mm) and 0.08-1.00 mm in width (average 0.26±0.38mm) and head capsule change into yellowish with 0.33 mm in width. Abdominal segments were clearly visible. Prolegs were present on 4^{th}, 5^{th}, 6^{th} and last abdominal segment. Larvae was capable to move by making semilooper of his body. The stage lasted for 2-4 days with an average of 2.9±0.56 days. Third instar larvae measured 10-12 mm (average 11.1±0.87 mm) in length and 1.0 to 1.4 mm (average 1.2±0.10 mm) in width. The larval body was light green with light yellow head capsule. All the body segments particularly head, abdomen and thorax was clearly developed and visible. The larvae moulted with 2-4 days (average 3.0 ± 0.66 days). The larvae consumed the soft leaves with making small holes. Freshly moulted fourth instar larvae measured 13-15 mm (average 13.6±0.84 mm) in length and 1.4-1.6 mm (average 1.48±0.06 mm) in width. The larval body was light green with light yellow head capsule. In this stage larvae consumed complete leaves leaving veins and leaves become skeletonised. The total duration of fourth instar larvae was 2 to 4 days with an average of 2.8±0.63 days. Fifth instar larvae was 16-20 mm in length and 1.8-2.0 mm in width with head capsule 1.80 mm in width. Body colour of the larvae was light green and head capsule was light shining brown. Two longitudinal parallel pale white lines were present on dorsolateral potion of the body. Three longitudinal lines were joint with transverse white lines in thorasic and abdominal segments. The brownish green thorasic legs were well developed, prothorasic and anal shield was light greenish brown. Larval feeding habit was similar to fourth instar larvae. The fifth instar larvae become full grown within 2-3 days (average 2.6±0.51 days). Total larval period was 9-17 days with an average of 13.0±2.84 days. Shrivastava *et al*. (1999) also reported the larvae of *Rivula* sp. moulted four times and total larval period was 19.2±0.33 days.

Pupa: The full grown larvae within 2-3 days stopped feeding and formed white silky cocoon on surface of the leaves. Most of the cocoon was formed on lower side of the leaves. Freshly formed pupa was green and within 2 days changed into dark brown. The size of the pupa was 8-9 mm in length and 1.9 to 2.1 mm in width. Female pupa was comparatively long in size than male. Pupal period ranged from 7-8 days with an average of 7.9±0.56 days. Where as Shrivastava *et al*. (1999) reported that pupal period was 5.94±0.05 days.

Adult: Medium sized moth measuring about 6.90±0.32 mm body length and 16.30±1.30 mm wing expanse. Fore wings were brown with three grey transverse bands and two dark encircled spots. Hind wings were transparent brown. The margin of hind wing is dark. Longevity of male and female was 3 to 6 and 2 to 8 days, respectively. The total duration from egg to adult emergence was completed in 18-28 days with an average of 20.9±3.40 days. Earlier Shrivastava *et al*. (1999) reported that the green semilooper completed one cycle from egg to adult within 22.14 days on soybean.

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Efficacy of different fungicides on incidence of *Alternaria* leaf spot of sesame (*Sesamum indicum* L.)

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ABSTRACT

A field experiment was conducted on sesame (*Sesamum indicum* L.) during rainy seasons of 2008 to 2010 at Agricultural Research Station, Mandor-Jodhpur (Rajasthan) to find out the effect of foliar sprays on incidence Alternaria leaf spot of sesame. The studies revealed that the fungicide foliar spray of Carbendazim + Iprodione @ 0.1 %, Carbendazim + Mancozeb @ 0.2% and Propiconazole @ 0.1% were found highly effective and economical for the management of the disease.

Key words: Alternaria leaf spot, Efficacy, Foliar spray, Sesame

Sesame (*Sesamum indicum* L.) is the indigenous oilseed crop cultivated in India with the largest area (29.3%), maximum production (25.8%) and highest export of its seeds (40%) in the world. *Alternaria* leaf spot (*Alternaria sesami*) is an economically serious disease of sesame and is increasing year after year in Jodhpur region of Rajasthan. The disease attacks all the plant parts and causes great loss in yield. Field experiment was conducted in randomized block design with nine treatments and four replications on sesame during rainy seasons of 2008 to 2010 at Agricultural Research Station, Mandore-Jodhpur (Rajasthan) to find out the effect of different fungicides as foliar sprays on incidence *Alternaria* leaf spot of sesame. Sesame variety RT 127, was sown in the month of July with plot size of 3 m x 2.4 m. The conidial suspension was sprayed in the evening. On the following day the crop was sprayed with water to provide favourable humidity for infection (Rajpurohit, 2004). Fungicides were sprayed twice starting from initial appearance of the disease at an interval of 15 days. The disease incidence was recorded 10 days after last spray in 0-5 scale (Rajpurohit, 1993). The studies on efficacy of fungicide foliar spray on incidence of diseases results showed that all the treatments were found significantly superior to reduce *Alternaria* leaf spot over control. Three years pooled analysis data (Table 1) revealed that minimum incidence of *Alternaria* leaf spot (4.01%) and highest seed yield (691 kg/ha) was observed in foliar spray of Carbendazim + Iprodione @ 0.1 % followed by Carbendazim+ Mancozeb (PDI 4.68% yield 674 kg/ha) and Propiconazole (PDI 5.93%, seed yield 658 kg/ha). In earlier studies, Rajpurohit *et al.* (1984) reported Mancozeb fungicide as highly effective against *Alternaria sesami in vitro.* Rajpurohit *et al.* (2005) also reported field efficacy of foliar sprays. In earlier studies, efficacy of combi products were not tested against this disease. Present studies shows that combi products *viz.* Carbendazim + Iprodione @ 0.1% and Carbendazim + Mancozeb @ 0.2% and Propiconazole @ 0.1% are highly effective and economical against *Alternaria* lead spot, hence, it can be recommended for management of the disease in sesame.

Table 1 Efficacy of foliar spray on incidence of foliar diseases

Treatment	*Alternaria* leaf spot (PDI)				Seed yield (kg/ha)				BC ratio
	2008	2009	2010	Mean	2008	2009	2010	Mean	
Carbendazim 50 WP (0.1 %)	11.20 (19.49)	8.2 (16.58)	8.1 (16.50)*	9.2	861	140	826	609	2.23
Chlorothalonil (0.2%)	11.10 (19.39)	7.4 (15.71)	8.6 (16.95)	9.03	840	142	795	592	0.99
Copperoxychloride 0.25% + Streptocycline 0.01%	13.20 (21.23)	10.0 (18.36)	9.6 (17.99)	10.93	826	100	808	578	1.08
Mancozeb (0.2%)	6.60 (14.77)	7.0 (15.29)	7.4 (15.73)	7.0	889	150	833	624	3.34
Propiconazole (0.1 %)	6.00 (13.93)	6.2 (14.22)	5.6 (13.61)	5.93	917	162	895	658	2.32
Wettable Sulphur (0.2%)	14.20 (22.08)	12.4 (20.47)	13.8 (21.77)	13.46	797	86	708	530	1.18
Carbendazim + Iprodione @ 0.1%	4.80 (12.46)	4.0 (11.29)	3.45 (10.47)	4.08	923	180	972	691	3.07
Carbendazim+ Mancozeb (0.1%)	5.00 (12.64)	5.75 (13.61)	4.30 (11.85)	4.68	893	172	958	674	2.47
Control	21.50 (27.49)	17.6 (24.52)	26.95 (31.74)	22.01	741	75	665	493	-
SEm ±	1.85	1.39	1.36		36	16	45.84		
CD (P=0.05)	3.78	4.01	3.97		104	46	133.8		
CV (%)	14.53	17.07	15.65		8.4	17.0	11.05		

*Angular transformation value

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Evaluation of single and three way hybrids of sunflower (*Helianthus annuus* L.) for *Alternaria* leaf blight

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ABSTRACT

A field experiment was conducted at Dharwad, Karnataka, India during the rainy season of 2006 to record the degree of incidence of *Alternaria* leaf blight in single and three way hybrids of sunflower (*Helianthus annuus* L.) under natural epiphytotic conditions at days to 50 % flowering and physiological maturity. The parental lines CMS 17 A, CMS 103 A, DCMS 51 A and R 64 were moderately resistant to leaf blight. The resistant reaction in two single (CMS 17 A x RHA 6D-1 and CMS 17 A x RHA 271) crosses was noticed when atleast one of the parents in the cross combination had moderate resistant reaction. Three way crosses even after diversification with inbred lines concerned has not yielded resistance over corresponding single cross hybrids. However, inclusion of inbreds DSI 2 and DSI 1017 which were moderately resistant as third parent in hybrid combinations of 103 A x DSI 2 x R 64 and DCMS 51 A x DSI 1017 x RHA 6D-1 ended up with resistance reaction with 2 and 4 grade, respectively. Hence, diversification may either improve or reduces resistance levels of three way crosses indicating that caution is to be exercised in selecting the parents for hybridization as well as the second parent for diversification.

Key words: Alternaria, Sunflower hybrids

Sunflower (*Helianthus annuus* L.) is an important oilseed crop incited by different fungal diseases like leaf blight, rust, downy mildew and head rot. Leaf blight caused by *Alternaria helianthii* is a serious potentially destructive disease and widely distributed wherever the sunflower crop is grown (Carson, 1985). Yield loss of more than 80% under severe disease condition were reported by Hiremath *et al.* (1990). Present day cultivated single cross hybrids were almost susceptible this fungus and hence a study has been attempted to know whether diversification of single cross hybrids by incorporation of third parent in this aspect will be useful or not.

The experimental material for the present study consists of CMS lines (5), restorer lines (6), inbreds (4), single cross hybrids (30), three way cross hybrids (15) and checks (3) as enlisted in table 1 were evaluated in randomized block design in three replications during the rainy season of 2006. The parents, inbreds, single and three way hybrids were treated as separate entities and randomization was done within each entity using random number table. All other recommended agronomic practices were followed to raise successful experimental crop. The disease severity was assessed on plot basis of each genotype/replication at days to 50% flowering and at physiological maturity using 0-9 scale of Mayee and Datar (1986). The genotypes were classified into following four groups as given below with little modifications (Nagaraju *et al.*, 1992) as none of the genotype was either immune or highly resistant.

2-5 : Resistant 5-7 : Moderately resistant

7-8 : Susceptible 8-9 : Highly susceptible

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The rainfall during crop season encourages, the incidence of *Alternaria* leaf blight. It was observed to be severe as some of the parents and hybrids recorded 9 grade. The lines CMS 17 A and DCMS 51 A found to be moderately resistant with grades 5 or 6 for the incidence of *Alternaria* leaf blight. The testers found to be highly susceptible except R-64, which recorded moderate resistance (6 grade). Out of 30 single cross hybrids evaluated, only two hybrids CMS 17 A x RHA-6D-1 and CMS 17 A x RHA-271 expressed resistance with grades 3 and 4, respectively. While CMS 17 A x RHA-95-C-1, CMS 17 A x R-64, CMS 17 A x RHA-272 and DCMS 51 A x R-64 expressed moderate resistance (5 to 6 grade) and were on par with the check hybrids KBSH-44 and GK-2002. However, rest of the hybrids showed either susceptible or highly susceptible reaction. The results on the incidence of *Alternaria* in respect of single and three-way crosses revealed that CMS 103 A x R 64 (4 grade) and DCMS 51 A x RHA-271 (7 grade) have shown resistant and susceptible reaction while its three-way crosses after diversification with DSI-2 and DSI 1017 have shown resistant reaction with lower grades such as 2 and 4, respectively. Increases in susceptibility from resistance reaction due to diversification was seen in three-way hybrids CMS 103 A x DSI-1 x R-64 and CMS 103 A x DSI-1005 x R-64 (7 grade) while its single cross has only 4 grade. The single crosses with respect to CMS 17 A x RHA-95-C-1 (KBSH-44), CMS 4546 A x R-298 (DSH-1) and CMS 234 A x RHA-6D-1 (KBSH-1) and corresponding three-way crosses after diversification were almost similar in their reaction exhibiting susceptibility.

Table 1 *Alternaria* leaf blight scoring in parents, inbreds, single and three way hybrids of sunflower

Genotype	*Alternaria* incidence (0-9) scale	
	At 50 % lowering	At physiological maturity
CMS line		
CMS 234 A	4	9
CMS 4546 A	2	9
CMS 103 A	2	6
CMS 17 A	3	6
DCMS 51 A	2	5
Restorer line		
RHA-6D-1	5	9
RHA-95-C-1	5	9
R-298	4	8
R-64	2	6
RHA-271	3	8
RHA-272	4	9
Inbreds		
DSI-1	2	6
DSI-2	1	4
DSI-1005	2	5
DSI-1017	2	6
Single and three way hybrid		
CMS 234 A x RHA-6D-1	3	8
(CMS 234 A x DSI-2) x RHA-6D-1	2	7
(CMS 234 A x DSI-1017) x RHA-6D-1	3	8
CMS 234 A x RHA-95-C-1	2	8
CMS 234 A x R-298	3	8
CMS 234 A x R-64	3	7
CMS 234 A x RHA-271	3	9
CMS 234 A x RHA-272	3	9
CMS 4546 A x RHA-6D-1	2	8
CMS 4546 A x RHA-95-C-1	3	8
CMS 4546 A x R-298	2	9
(CMS 4546 A x DSI-1017) x R-298	3	7
CMS 4546 A x R-64	2	7
CMS 4546 A x RHA-271	1	8
CMS 4546 A x RHA-272	2	9
CMS 17 A x RHA-6D-1	2	3
CMS 17 A x RHA-95-C-1	2	5
(CMS 17 A x DSI-1) x RHA-95-C-1	2	7
(CMS 17 A x DSI-2) x RHA-95-C-1	2	6
(CMS 17 A x DSI-1005) x RHA- 95-C-1	2	7
(CMS17 A x DSI-1017) x RHA- 95-C-1	2	7
CMS 17 A x R-298	1	7
CMS 17 A x R-64	2	6
CMS 17 A x RHA-271	1	4
CMS 17 A x RHA-272	2	5
CMS 103 A x RHA-6D-1	2	8
CMS 103 A x RHA-95-C-1	3	8
CMS 103 A x R-298	3	8
CMS 103 A x R-64	2	6
(CMS 103 A x DSI-1) x R-64	2	7
(CMS 103 A x DSI-2) x R-64	1	2
(CMS 103 A x DSI-1005) x R-64	2	7
(CMS 103 A xDSI-1017) x R-64	1	5
CMS 103 A x RHA-271	2	9
CMS 103 A x RHA-272	3	8
DCMS 51 A x RHA-6D-1	3	6
(DCMS 51 A x DSI-1017) x RHA-6D-1	2	6
DCMS 51 A x RHA-95-C-1	2	6
(DCMS 51 A x DSI-1017) x RHA-95-C-1	2	7
DCMS 51 A x R-298	2	8
DCMS 51 A x R-64	2	5
(DCMS 51 A x DSI-1017) x R-64	2	5
DCMS 51 A x RHA-271	2	8
(DCMS 51 A x DSI-1017) x RHA-271	2	4
DCMS 51 A x RHA-272	2	8
Checks		
KBSH-1	4	9
KBSH-44	2	5
GK-2002	2	5

Among CMS lines, CMS 17 A, CMS 103 A and DCMS 51 A and one restorer line R-64 among restorers have shown moderate resistance to Alternaria with scores 5 or 6, while rest of the parents recorded high degree of susceptibility (8 and 9). Among the hybrids, the cross combination of CMS 17 A (A line of KBSH-44) and RHA-6D-1 (R lines of KBSH-1) has recorded resistant reaction (3 grade), although RHA-6D-1 (9 grade) is found highly susceptible. Thus, different alleles are involved in the inheritance of *Alternaria* (Kong *et al.,* 1996 and Garcia *et al.,* 2003). A similar degree of resistance has also been noticed in CMS 17 A x RHA-95-C-1 (5 grade) and CMS 17 A x RHA-272 (5 grade) in which A line has shown moderate resistance. The cross combination CMS 17 A x R-64 (5 grade) where both A and R lines show moderate resistance has also transgressed into hybrids with similar or lesser degree of susceptibility supporting the view that alleles are common between the parents involved in the hybrids. In none of the cases, parents with higher susceptible reaction resulted in a resistant hybrid. The present study clearly indicates that it is possible to synthesize hybrids with reasonable degree of resistance by involving atleast one or both the parents showing moderate resistance. The extent of resistance however, can be enhanced when allelic differences exists between the parents and by subjecting above crosses to recurrent selection (Ravikumar *et al*., 1995 and Shobharani, 2003). The works in the detection of *Alternaria* resistance is quite meager in sunflower because of lack of resistance in the entire world collections. Further, tolerance to Alternaria is reported to exhibit differential reaction with the environment (Nagaraju *et al.,* 1992). Therefore in the absence of high level of resistance to *Alternaria*, there is no option but to involve parents with moderate tolerance in hybrid combinations as has been evidenced in some of resistant hybrids to maintain similar level of resistance.

The three-way crosses even after diversification with inbred lines concerned has not yielded resistance over corresponding single cross hybrids in most of the cases. However, inclusion of inbreds DSI-2 and DSI-1017 in hybrid combinations of RSFH-1, where parents involved also exhibited moderate resistance have ended up with resistant three-way crosses CMS 103 A x DSI-2 x R-64 (2 grade) and DCMS 51 A x DSI-1017 x RHA-6D-1 (4 grade). This indicates that one of the parents in the cross must invariably be moderate resistant one in order to get resistant three-way cross after diversification with a suitable second parent. It is also evident that increases in the susceptibility from resistance due to diversification as seen in respect of three-way hybrids CMS 103 A x DSI-1 x R-64 and CMS 103 A x DSI-1005 x R-64. Thus, diversification may either improve or reduce resistance levels of three-way crosses indicating that caution is to be exercised in selecting parents for hybridization as well as the second parent for diversification.

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Critical analysis of extension and research gap in adoption of groundnut (*Arachis hypogaea* L.) production technology in Dharwad district, Karnataka

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ABSTRACT

A research study on critical analysis of extension and research gap in groundnut (*Arachis hypogaea* L.) production technology among the farmers of Dharwad district was conducted during 2010-2011. The Ex-post-facto research design was employed to collect the data from 150 sample farmers cultivating groundnut crop. The focus group discussions were also conducted for the triangulation of the collected data. The results revealed the existence of technological gap in zinc application (84.5%), Rhizobium seed treatment (79.3%), control of diseases (67.4%) and gypsum application (51.9%). The major extension strategies expressed were the ensured availability of critical inputs nearby villages at the required time of field operations (100%), popularizing seed production (84.5%), implementing effective extension programmes (81.5%), and information dissemination through electronic media and extension literature (63.7%). All the farmers expressed the research priorities such as screening of suitable spreading, high yielding, collar rot resistant, drought tolerant and table purpose varieties. The suitable seed drill to take up groundnut sowing in paddy fallow land through moisture conserving, popularising green pod harvester and technology for controlling collar rot disease were the other research priorities expressed for increasing area and productivity of groundnut crop.

Key words: Extension and research gap, Groundnut, Karnataka, Technological gap

Groundnut (*Arachis hypogaea* L.) being an important oilseed crop of Dharwad district covers an area of around 36,000 to 37,000 ha both in rainy and winter/summer seasons of the total oilseed area of around 50,000 ha. At present the productivity levels are fluctuating at 5.0 to 6.0 q/ha. against the state average productivity of around 8.00 q/ha whereas, demonstration yields are around 16-18 q/ha. This shows that there is a wide gap in productivity of groundnut crop on farmers' fields. Hence, there is a need to divert concerted attention in understanding the existing cultivation practices amongst the farmers of Dharwad district. In view of this, the present study has been formulated to analyse the gap in adoption of recommended practices in groundnut cultivation amongst the farmers.

Ex-post-facto research design has been employed for the study. Covering the three agro-climatic situations and diversity of soil and other climatic parameters of the district, 15 villages which were predominantly groundnut growing were selected. Ten farmers from each village were selected to constitute a total sample of 150 growers for the study. By discussing with the experts, extension officers and progressive farmers, interview schedule was developed with important components of groundnut production technology.

The required data were collected through personal interview method. The participatory methods such as focus group discussion was also conducted for the triangulation of collected data. After final verification of the data, it was possible to get 135 completed schedules.

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Keeping in view of the importance of recommended groundnut cultivation practices and in consultation with the scientists of the groundnut crop, field extension workers and experienced farmers adoption of the recommended groundnut production technology was measured by taking into consideration 13 items *viz*., sowing time, spacing, HYVs, seed rate, seed treatment, application of organic manure, use of vermin compost, fertiliser use, micronutrient use, pest/disease/weed management and harvesting. Accordingly the different formats and patterns of questions were framed in the schedule. The well structured interview schedule was developed by consulting the scientists and extension officers working in the area of groundnut crop research and field extension. The developed schedule was tested for validity and reliability in the non sample area. Thus, the schedule was employed for collection of required information from the selected sample farmers. The focus group discussion was also conducted for the triangulation of the collected data. The collected data were tabulated and the simple statistical tools such as frequency, percentage and mean were used for analysis. Interpretation was made in consultation with the scientists, extension workers and progressive farmers. The results have been presented under the broad categories *viz*., (I) existing groundnut cultivation practices amongst the farmers, (ii) assessing the technological gap in adoption of these individual practices, (iii) the reasons for the gap in adoption, (iv) extension strategies for strengthening the capacity of farmers, and (v) the identified research priorities to improve productivity and area under groundnut cultivation.

Based on the significance of recommended cultivation practices and their importance in improving the groundnut productivity, the results as presented in table 1.

The critical analysis of the felt extension strategies reveals that all the sample farmers expressed the need for ensured availability of critical inputs at nearer places at required time of field operation (Table 2). Similarly, a high percentage of farmers expressed the need for popularising seed production programme in the villages and focus on updating the knowledge of farmers at critical stages of crop cultivation through effective demonstrations, group meetings, and field trainings.

The need for identifying educated and cooperative farmer in the village who can guide the other farmers and act as information source, and the need for more publicity of the package of practice through electronic media, posters, extension literature with a focus on pictorial presentation were also expressed by farmers (Table 2).

Table 1 Technological gap in adoption of recommended cultivation practices in groundnut among the farmers of Dharwad district (n=135)

Item of package	Existing practice among the farmers		Farmers noticed in technological gap (TG)		Reason for the TG
	Details	Extent of adoption	Full TG	Partial TG	
Sowing: time	June 2nd week to July end	135 (100.00)	-	-	-
	Dec end to Jan 2nd week/Jan end	135 (100.00)	-	-	-
Spacing	15"- 18" for the best soils	56 (41.48)	-	56(41.48)	* More spacing in fertile soil will increase the yield (75-100 Kg/ha) * Scope for taking up intercrop
	12"	79 (58.52)			
Varieties: Rainfed	GPBD-4, TMV-2, JL-24	119 (88.15)	16(11.85)	-	* Non availability of seed * Time constraint * Inability to purchase
	Local seed	16 (11.85)			
Irrigated	GPBD-4, TMV-2, JL-24	135 (100.00)	-	-	-
Seed rate (kg/ ha)	K: 75-90	47 (34.82)	-	47(34.82)	* Fertile soil * More vegetative growth
	K: 110-125	88 (65.18)	-	-	-
	S: 80-100	79 (69.05)	-	29(69.05)	-
	S: 140-150 Two way sowing	13 (30.95)	-	-	-
Seed treatment	Dry coating of *Rhizobium*	28 (20.74)	107(79.26)	-	* Time constraint * Fear of seed coat damage * Problem of seed flow in the seed drill
	Trichoderma, PSB 5-6gm	48 (35.55)	87(64.45)	48(35.55)	* Not aware of the recommendation * Not convinced of the technology
Organic manure (t/ ha)	4-5 tonnes once in 2-3 years for rainfed and every year for irrigated lands	86 (63.70)	-	135(100.0)	* Non availability of quality FYM * Costly to apply
	1 tonne once in 2-3 years	49 (36.30)			
	FYM applied plot will not be used for groundnut cultivation during rainy season	117 (86.67)	-	-	* Problem of termites, sclerotium rot
Vermicompost (t/ha)	0.50 to 0.75	8 (5.90)	127(94.10)	8(5.90)	* Not producing on their farm * Costly to purchase * Nonavailability of quality vermicompost

Table 1 (Contd...)

Fertilizer (kg/ha)	Basal: 23-58-0 NPK Top dress (30-35 DAS): 50-60 N	65 (48.15)	-	135(100.00)	* Usual practice * Not aware of and not convinced of the recommendation * Mixing of potash fertiliser leads to softening and watery of fertiliser mix
	Basal: 15-35-0 NPK Top dress (30-35 DAS): 25-30 N	18 (13.33)			
	Basal: 28-28-28 NPK Top dress (30-35 DAS): 25-30 N	21 (15.55)			
	Basal: 23-58-0 NPK Top dress (30-35 DAS):25-25-25 NPK	31 (22.76)			
Micro nutrient application	100-150 kg gypsum	28 (20.74)	70(51.86)	53(39.26)	* Not possessed the knowledge * Not convinced of the practice
	250-375 kg gypsum	25 (18.52)			
	500 kg gypsum	12 (8.88)			
	12.50 kg Zn	21 (15.55)	114(84.45)	21(15.55)	
Pest management	Monocrotophos 1-2 ml or Quinalphos 2-3 ml : one spray for sucking pests, leaf miner	92 (68.15)	25(18.52)	110(81.48)	* Usual practice * Not knowing the recommendation * Less incidence of pests
	Monocrotophos 1-2 ml or Chloropyriphos 2.5 ml: 2 sprays	18 (13.33)			
	Handpicking of root grub	28 (20.74)	-	-	
	Use of Phermone traps	15 (11.11)	-	-	
Disease management	Bavistin 0.5-1.0 g/ltr	26 (19.25)	91(67.42)	44(32.58)	* Not knowing the recommendation
	Mancozeb 2.5-3.5 g/ltr	18 (13.33)			
Weed management	- Mechanical : 2-3 number of intercultivation	135 (100.00)	-	-	-
	- Herbicide	-	135(100.0)	-	* Not required * Costly * Residual effect

Figures in the parentheses indicate the percentage

Table 2 Identified extension strategies for strengthening the capacity of farmers

(n=135)

Extension strategy	Response
Ensured availability of critical inputs at nearby places at required time of field operation	135 (100.00)
Popularising seed production programme in the villages	114 (84.45)
Focus on updating the knowledge of farmers at critical stages of crop cultivation through effective demonstrations, group meetings, field trainings, and supply of extension literature	110 (81.48)
Identifying educated and cooperative farmer in the village who can guide the other farmers and act as information source	92 (68.15)
More publicity of the package of practice through electronic media, posters, extension literature with a focus on pictorial presentation	86 (63.70)

Figures in the parentheses indicate the percentage

Keeping the limitations in adopting the recommended production technology, the research priorities were finalized in Research -Extension- Farmer linkage meetings conducted in the village. The results reveals that the research priority for screening of suitable spreading, high yielding, collar rot resistant and drought tolerant varieties for different locations of the district was identified due to short fall of moisture during critical stages of crop growth. Similarly, the need for developing and/or screening table purpose varieties was expressed due to demand for export and local consumption which fetches higher price than oil crushing.

Since, the summer groundnut cultivation in paddy fallow land in Zone IX was the popular practice and the farmers experience that the usual practice of land preparation will deplete the moisture for taking up summer groundnut, it was felt that a suitable seed drill need to be designed so that moisture can be conserved for taking the advantage of existing soil moisture. Similarly, the farmers expressed the problem of drying harvested groundnut crop which is required for removing pods. The farmers suggested the research need for designing and fabrication and/popularising green pod harvester to pluck pods from the green plants so that farmers will be free of post harvest problem and motivate them to increase area under groundnut cultivation. Lastly, the groundnut growers expressed that if the harvesting coincides with rainfall, the problem of collar rot incidence may cause pod loss of 30-50% and because of this the groundnut cultivating area year by year is declining to the extent of 40-50%. Hence, immediate research is required to develop technology for effective management of collar rot.

Similarly, the research study conducted by Reddy *et al*. (2012) suggested for improved varieties with attributes like drought tolerance, high oil content, high productivity for large-scale seed multiplication and distribution by public and private agencies, viable village seed banks and seed networks through cycles of post-rainy season seed multiplication to meet the seed requirements in the rainy season and vice versa and adoption of low-cost technologies to increase profitability and reduce risk by the groundnut growers.

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Constraint analysis of the farmers on climate variability in castor (*Ricinus communis* L.)

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ABSTRACT

Castor (*Ricinus communis* L.) is cultivated extensively in Mahaboobnagar district of Andhra Pradesh because of the commercial importance of its oil. The area and production of castor in Mahaboobnagar is gradually decreasing for which one of the most important reasons is the high incidence of *botrytis* greyrot disease due to conducive climate variations. Apart from this, the frequent droughts in the region also influence in reduction of area. Keeping this in view the present study was carried out to understand the problems and suggestions as perceived by farmers on adaptation to climate variability in castor. The results indicated that high incidence of *botrytis* disease in rainy season, lack of training on climate variability coping mechanisms were some of the problems. Development of cultivars resistant to *botrytis* disease with short stature and profuse branching, providing training to farmers and extension officials on techniques of crop production and adaptation options to face the climate variability in castor were some of the perceived suggestions. Based on the results a strategy was developed to enhance the adaptability of castor farmers towards climate variability.

Key words: *Botrytis*, Castor, Climate variability

Castor (*Ricinus communis* L.) is an important non-edible oilseed crop in the Mahaboobnagar district of Andhra Pradesh state. The area under castor cultivation in Mahaboobnagar is 90.25 mt and the productivity is 733 kg/ha (India stat.com 2010-2011). The area under castor in Mahaboobnagar district is decreasing due to frequent droughts, high incidence of *botrytis* and competitive crops like Bt Cotton and Maize. The humid and cloudy weather during cyclonic showers during September-November, when the rainy season sown castor is in flowering and at capsule formation stage often affects the spikes with fungal disease (*botrytis*). The major limitation of crop is *botrytis* grey rot which is threatening crop's continuance in the district. High temperature above 41°C at flowering time even for a short period result in occurrence of male flowers lead to poor seed set. Thus, current focus is oriented towards mitigation of the problems like *botrytis* and drought tolerance. Keeping this in view, the present study was conducted to understand the problems and suggestions of castor farmers on adaptation to climate variability in castor.

Mahaboobnagar district of Telangana region of Andhra Pradesh state was selected and an ex-post facto research design was followed in the present investigation. Four manadals and three villages from each mandal making a total of 12 villages were selected at random. The selected villages were Shettipally, Akuthotapally and Jangireddypalli from Amanagal manadal; Nagaram, Dokur and Marrikal from Deverakadra manadal; Gangaram, Boyapally and Mahadenpet from Bejenepally mandal; while Chitlankunta, Macharam and Padara were selected from Amrabad manadal. From each selected village, 10 castor farmers were chosen by random sampling method, making a total sample size of 120. Data were collected from the respondents on the problems in adaptation to climate variability in castor and suggestions to overcome the same. Suitable standard statistical tools are used for analysis of data

The results indicated that the problems perceived by farmers related to research were high incidence of *botrytis* disease in rainy season (95% of the respondents). This was probably due to humid and cloudy weather during cyclonic showers in September-November when the rainy season sown castor is in flowering and capsule formation stage. The farmers' suggestion was to develop cultivars resistant to *botrytis* disease with short stature and profuse branching. Varieties like Jwala and Kiran show moderate tolerance to the disease. The second constraint expressed by 83 % of the respondent was lack of drought mitigation strategies in castor crop. The suggestion given by the farmers was to work out suitable strategy/contingency plan by the researchers to minimise the effect of drought in castor. The last constraint expressed by 67% of the respondent was less relevance of weather forecasting data to cope-up the climate variation (Gwimbi, 2009). Hence, the location specific weather information has to be provided (Table 1).

The extension related problems were lack of awareness on *botrytis* tolerant varieties as perceived by 86 % of the respondents. This may be due to poor exposure of extension, which led to less awareness on *botrytis* management. The

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suggestion offered was to create awareness among the farming community on availability of varieties such as Jwala and Kiran, which can tolerate *botrytis* disease. More demonstrations may be conducted to show the value and worth of these varieties along with other management practices in order to compare with the traditional varieties which are highly susceptible to *botrytis*. The second constraint as expressed by 85% of the respondent was non availability of seeds of *botrytis* tolerant varieties on time, even though they want to purchase seeds of such varieties to adopt as a strategy for adaptation to climate variability. The suggestion given by farmers was to produce seeds of the varieties, which are tolerant to *botrytis* disease and made available to farmers on time. This was followed by lack of effective advisory system on variability in climate (83%). The suggestion offered was to develop an integrated mechanism with the coordination of Agriculture University, Department of Agriculture, NGOs (Non Government Organizations) and private organizations to provide an effective advisory system and to counsel the farmers on various issues pertaining to the climate variability and measures to overcome the same. (Table 2).

Table 1 Research problems perceived by the castor farmers in adaptation to climate variability in castor

Problem	Frequency and %	Rank
High incidence of *botrytis* disease in rainy season	114 (95%)	I
Lack of drought mitigation strategies in castor crop	100 (83%)	II
Absence of suitable rain water harvesting structures	84 (70%)	III
Less relevance of weather forecasting data to cope up the climate variability	81 (67%)	IV

Table 2 Extension problems perceived by the castor farmers in adaptation to climate variability in castor

Problem	Frequency and %	Rank
Lack of awareness on *botrytis* tolerant varieties	103 (86%)	I
Lack of group action to follow the biological control measures on castor pests	91 (75%)	V
Lack of information pertaining to adaptation options to cope up the climate variability	92 (76%)	IV
Lack of availability of seeds of *botrytis* tolerant varieties	102 (85%)	II
Lack of sufficient technical guidance on micro irrigation	79 (65%)	VI
Lack of effective advisory system on changes in climate	100 (83%)	III

In institutional related problems, lack of training on climate variability coping mechanisms was the most important problem as mentioned by 89% of the respondent; this was probably due to lack of awareness about the training programmes conducted by various agencies among the farmers. The suggestion offered was to give training to farmers and extension officials on techniques of crop production and adaptation options to face the climate variability in castor crop. These trainings may be offered at local, national and international level to address various issues on climate variability. This was followed by lack of guidance on insuring the crop against the climate variability (82%). Crop insurance is one of the important inputs for adaptation to climate variability for the farmers in the state where adverse impact of climate variability reduced the production and also sometimes resulted in total loss of the crops (Pynbianglang Kharumnuid, 2011). Farmers suggested that an institutional arrangement may be established by the government with the banks to insure the castor crop against the weather extremes. The third constraint expressed by 81% of the respondent was frequent interruptions in power supply (Nagabhushana, 2007). Farmers suggested that government has to provide seven hours of continuous uninterrupted power supply to irrigate the crop for better crop production (Table 3).

The natural related problems, declining ground water was the most important problem as mentioned by 74% of the respondents. They offered to adopt corrective measures at farm level to store the rain water as well as *in situ* moisture conversation for sustenance of moisture content in the soil. The establishment of rain water harvesting structure at individual farms may recharge the water table in the ground. This was followed by poor soils of the region (72%) for which farmers believed that sensitization on application of organic material in the form of manures, cakes, powders, compost, bio fertilizers would be needed. These will improve the soil fertility by enriching the nutrient content in the soil (Table 4).

A strategy was developed based on the results/ responses of castor farmers for better adaptability towards climate variability in castor. The strategy includes the interventions to be taken up by the research, extension system, at government level, at community level and at individual level.

- Evolving strategic and integrated control measures of *botrytis* disease in rainy season castor as well as in winter season castor also.
- Organizing frequent training programmes for farmers on importing knowledge and skills related affects and coping mechanisms to climate variability.
- Farmers should be encouraged to take crop insurance against climate variability in castor to face any eventuality.
- The designed contingency plans may be translated in to meaningful actions which are to be followed by the farmers in true spirit to escape the affects of climate variability

Table 3 Institutional problems perceived by the castor farmers in adaptation to climate variability in castor

Problem	Frequency and %	Rank
Frequent interruptions in power supply	98 (81%)	III
No sufficient training on climate variability coping mechanisms	107 (89%)	I
Lack of guidance on insuring the crop against the climate variability	99 (82%)	11
Lack of proper storage facility for the castor produce	70 (58%)	IV

Table 4 Natural problems perceived by the castor farmers in adaptation to climate variability in castor

Problem	Frequency and %	Rank
Declining ground water	89 (74%)	I
Repetitive occurrence of extreme weather conditions	83 (69%)	III
Poor soils of the region	87 (72%)	II

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