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Genetic variability for fresh seed dormancy in Spanish bunch advanced breeding lines of groundnut (*Arachis hypogaea* L.)

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ABSTRACT

A study was carried out to identify genotypes possessing fresh seed dormancy in Spanish bunch genetic background. Analysis of variance revealed highly significant differences among the genotypes for fresh seed dormancy at all the stages. Among the three parameters of fresh seed dormancy, only intensity of fresh seed dormancy at weekly interval instead of only at 7 days after sowing was found very important parameter to identify ideal sources of fresh seed dormancy in Spanish types. Two years results revealed that seven genotypes *viz.,* PBS-12190, PBS-12191, PBS-12192, PBS-12171, PBS-12187, PBS-12189 and TPG-41 were the best genotypes which recorded average more than 90 per cent intensity of fresh seed dormancy for 21 days and these also had 100 per cent fresh seed dormancy at 7 DAS except PBS-12191, PBS-12171 and PBS-12189. However three genotypes PBS-12200, PBS-12200B and PBS-12201 also had more than 90 per cent fresh seed dormancy for 14 days. Therefore, these genotypes were identified as new sources of fresh seed dormancy with high intensity and high degree of fresh seed dormancy for over 2-3 weeks. These genotypes could be used as donor parents in breeding programmes to develop high yielding Spanish bunch varieties with 3-4 week fresh seed dormancy in groundnut.

Keywords: Advanced breeding lines, Fresh seed dormancy, Genetic variation, Groundnut, Spanish bunch

Groundnut (*Arachis hypogaea* L.) is an important self-pollinated oilseed crop grown in 117 countries with different agro-climatic conditions between 40°N to 40°S latitudes. It is cultivated globally in 26.2 million ha area with a production of 43.6 million tonnes and productivity of 1666 kg/ha during 2012 to 2014 (triennial average) (FAO, 2017). India is second largest area and production of groundnut after China. In India, it is cultivated in about 4.87 million ha area with the production and productivity of 7.22 million tonnes and 1543 kg/ha respectively during 2014-15 to 2016-17 (Anonymous, 2017). Groundnut is valued as a rich source of oil (48-50%), protein (25-28%), dietary fiber, minerals, vitamins and energy (Mondal and Badigannavar, 2016). Groundnut haulms and cake are important sources of animal feed. Groundnut belonging to Spanish (subsp. *fastigiata* var. vulgaris) and Valencia (subsp. *fastigiata* var. *fastigiata*) types have short life cycle and are generally lack of seed dormancy while Virginia (subsp. *hypogaea* var. *hypogaea*) types have longer life cycle with seed dormancy (Upadhyaya and Nigam, 1999). The physiological basis of dormancy in groundnut is due to hormonal balance between abscisic acid and ethylene, which is produced by the embryo through the action of cytokinin during seed imbibition (Ketring and Morgan, 1971; 1972). Nautiyal *et al.* (1994) has been reported that genetic constitution and different seed parts like seed coat, cotyledons and embryo have a role in imparting dormancy in groundnut. Lack of seed dormancy in the Spanish bunch varieties have a major problem resulting in 20-50 per cent loss in pod yield due to *in-situ* germination resulting from unpredictable rainfall at the time crop maturity (Reddy, 1982; Nagarjun and Radder, 1983). In India, groundnut is cultivated mainly in the *kharif, rabi* and summer seasons. To fit groundnut in these cropping seasons, short duration cultivars are required. Spanish and Valencia type varieties have short duration but have a major problem of *in-situ* germination due to unpredictable rains, prolonged rainy season and irrigation at the time of crop maturity to enable easy harvest and to avoid pod loss. Hence under such conditions at least 2-3 week fresh seed dormancy would be required to avoid yield losses. Therefore, present investigation was to study genetic variability among Spanish bunch advanced breeding lines for fresh seed dormancy and to identify genotypes with 2-3 week seed dormancy.

MATERIALS AND METHODS

Plant material and field experiment: The experimental material consisted of 27 Spanish advanced breeding lines and three high yielding popular Spanish bunch varieties *viz.,* TG 37A, Dh 86 and TPG 41. These genotypes were harvested at maturity as indicated by blackening of inner parenchyma of the pod (Miller and Burns, 1971). To study fresh seed dormancy, a sample of mature pods were randomly collected and shelled immediately after harvesting from each genotype. Enough care was taken to prevent any damage of the seed testa, cotyledons and embryo while removing seeds from

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pods. Before sowing the seeds were treated with carbendazim (3g/kg of seed) to protect from soil-borne diseases. A total of 30 genotypes were evaluated during 2016 and 2017 (June-July) at ICAR-Directorate of Groundnut Research, Junagadh, Gujarat (Latitude 21°31' N, Longitude 70°36' E) in medium black calcareous soil. The experiment was laid out in a randomized complete block design with three replications. Each replication consisted of 20 fresh harvested seeds sown at 2 to 3 cm deep for each genotype. The seeds of each genotype were sown at 45 cm spacing between rows and 10 cm between plants. The soil moisture was maintained at field capacity during the growth period up to 35 days after sowing (DAS). The observations were recorded on number of seeds germinated at weekly interval until the end of experiment.

Estimated parameters: Fresh seed dormancy is characterized by its duration and intensity. These two parameters were studied in the present investigation for all the genotypes for two seasons. The percentage of germinated seeds for entry at a given date was calculated by the following formula:

$$\text{Germination (\%)} = \frac{\text{Number of germinated seeds}}{\text{Total number of sown seeds}} \times 100$$

Duration of fresh seed dormancy was measured by days taken to attain 50 per cent germination by a genotype and intensity of fresh seed dormancy was measured as percentage of non-germinated seed at seven days after sowing. These parameters were estimated using the method suggested by Kumar *et al.* (1991). Degree of dormancy was classified using 1-8 scale according to the scale devised by Landfort *et al.* (1965) where scale 1 = 0-10%, 2=11-20%, 3=21-40%, 4=41-60%, 5=61-70%, 6=71-80%, 7=81-99% and 8=100% non-germinated seeds.

Statistical analysis: Analysis of variance was performed using the statistical package DSAASTAT (Onofri, 2007). The partitioning of means was made with Duncann's multiple range Test at 5% probability level.

RESULTS AND DISCUSSION

Analysis of variance for germination per cent at weekly intervals revealed that highly significant genotypic differences for fresh seed dormancy at all the stages while genotype × year interaction was highly significant at 7 and 21 DAS was highly significant (Table 1). Significant interaction effects indicated that germination per cent varies from one year to other which could be attributed to environmental conditions like temperature, moisture and other non-genetic factors (Toole *et al.*, 1964). It was observed that there was sufficient genetic variability was observed among all the genotypes studied for germination per cent at different weekly intervals during both the year. Germination percentage of genotypes averaged over two seasons is presented in Table 2. At 7th day an average germination per cent ranged from 0 to 64.2 per cent and genotypes *viz.,* PBS-12187, PBS-12190, PBS-12192, PBS-12200 and TPG-41 had no germination during both the years and these genotypes also recorded less than 10 per cent germination up to 21 days after sowing. Hence, these genotypes can be recommended for areas where an unpredictable rain is a common feature.

Germination per cent results revealed that seven genotypes *viz.,* PBS-12190, PBS-12191, PBS-12192, PBS-12171, PBS-12187, PBS-12189 and TPG-41 had average less than 10 per cent germination up to 21 days and also had no germination at 7 DAS except PBS-12191, PBS-12171 and PBS-12189 which had less than 5 per cent germination at 7 DAS. However three genotypes PBS-12200, PBS-12200B and PBS-12201 also exhibited less than 10 per cent germination for 14 days and except PBS 12200 had no germination at 7 DAS. Hence these were the genotypes recommended to be used as donors in hybridization programme. These findings are in agreement with the results of Kumar *et al.* (1991) and Faye *et al.* (2009).

Table 1 Analysis of variance for germination percentage at weekly intervals during 2016 and 2017

Sources of variation	DF	7 DAS	14 DAS	21 DAS	28 DAS	35 DAS
Year	1	19858.2	1190.0	62.5	161.9	747.0
Rep (Year)	4	111.5	177.8	187.9	121.9	199.6
Genotype	29	2981.5**	6082.1**	5880.1**	2871.0**	1857.5**
Genotype × Year	29	785.3**	198.4	342.9**	426.9	434.3
Residual	116	101.3	188.0	152.7	273.2	282.0
Total	179	789.3	1149.9	1111.7	715.0	562.7

*Significance at P< 0.05 level, **Significance at P< 0.01 level

Table 2 Germination percentages of genotypes tested at weekly intervals in the field after harvesting during 2016 and 2017

Genotypes	7 DAS		14 DAS		21 DAS		28 DAS		35 DAS	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
PBS12029B	61.7b-e	31.1a-c	83.3a	71.1a-b	86.7a-b	71.1a-e	93.3a	73.3	95.0a	75.6a-c
PBS-12171	1.7i	0.0h	1.7i	14.4d-f	5.0h	17.8j-k	16.7d	53.3	25.0g	64.4a-c
PBS-12187	0.0i	0.0h	3.3i	0.0f	6.7h	4.4k	18.3d	33.3f-g	35.0e-g	46.7c-d
PBS-12189	1.7i	0.0h	1.7i	2.2e-f	10.0g-h	6.7k	18.3d	40.0e-g	31.7f-g	62.2a-c
PBS-12190	0.0i	0.0h	1.7i	0.0f	6.7h	2.2k	13.3d	13.3g	25.0g	15.6d
PBS-12191	5.0h-i	0.0h	3.3i	6.7e-f	1.7h	6.7k	13.3d	51.1d-f	18.3g	68.9a-c
PBS-12192	0.0i	0.0h	1.7i	2.2e-f	1.7h	2.2k	20.0d	51.1d-f	46.7d-g	66.7a-c
PBS-12199	46.7d-e	31.1a-c	75.0a-b	71.1a-b	86.7a-b	77.8a-d	88.3a	75.6a-d	73.3a-d	77.8a-c
PBS-12200	0.0i	0.0h	10.0i	8.9e-f	18.3g-h	46.7f-h	81.7a-b	73.3a-d	83.3a-c	88.9a
PBS-12200B	11.7g-i	2.2g-h	13.3h-i	6.7e-f	20.0g-h	31.1h-j	50.0b-c	64.4a-f	51.7c-g	68.9a-c
PBS-12201	5.0h-i	0.0h	5.0i	6.7e-f	8.3h	20.0i-k	61.7a-c	66.7a-e	65.0a-e	75.6a-c
PBS-12202	6.7g-i	0.0h	20.0g-i	15.6d-f	45.0e-f	37.8g-j	51.7b-c	60.0b-f	60.0b-f	75.6a-c
PBS-12203	58.3c-f	4.4f-h	66.7a-d	77.8a-b	76.7a-c	82.2a-c	78.3a-b	84.4a-c	75.0a-d	80.0a-c
PBS-12204	15.0g-i	6.7e-h	48.3c-f	37.8c-d	60.0c-e	68.9b-f	75.0a-b	80.0a-d	76.7a-d	77.8a-c
PBS-12204B	11.7g-i	0.0h	38.3f-g	13.3d-f	48.3d-f	46.7f-h	66.7a-c	77.8a-d	68.3a-d	82.2a-b
PBS-12205	24.4g	24.4b-e	48.2c-f	53.3b-c	61.7c-e	73.3a-e	73.6a-b	80.0a-d	75.3a-d	88.9a
PBS-12206	6.7g-i	22.2b-f	36.7f-h	37.8c-d	31.7f-g	71.1a-e	78.3a-b	82.2a-d	85.0a-b	86.7a
PBS-12207	71.7a-c	40.0a-b	81.7a	91.1a	81.7a-c	91.1a-b	75.0a-b	86.7a-b	83.3a-c	88.9a
PBS-12208	88.3a	40.0a-b	88.3a	82.2a	90.0a	82.2a-c	90.0a	80.0a-d	90.0a-b	80.0a-c
PBS-12209	75.0a-c	20.0c-h	81.7a	68.9a-b	90.0a	66.7e-f	93.3a	64.4a-f	91.7a-b	66.7a-c
PBS-12210	50.0d-f	8.3d-h	76.7a-b	70.7a-b	73.3a-c	76.0a-d	70.0a-c	73.7a-d	73.3a-d	78.2a-c
PBS-12211	80.0a-b	26.7b-d	88.3a	88.9a	91.7a	93.3a	91.7a	93.3a	91.7a-b	93.3a
PBS-12212	71.7a-c	6.7e-h	75.0a-b	73.3a-b	91.7a	86.7a-c	93.3a	86.7a-b	93.3a-b	91.1a
PBS-12213	43.3d-f	2.2g-h	65.0a-e	20.0d-f	68.3a-d	42.2g-i	78.3a-b	73.3a-d	80.0a-c	73.3a-c
PBS-12214	83.3a	20.3c-g	73.3a-c	74.9a-b	90.0a	72.5a-e	86.7a	77.3a-d	91.7a-b	77.3a-c
PBS-13003	21.7g-h	4.4f-h	43.3d-g	19.2d-f	65.0b-e	40.8g-i	90.0a	64.7a-f	90.0a-b	71.4a-c
PBS-18035	11.7g-i	2.2g-h	40.0e-g	28.9c-e	45.0e-f	51.1e-h	71.7a-c	77.8a-d	80.0a-c	84.4a-b
TG-37A	81.7a	46.7a	85.0a	73.3a-b	88.3a-b	73.3a-e	86.7a	73.3a-d	88.3a-b	73.3a-c
Dh 86	61.7b-c	26.2b-d	55.0b-f	45.2c	80.0a-c	54.8d-g	80.0a-b	54.8	81.7a-c	76.2a-c
TPG-41	0.0i	0.0h	11.7i	6.7e-f	11.7g-h	8.9k	41.7c-d	37.8e-g	60.0b-f	51.1b-c

The data reveled that an average germination per cent increased from 23 to 42, 51, 66 and 71 per cent at 7, 14, 21, 28 and 35 days after sowing respectively during both the years. Highest percent increase in germination was observed from 7 to 14 DAS (19%) followed by 21 to 28 DAS (15%), 14 to 21 DAS (9%) and 28-35 DAS (5%). It implying that seed of genotypes studied in the experiment were viable and having minimum germination percentage standard criteria (70%) at 35 DAS of groundnut. Hence genotypes identified under study had only fresh seed dormancy. The variability in fresh seed dormancy among Spanish advanced breeding lines in the present study was in agreement with earlier works like Yaw *et al.* (2008), Rathanakumar *et al.* (2009), Faye *et al.* (2009; 2010), Wang *et al.* (2012) and Gaikwad and Bharud (2016).

Duration of fresh seed dormancy: Duration of fresh seed dormancy was measured by days taken to attain 50 per cent germination by a genotype. Genotypes showed different durations of dormancy and it ranged from 7 to >35 days during both the year. Results of durations of fresh seed dormancy showed that two advanced breeding lines PBS-12187 and PBS-12190 had more than 35 days duration of fresh seed dormancy (Table 3). Five advanced breeding lines PBS-12171, PBS-12189, PBS-12191, PBS-12192, PBS-12200B and one cultivar TPG-41 had 28 days duration of fresh seed dormancy. Five advanced breeding lines *viz.,* PBS-12200, PBS-12201, PBS-12202, PBS-12204B and PBS 18035 had 21 days duration of fresh seed dormancy while PBS-12204, PBS-12205, PBS-12206, PBS-12213 and PBS-13003 had 14 days duration of fresh seed dormancy. These genotypes were thus identified as new sources of fresh seed dormancy of 2-5 weeks in Spanish bunch groundnut genotypes. These results were in agreement with the findings of Kumar *et al.* (1991) and Faye *et al.* (2009). Mathur *et al.* (2000) also observed that two advanced breeding lines PBS-12115 and PBS-12126 possessed fresh seed dormancy of 21-28 and 14-21 days, respectively in groundnut.

Intensity of fresh seed dormancy: Intensity of dormancy is defined as the percentage of seeds that not germinated even seven days after the harvest (Kumar *et al.* 1991). It ranged from 11.7 to 100 per cent and 53.3 to 100 per cent during 2016 and 2017, respectively (Table 3). The results showed that five genotypes *viz.,* PBS-12187, PBS-12190, PBS-12192, PBS-12200 and TPG-41 had 100 per cent intensity followed by eight advanced breeding lines *viz.,* PBS-12171, PBS-12189, PBS-12191, PBS-12201, PBS-12202, PBS-12200B, PBS-12204B, PBS-18035 with an average more than 90 per cent fresh seed dormancy during both the year, while the advanced breeding lines PBS-12204, PBS-12206, PBS-13003 had 80-89 per cent intensity of fresh seed dormancy during both the year at 7 DAS. Intensity of dormancy was found very important at all the weekly intervals instead of only at 7 DAS from practical point of view. In the present investigation we have considered only those genotypes having 90 per cent dormancy for at least 2-3 weeks. It was observed that four genotypes *viz.,* PBS-12187, PBS-12190, PBS-12192 and TPG-41 had 100 per cent fresh seed dormancy at 7 DAS along with more than 90 per cent fresh seed dormancy for 21days and while three genotypes PBS-12191, PBS-12171 PBS-12189 also had more than 95 per cent fresh seed dormancy at 7DAS along with more than 90 per cent dormancy for 21days. Three genotypes PBS-12200, PBS-12200B and PBS-12201 had more than 90 per cent fresh seed dormancy for 14 days and except PBS-12200 (Table 4). This large variation in intensity of dormancy could be due to genotypic differences among the genotypes. These findings are in agreement with the results of Kumar *et al.* (1991) and Faye *et al.* (2009).

Table 3 Duration, intensity and scale of fresh seed dormancy at 7 days after sowing during 2016 and 2017

Genotype	Duration of dormancy (days)		Intensity of dormancy (%)		Dormancy scale	
	2016	2017	2016	2017	2016	2017
PBS-12029B	7	14	38.3	68.9	3	5
PBS-12171	35	28	98.3	100.0	7	8
PBS-12187	35	35	100.0	100.0	8	8
PBS-12189	35	28	98.3	100.0	7	8
PBS-12190	35	35	100.0	100.0	8	8
PBS-12191	35	28	95.0	100.0	7	8
PBS-12192	35	28	100.0	100.0	8	8
PBS-12199	7	14	53.3	68.9	4	5
PBS-12200	21	21	100.0	100.0	8	8
PBS-12200B	28	28	88.3	97.8	7	7
PBS-12201	21	21	95.0	100.0	7	8
PBS-12202	21	21	93.3	100.0	7	8
PBS-12203	7	14	41.7	95.6	4	7
PBS-12204	14	14	85.0	93.3	7	7
PBS-12204B	21	21	88.3	100.0	7	8
PBS-12205	14	14	76.5	75.6	6	6
PBS-12206	21	14	93.3	77.8	7	6
PBS-12207	7	7	28.3	60.0	3	4
PBS-12208	7	7	11.7	60.0	2	4
PBS-12209	7	7	25.0	80.0	3	6
PBS-12210	7	14	50.0	92.7	4	7
PBS-12211	7	7	20.0	73.3	2	6
PBS-12212	7	7	28.3	93.3	3	7
PBS-12213	14	21	56.7	97.8	4	7
PBS-12214	7	14	16.7	79.5	2	6
PBS-13003	14	21	78.3	94.7	6	7
PBS-18035	21	21	88.3	97.8	7	7
TG-37A	7	7	18.3	53.3	2	4
Dh 86	7	14	38.3	73.8	3	6
TPG-41	28	28	100.0	100.0	8	8

Table 4 Intensity of fresh dormancy among the genotypes at weekly intervals during 2016 and 2017

Intensity of dormancy	Fresh seed dormancy (days)			
	7 DAS	14 DAS	21 DAS	28 DAS
100%	PBS-12187, PBS-12190 PBS-12192, PBS-12200, TPG-41	--	--	--
95-99%	PBS-12171, PBS-12189, PBS-12191, PBS-12201, PBS-12202	PBS-12187, PBS-12189, PBS-12190, PBS-12191, PBS-12192	PBS-12190, PBS-12191, PBS-12192	--
90-94%	PBS-12200B, PBS-12204B, PBS-18035	PBS-12171, PBS-12200, PBS-12200B , PBS-12201, TPG-41	PBS-12171, PBS-12187, PBS-12189, TPG-41	--
80-89%	PBS-12204, PBS-12206, PBS-13003	PBS-12202	PBS-12201	PBS-12190

Degree of fresh seed dormancy: Degree of fresh seed dormancy of genotypes was recorded on a 0 to 8 scales of Landfort *et al.* (1965), wherein scale 0 indicates least dormant and scale 8 indicates most dormant genotype. In the present study it ranged from 2-8 during both the years. Results revealed that five advanced breeding lines PBS-12187, PBS-12190, PBS-12192, PBS-12200 and TPG-41 had an average score 8 while nine advanced breeding lines *viz*., PBS-12171, PBS-12189, PBS-12191, PBS-12200B, PBS-12201, PBS-12202, PBS-12204, PBS-12204B and PBS-18035 had an average score more than 7 during both the year at 7 DAS. Therefore, these genotypes were identified with high degree of fresh seed dormancy than other genotypes. The present results are in agreement with the observations made by Faye *et al.* (2009).

Present investigation showed significant genetic variation for germination percent at different weekly intervals, duration, intensity and degree of fresh seed dormancy in 30 Spainsh genotypes. While considering all the parameters, only intensity of dormancy was found very important at all the stages (weekly intervals) from practical point of view. In the present investigation we have considered only those genotypes having 90% dormancy for at least 2-3 weeks. It was concluded that seven genotypes *viz.,* PBS-12171, PBS-12187, PBS-12189, PBS-12190, PBS-12191, PBS-12192 and TPG-41 had more than 90 per cent fresh seed dormancy up to 21 days and while three genotypes PBS-12200, PBS-12200B and PBS-12201 had more than 90 per cent fresh seed dormancy for 14 days. Therefore, these genotypes were identified as new sources in groundnut for different duration, intensity and degree of fresh seed dormancy and could be used in breeding programs to develop genotypes with in-built fresh seed dormancy.

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Evaluation of new inbreds for fertility restoring and maintaining behaviours in two diverse CMS sources of sunflower (*Helianthus annuus* L.)

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ABSTRACT

Eight cytoplasmic male sterile (CMS) lines of sunflower (*Helianthus annuus* L.) belonging to two different sources of cytoplasmic male sterility, PET-1 (*H. petiolaris*) (CMS-852A, CMS-7-1A, CMS-234A, CMS-2A, COSF-1A, COSF-7A and CMS-10A) and CMS I (*H. lenticularis*) (IMS-852A) were crossed with newly developed 20 inbred lines to identify the maintainer or restorer behaviour in Line x Tester fashion and evaluation of test cross progenies was conducted. The presence or absence of pollen in F_1s was recorded in the field whereas pollen fertility was confirmed in the laboratory by acetocarmine staining test. All the inbreds were categorized into complete, partial restorer and maintainer through cytological observation. Twelve inbreds *viz.,* RHAGKVK-1, RHAGKVK-2, AKSFI-49-3, AKSFI-49-4, AKSFI-46-2, HOHAL-37, CSFI-5134, CSFI-5055, CSFI-5133, CSFI-5185, CSFI-5075 and Selection-I restored the fertility for most of the PET-1 CMS lines, while CSFI-5033, IB0-50, IB-60, IB-61, IB-67 and IB-101 inbreds maintained sterility. The second CMS line IMS-852A, was maintained by 13 inbreds indicating involvement of different gene(s), while one inbred CSFI-5134 was restored its fertility. Some of the inbreds (AKSFI-49-3 and AKSFI-49-4) were behaved as partial restorers for CMS-10A. The range of fertility restoration in different cross combinations was between 46.6 and 99.5 per cent. In the present study 50 to 65 per cent frequency of pollen fertility was reported for PET-1. However, only 5 per cent frequency of pollen fertility was observed for CMS I. From the study it was evident that among the two CMS sources, restorers for CMS I are rather scarce. Efforts should be made to locate restorers for CMS I for its utilization in production of more productive sunflower hybrids.

Keywords: CMS sources, Inbreds, Maintainer, Restorer, Sunflower

Cytoplasmic male sterility (CMS) and associated restorer genes (*Rf*) have been the major promoters for the development of commercial sunflower hybrids in the world in order to guarantee a 100 per cent cross pollination and high yielding hybrids (Miller and Fick, 1997). Development and commercialization of hybrids in sunflower started with the discovery of cytoplasmic male sterility among progenies of the interspecific cross *Helianthus petiolaris* x *H. annuus* (Leclercq, 1969) in France and subsequent identification of pollen fertility restorers (Kinman, 1970; Leclercq, 1971; Vranceanu and Stoenescu, 1971) which shifted the interest from population breeding to heterosis breeding. It opened a new era in sunflower breeding, since it has been a shift from population breeding to development of hybrids and leads to the exploitation of hybrid vigour and commercial hybrid seed production. Although several new CMS sources are available, the extremely low frequency of genes for pollen fertility restoration in the present cultivated sunflower has been one of the most important difficulties in using the diverse sterile cytoplasm for producing commercial hybrid seed (Anaschenko, 1974). For over 40 years, the hybrid sunflower seed industry has largely relied on a single CMS, PET-1, and its corresponding fertility restoration gene *Rf1* (Dominguez-Gimenez and Fick, 1975; Horn *et al.,* 2003; Jan and Vick, 2007) because of its stability and availability of fertility restorers and maintainers easily (Friedt, 1992) which creates a high degree of genetic vulnerability in hybrid sunflower. This narrow genetic base may limit the progress in sunflower breeding programmes. In order to minimize such a risk, new sources of cytoplasmic male sterility and fertility restorers are essential to reduce the genetic vulnerability of commercial sunflower hybrids because of the current use of a single male sterile cytoplasm and a few fertility restoration genes (Ardilla *et al.,* 2010; Meena and Sujatha, 2013). The use of new CMS sources would allow broadening of the genetic base of the cytoplasm. But using this diverse CMS sources, hybrids could not be developed because of the non-availability of effective restorers for these new CMS sources. To overcome this problem, increasing the diversity of hybrid parents especially in restorer lines, is always a primary breeding goal. Present investigation was taken up to explore the possibilities of finding out good restorers and maintainers based on sterility and fertility reactions in two different CMS sources. We herein make use of the easy method (Chaudhary *et al.,* 1981), for ascertaining the pollen fertility of crosses; leading to the identification of selected superior inbreds as maintainers and restorers of two diverse CMS sources, for the practical use of these inbreds

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in future sunflower breeding programme to augment the genetic diversity of sunflower hybrids. In view of this limitation, an attempt was made at the ICAR-Indian Institute of Oilseeds Research (IIOR), Hyderabad to identify effective restorers for the above mentioned diverse CMS sources. The best inbreds identified have to be converted in to CMS lines before using them in hybrid development. The inbreds, from maintainer gene pool are used for new CMS lines development and those from restorer gene pool are used as male lines in hybrid programme.

MATERIALS AND METHODS

The breeding material comprised of two diverse cytoplasmic male sterile sources of sunflower *viz., H. petiolaris* and *H. lenticularis.* In this study we used seven CMS lines from PET-1 background *viz.,* CMS-852A, CMS-7-1A, CMS-234A, CMS-2A, COSF-1A, COSF-7A and CMS-10A and one CMS from IMS (*H. lenticularis*) background *viz.,* IMS-852A maintained by ICAR-IIOR, Hyderabad, and newly developed twenty trait specific inbred lines (testers) i.e. four inbreds *viz.,* AKSFI-49-3, AKSFI-49-4, AKSFI-46-2 and AKSFI-42-1 (high autogamy) from Akola (Maharashtra) center, one advanced breeding line i.e. HOHAL-37 (High oil high autogamy) from Ludhiana (Punjab) centre; seven inbred lines i.e. CSFI-5134, CSFI-5055, CSFI-5261, CSFI-5133, CSFI-5185, CSFI-5033 and CSFI-5075 from Coimbatore (Tamil Nadu) centre; two inbreds i.e. RHAGKVK-1 and RHAGKVK-2 from Bangalore (Karnataka) center and six other advanced lines i.e. IB-50, IB-60, IB-61, IB-67, IB-101 and Selection-I from ICAR-IIOR, Hyderabad, respectively. The eight cytoplasmic male sterile lines five rows each from both cytoplasmic backgrounds and two rows each of the twenty testers (inbreds) were planted during the *rabi* season of the year 2012-13, with a spacing of 60 cm x 30 cm in a row length of 4.5 m. Staggered sowings of male and female parents, at weekly interval, was done to synchronize the flowering. Recommended agronomic practices were followed. The heads of male sterile (female) lines and the inbreds (male lines) were covered with cloth bags at the ray floret stage i.e. just before the commencement of flower opening. The eight CMS lines from two different CMS sources were crossed to all the twenty inbreds in a Line x Tester fashion. Crossing was done by collecting pollen from the inbreds in a petridish with the aid of a small brush which was applied on five florets each of the corresponding CMS lines between 8: 00 to 11: 00 am and the procedure repeated till the opening of all disc florets. Precautions were taken to avoid possible contamination. F_1 seeds from each of the 160 crosses were collected separately at maturity for assessing the fertility restoration of the 20 inbreds on the 8 CMS lines. The identification of inbred behaviour, with respect to maintenance and restoration of the cytoplasmic male sterile sources of sunflower involved in the present study, was conducted during the *kharif* season of the year 2013-14 at Narkhoda Research Farm, ICAR-IIOR, Hyderabad. F_1 seeds from the 160 crosses were planted in a randomized block design with two replications. Two rows of 3 m for each F_1 entry were planted maintaining a row to row distance of 60 cm and a plant to plant distance of 30 cm. The hybrids were classified as male fertile/male sterile based on the dehiscence and pollen shedding at anthesis. Further, pollen fertility was confirmed in the laboratory by using 1% acetocarmine. Based on visual observation, the pollen parents leading to sterile crosses were classified as maintainers, while those that gave fertile crosses were classified as restorers of the corresponding CMS lines. Pollen fertility percentage was calculated by classifying pollen grains as sterile or fertile (Chaudhary *et al.,* 1981). For pollen study anthers were collected from all the fertile F_1 hybrids. Pollen grains were treezed out of the anther on glass slide. The fertile and sterile pollen grains were counted under a light microscope. The pollen fertility was calculated as the ratio between the number of fertile (round and darkly stained) and sterile (yellow, shrivel, partial stained or unstained) pollen grain in the microscopic field (Fig. 1). Plants were classified into different fertility-sterility groups based on proportion of stained-round pollen grains, as the number of fertile grains/total number observed x 100. Based on fertility, plants were classified as effective or complete restorers (> 90% pollen fertility), partial restorers (20-80% pollen fertility) and effective maintainers (< 1% pollen fertility or no pollen).

RESULTS AND DISCUSSION

The inbreds which produced sterile F_1s were classified as maintainers, while the ones that produced fertile F_1s were classed as restorers of the respective CMS sources based on cytological observation (per cent pollen fertility). It can be shown from Table 1 that six inbreds namely CSFI-5033, IB-50, IB-60, IB-61, IB-67 and IB-101 produced sterile F_1s on the PET-1 CMS (COSF-7A, COSF-1A, CMS-10A, CMS-2A, CMS-234A and CMS-852A). Further, 13 inbreds produced sterile F_1s on CMS I as well, while only one inbred CSFI-5134 behaved as restorer on CMS I. Though a minute fraction of aborted pollens (sterile pollens) was also observed (Table 1), it can be seen from the Table 1 that eleven (RHAGKVK-1, AKSFI-49-3, AKSFI-49-4, AKSFI-46-2, HOHAL-37, CSFI-5133, CSFI-5134, CSFI-5055, CSFI-5185, RHAGKVK-2 and Selection-I) out of twenty inbreds produced sufficient fertile F_1s with PET 1 (COSF-7A, COSF-1A, CMS-7-1A, CMS-10A, CMS-2A, CMS-234A and CMS-852A). At the same time inbred CSFI-5075 behaved as restorer for other PET-1 CMS (COSF-7A, COSF-1A, CMS-7-1A, CMS-10A, CMS-2A and CMS-234A). While it behaved as segregating type (fertile and sterile plants) on CMS-852A means the fertility restorer genes present in this inbred is in heterozygous condition. It is indicated that cytoplasm of CMS-852A is different from other PET-1 CMS. Similar conclusions drew regarding the differences of three new CMS sources with the French CMS source PET 1 (Petrov and Nenov, 1992). The present findings agree with the conclusion of Spirova (1990), regarding the infrequency observed for fertility restoration. This is more obvious in case of IMS-852A; whose fertility was restored by only one inbred evaluated in the present study. The data clearly indicates that the majority of the inbreds tested behaved as maintainers for the new CMS source. Similar results of differences in fertility restoring genes for different CMS background have been reported (Whelan, 1981; Virupakshappa *et al.,* 1991). Many other authors also reported lack of fertility restorers other than PET-1 (Reddy *et al.,* 2008; Satish Chandra *et al.,* 2011; Rukminidevi *et al.,* 2006; Manivannan *et al.,* 2002; Sujatha and Reddy, 2008; Madhavilatha, 2002; Venkanna *et al.,* 2008; Channamma, 2009; Zhao Liul *et al.,* 2013). In general most of the inbreds tested behaved as maintainers for the new CMS sources. Even the identified effective restorers of the traditional PET-1 cytoplasm, behaved mostly as maintainers and only one of the inbred *viz.,* CSFI-5134 under study was identified to restore fertility on all PET-1 and CMS I. Similar observations were also made by Serieys and Vincourt (1987) and Bijral *et al.* (1987).

The same pollen parent exhibited different type of fertility restoration behavior in different CMS line combinations have been found in the material under study. Variation in the restoration ability of restorer lines for the same cytoplasm indicated that the cytoplasm of CMS interact differently with individual pollinator varieties. Such type of results obtained may be due to the minor gene(s) with additive gene action with the cytoplasmic gene of different CMS line. The different behaviors of pollen parents on different CMS sources indicate significant diversity among cytoplasmic sources and lines for fertility restoration as reported by earlier study (Divya Ambati, 2010). Different kinds of fertility restoration behaviour among the crosses were observed that some inbreds restoring fertility on one source failed to restore on another source indicating that different genes are responsible for the restoration of fertility (Venkanna *et al.,* 2008). Similar differences in fertility restoration in different CMS background have been reported (Hu, 1983). The differential behavior of the lines for fertility/sterility reaction may be attributed to genetic architecture especially the number of genes controlling and their interactions with cytoplasm in restoring fertility.

Table 1 Frequency of F_1 stained pollens and unstained pollens from anthers of *H. annuus* plants after crossing with seven CMS of PET 1 and one CMS of IMS with 20 inbred testers

Inbred	COSF-7A				IMS-852A				CMS-7-1A				CMS-234A			
	SP	USP	TP	% PF	SP	USP	TP	% PF	SP	USP	TP	% PF	SP	USP	TP	% PF
RHAGKVK-1	247	3	250	98.8	0	0	0	0	590	10	600	98.3	492	8	500	98.4
AKSFI-49-3	287	13	300	95.6	0	450	450	0	697	3	700	99.5	496	4	500	99.2
AKSFI-49-4	349	11	360	96.9	0	0	0	0	497	3	500	99.4	297	3	300	99.0
AKSFI-46-2	347	3	350	99.1	0	0	0	0	363	7	370	98.1	492	8	500	98.4
AKSFI-42-1	S	S	S	-	S	S	S	-	S	S	S	-	S	S	S	-
HOHAL-37	417	3	420	99.2	0	0	0	0	391	9	400	97.7	344	6	350	98.3
CSFI-5134	290	10	300	96.6	297	3	300	99.0	594	6	600	99.0	594	6	600	99.0
CSFI-5055	440	10	450	97.7	0	0	0	0	541	9	550	98.3	546	4	550	99.3
CSFI-5261	S	S	S	S	-	S	S	-	S	S	S	-	397	3	400	99.2
CSFI-5185	294	6	300	98	0	0	0	0	356	4	360	98.9	346	4	350	98.8
CSFI-5133	247	3	250	98.8	S	S	S		593	7	600	98.8	654	6	660	99.1
CSFI-5033	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSFI-5075	488	12	500	97.6	0	0	0	0	688	12	700	98.3	544	6	550	98.9
RHAGKVK-2	439	11	450	97.5	0	0	0	0	447	3	450	99.3	748	2	750	99.7
Selection-I	422	9	413	97.8	0	0	0	0	359	10	349	97.2	450	8	442	98.2
IB-50	0	0	0	0	S	S	S	-	0	0	0	0	0	0	0	0
IB-60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IB-61	0	0	0	0	0	350	350	0	0	0	0	0	0	0	0	0
IB-67	0	0	0	0	S	S	S	-	0	0	0	0	0	0	0	0
IB-101	0	0	0	0	S	S	S	-	0	0	0	0	0	0	0	0

Contd..

Table 1 Contd...

Inbred	CMS-10A				CMS-2A				COSF-1A				CMS-852A			
	SP	USP	TP	%PF	SP	USP	TP	% PF	SP	USP	TP	% PF	SP	USP	TP	% PF
RHAGKVK-1	491	9	500	98.2	445	5	450	98.8	494	6	500	98.8	544	6	550	98.9
AKSFI-49-3	441	9	550	80.2	S	S	S	-	394	6	400	98.5	591	9	600	98.5
AKSFI-49-4	494	6	500	98.8	S	S	S	-	644	6	650	99.1	691	9	700	98.7
AKSFI-46-2	280	320	600	46.6	407	13	420	96.9	397	3	400	99.2	541	9	550	98.3
AKSFI-42-1	S	S	S	-	S	S	S	-	S	S	S	-	S	S	S	-
HOHAL-37	396	3	400	99.0	294	6	300	98.0	646	4	650	99.4	496	4	500	99.2
CSFI-5134	348	2	350	99.4	387	13	400	96.7	495	5	500	99.0	442	8	450	98.2
CSFI-5055	597	3	600	99.5	392	8	400	98.0	684	16	700	97.7	397	3	400	99.2
CSFI-5261	S	S	S	-	S	S	S	-	S	S	S	-	S	S	S	-
CSFI-5185	440	10	450	97.7	494	6	500	98.8	784	16	800	98.0	493	7	500	98.6
CSFI-5133	393	7	400	98.2	489	11	500	97.8	296	4	300	98.6	394	6	400	98.5
CSFI-5033	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSFI-5075	397	3	400	99.2	495	5	500	99.0	590	10	600	98.3	S	S	S	-
RHAGKVK-2	545	5	550	99.1	490	10	500	98.0	597	3	600	99.5	446	4	500	89.2
Selection-I	442	10	432	97.7	350	9	341	97.4	522	13	509	97.5	365	12	353	96.7
IB-50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IB-60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IB-61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IB-67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IB-101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SP=Stained pollen; S=Segregating type (male sterile/fertile plants); USP=Unstained pollen; 0=No pollen; TP=Total pollen; %PF=Per cent pollen fertility

Table 2 Identification of inbred behavior for maintenance and restoration of two diverse CMS sources of sunflower

Inbred	Cytoplasmic male sterile line							
	PET-1 CMS (*H. annuus*)							IMS (*H. lenticularis*)
	COSF-7A	COSF-1A	CMS-7-1A	CMS-234A	CMS-10A	CMS-2A	CMS-852A	IMS-852A
RHAGKVK-1	R	R	R	R	R	R	R	M
AKSFI-49-3	R	R	R	R	PR	S	R	M
AKSFI-49-4	R	R	R	R	R	S	R	M
AKSFI-46-2	R	R	R	R	PR	R	R	M
AKSFI-42-1	S	S	S	M	S	S	S	S
HOHAL-37	R	R	R	R	R	R	R	M
CSFI-5134	R	R	R	R	R	R	R	R
CSFI-5055	R	R	R	R	R	R	R	M
CSFI-5261	S	S	S	S	S	S	S	S
CSFI-5185	R	R	R	R	R	R	R	M
CSFI-5133	R	R	R	R	R	R	R	S
CSFI-5033	M	M	M	M	M	M	M	M
CSFI-5075	R	R	R	R	R	R	S	M
RHAGKVK-2	R	R	R	R	R	R	R	M
Selection-I	R	R	R	R	R	R	R	M
IB-50	M	M	M	M	M	M	M	S
IB-60	M	M	M	M	M	M	M	M
IB-61	M	M	M	M	M	M	M	M
IB-67	M	M	M	M	M	M	M	S
IB-101	M	M	M	M	M	M	M	S

S=Segregating type (male sterile/fertile plants); PR=Partial restorer; R=Restorer; M=Maintainer

A few crosses showed segregation with one or two fertile/sterile plants in their progeny. AKSFI-42-1 and CSFI-5261 inbreds acted as segregating type (male sterile/fertile plants) for most of the PET-1 CMS lines while acted as maintainers for CMS-234A. Inbred CSFI-5075 is also acted as segregating type for CMS-852A but acted as restorer for other PET-1 CMS lines (Table 2). Six inbreds *viz.,* AKSFI-42-1, CSFI-5261, CSFI-5133, IB-50, IB-67 and IB-101 out of twenty behaved as segregating type in CMS I background. This was attributed either to contamination of foreign pollen or the heterozygosity of the lines to restorer genes (Virupakshappa *et al.,* 1991) or may be due to modifying effects of genes (Dominguez-Gimenez and Fick, 1975). Thus, these lines have to be improved further for fertility restoration. However, these crosses will be further evaluated during the next season. For stabilizing fertility restorer and maintainer genes in male lines some more selfing generation is required.

Partial restoration of male fertility causes a reduction in the amount of viable pollen thus reduced the seed setting in sunflower head and ultimately reduced the seed yield in absence of pollinators. The degree of fertility restoration mediated by such partial restorer lines considerably depends on environmental effects and seed parent by pollinator line interaction. Based on visual observation inbreds AKSFI-49-3 and AKSFI-46-2 behaved as restorer for CMS-10A but based on cytological study we identified that these inbreds are not a perfect restorers for CMS-10A because the pollen fertility per cent was 80 and 46.6 per cent, respectively. Both the inbreds behaved as partial restorers for CMS-10A. Based on visual observation, all the restorers identified for different CMS sources were also confirmed by cytological study. The percentage of stained pollen and or the percentage of typical aborted pollen should be used as an essential index for determining plant fertility. Most research confirms that pollen fertility could be a main criterion for assessing fertility. In rice (Ahirwar *et al.,* 2013) and in wheat (Gouri Shankar *et al.,* 2007), reported that percentage of fertile pollen was the most reliable criterion for fertility. Pollen study is very important because it gives the clear picture about restorer or maintainer behavior of any breeding material. For development of good hybrids in sunflower a complete restorer male parent (>90% pollen fertility) is required. Because the partial restorer is also set seed in F_1 hybrids in open pollination but when grow these hybrids in isolation for seed multiplication or breeder seed production the seed setting will be very poor due to partial pollen or fertility and ultimately reduced the seed yield in absence of pollinators. For avoid such type of mistake we should confirm F_1 hybrids through cytological study. For example in Figure 1A, (CMS-234A x RHAGKVK-2), the complete restorer (>90% pollen fertility), in Figure 1B (CMS-10A x AKSFI-46-2), partial restorer (20-80% pollen fertility) and in Figure 1C and D (IMS-852A x IB-61; IMS-852A x AKSFI-49-3) complete maintainer (< 1% pollen fertility or no pollen) were observed.

Table 3 Classification of F_1 population based on pollen fertility in sunflower

Class	Pollen fertility per cent
Complete restorer	> 90
Partial restorer	50-89
Complete maintainer	<1 or 0

Frequency of tested material as maintainer, complete restorer, partial restorer and segregating types based on percent pollen fertility restoration were presented in Table 4. In the present study 50 to 65 per cent frequency of pollen fertility was reported for PET-1. The maximum per cent pollen fertility (65%) was observed for CMS-234A followed by COSF-7A, COSF-1A, CMS-7-1A (60%) and the minimum per cent pollen fertility (50%) was observed for CMS-10A and CMS-2A. However, only 5 per cent frequency of pollen fertility was observed for CMS I. Maximum frequency (65%) of tested material as maintainer was recorded for CMS I. Ten per cent frequency of partial restorer was observed for CMS-10A. This finding is in agreement with other (Hu, 1983) reported that most of the lines reported fertility for classical petiolaris cytoplasm PET-1. Only a few could restore fertility on new CMS sources. In that study they also identified the lack of availability of fertility restoration for other CMS sources. Only two inbreds out of 40 could restore fertility for CMS PF and three inbreds were effective restorers, for CMS I (Satish Chandra *et al.,* 2011). Many more research workers from India and abroad were reported very low frequency of fertility restoration genes for different CMS sources (Gouri Shankar *et al.,* 2007). They concluded that hybrids could not be developed because of the non-availability of effective restorers for these new CMS sources. These results suggest that, in some cases, genotypes acted as restorer for one CMS line and maintainer for another. This kind of differential reaction of some sunflower genotypes with different CMS lines of the same cytoplasmic source has also been reported by Meena *et al.* (2013) and Meena and Sujatha (2013). This may be due to the influence of the female genetic background on the restoration ability of the genotypes tested. The variation in the behaviour of fertility restoration could be because (1) the pollen fertility restoring genes differ, (2) their penetrance or expressivity differed with the genotypes of the parents, or (3) modifiers genes are present. Same conclusion was made working with rice crop (Pande *et al.,* 1989).

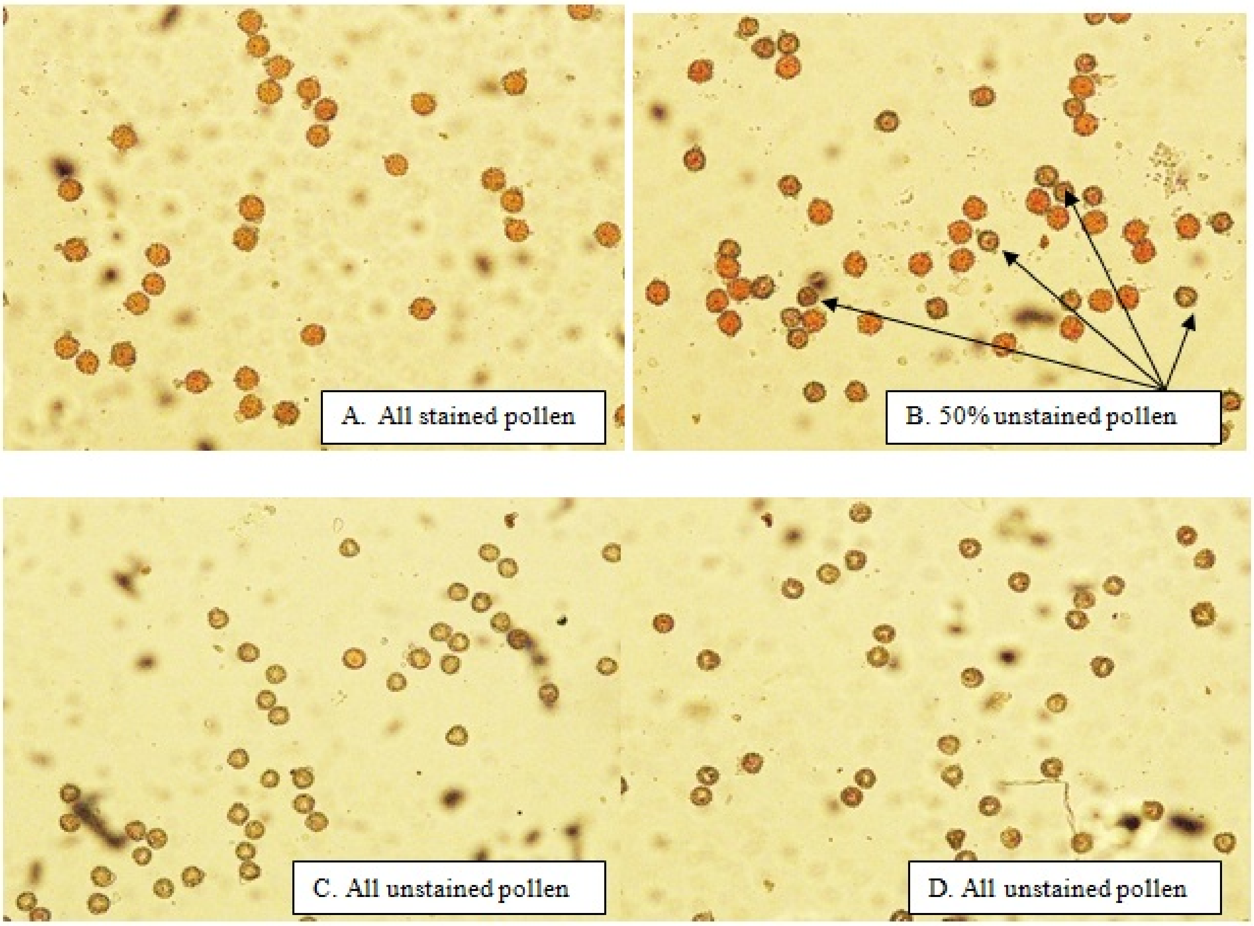

Fig. 1. A). All stained pollen (Complete restorer). B). 50% unstained pollen (Partial restorer)
C&D). All unstained pollen (Maintainer)

A. CMS-234A x RHAGKVK-2 (Complete restorer)
B. CMS-10A x AKSFI-46-2 (Partial restorer)
C. IMS-852A x IB-61(Complete maintainer)
D. IMS-852A x AKSFI-49-3(Complete maintainer)

Table 4 Frequency of tested material as maintainer, complete restorer, partial restorer and segregating types based on per cent pollen fertility restoration

CMS line	No. of inbred lines tested	M	Percentage (%)	R	Percentage (%)	SG	Percentage (%)	PR	Percentage (%)
COSF-7A (PET-1)	20	6	30	12	60	2	10	-	-
COSF-1A (PET-1)	20	6	30	12	60	2	10	-	-
CMS-7-1A (PET-1)	20	6	30	12	60	2	10	-	-
CMS-234A (PET-1)	20	7	35	13	65	-	-	-	-
CMS-10A (PET-1)	20	6	30	10	50	2	10	2	10
CMS-2A (PET-1)	20	6	30	10	50	4	20	-	-
CMS-852A (PET-1)	20	6	30	11	55	3	15	-	-
IMS-852A (IMS)	20	13	65	1	5	6	30	-	-

M = Maintainer; R= Restorer; SG= Segregating type; PR= Partial Restorer

The findings of present study are evident for fertility restoration reaction of the genotypes varies with genetic background of CMS lines. Success in identifying restorers from the limited number of genotypes tested indicates the availability of restorers in the cultivated varieties of sunflower for PET-1. Since only one restorer for CMS I could be identified, it indicated that IMS to be distinct from those of commercially used PET 1 cytoplasm. Hence it is safe to conclude that, while PET 1 can continue to be utilized for the production of commercial sunflower hybrids. Similarly chances do exist for the development of hybrids with CMS I cytoplasmic background. Nevertheless, efforts towards identification of different restorers for CMS I are desirable for greater genetic diversity to be used in the development of new restorer inbred lines and the hybrids. The restorer for one CMS line behaved as maintainer for another line of the same CMS source, reconciling the diversity among CMS lines of the same source and between the different sources. The newly identified maintainers also will have greater application in developing new and superior agronomic background coupled with good general combining ability new CMS lines for further utilization in hybrid breeding program for developing diverse hybrids with better heterosis and resistance to diseases and insect pests. The new restorers identified for the diverse CMS lines will help in developing hybrids with broad cytoplasmic base, which may further lead to enhanced production and productivity of sunflower by breaking the yield stagnation or yield barrier and enhanced heterosis and strengthen the future hybrid sunflower breeding programme.

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Effect of drip irrigation, fertigation and plant geometry on yield and water use efficiency in summer groundnut (*Arachis hypogaea* L.)

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ABSTRACT

A field experiment was conducted during summer seasons of 2014, 2015 and 2016 at Main Oilseeds Research Station, Junagadh Agricultural University, Junagadh, Gujarat. The study was designed to investigate the effect of planting geometry and nutrient management under drip and check basin method of irrigation on productivity of summer groundnut. Split-plot design with three replications was adopted to carry out the experiment. The treatments consisted of two methods of irrigation *viz.,* drip irrigation at 0.8 PEF and check basin method at 1.0 IW/CPE as main plot treatments, three planting geometries *viz.,* plant population @ 3.33 lakh/ha (spacing 30 cm x 10 cm), plant population @ 4.00 lakh/ha (spacing 25 cm x10 cm) and plant population @ 5.00 lakh/ha (spacing 20 cm x10 cm) as sub plot treatments and three fertility levels *viz.,* 75% RDF (18.75:37.50 NP kg/ha), 100% RDF (25.0:50.0 NP kg/ha) and 125% RDF (31.25:62.50 NP kg/ha) as sub sub plot treatments. The results revealed that drip irrigation @ 0.8 PEF on alternate day (lateral spacing 60 cm, dripper spacing 45 cm, dripper discharge 2 LPH, operating time 1 hour and 5 minutes with pressure 1.2 kg/cm^2) and water soluble fertilizer @ 75% of RDF (18.75-37.50 kg NP/ha) in five equal splits through fertigation at an interval of 8 days starting from 20 DAS and plant population @ 5.00 lakh/ha (spacing 20 cm x 10 cm) recorded significantly the higher pod yield, haulm yield and net returns, beside 23.45 per cent water and 25 per cent fertilizer saving as compared to conventional practices.

Keywords: Drip irrigation, Fertigation, Planting geometry, Summer groundnut

Groundnut is one of the most popular and universal crop cultivated in more than 120 countries. In India, it is cultivated on area of 5.53 million ha with production of 9.67 million tonnes and productivity of 1750 kg/ha during 2013-2014. Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu, Maharashtra and Rajasthan account for more than 90 per cent of the total groundnut area and 89.3 per cent of total groundnut production. Among the major groundnut growing states, Gujarat rank first in area (1.84 million ha) and production (4.92 million tonnes) with productivity of 2670 kg/ha (Anonymous, 2015). During summer season, there is a higher yield potential of groundnut in Saurashtra and Kutch region of Gujarat State. Drip irrigation system is an effective means of supplying water directly to soil and nearer to the plant root without much loss of water resulting in higher water productivity (Bandyopadhyay *et al.,* 2005; Padmalatha *et al.,* 2016). Plant density is highly associated with yield potential and optimum plant density per unit area is an important non monetary input to decide the maximum groundnut productivity. Fertilizer management is another key factor in improving groundnut yield. Hence, it is essential to use limited water for irrigation as a judiciously as possible. Thus, the present investigation was undertaken to find out the effect of drip irrigation, plant densities and different fertilizer levels (water soluble fertilizer) on the yield and its attributes in groundnut.

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MATERIALS AND METHODS

The experiment was carried out at Main Oilseeds Research Station, Junagadh Agricultural University, Junagadh, Gujarat, India to find out the effect of fertilizer doses, plant geometry and irrigation methods on growth, yield and yield attributes of groundnut with system lay out during summer season for consecutive three years (2014 to 2016). The soil of the experimental plot was clayey in texture and slightly alkaline in reaction. The soil has an organic carbon content of 0.59 per cent and was medium in available nitrogen (215 kg/ha), phosphorus (29.50 kg/ha) and sulphur (16.85 kg/ha) and high in potassium (314 kg/ha). The moisture content of the experimental plot at field capacity and permanent wilting point were 28.4 and 12.1 per cent, respectively, while the bulk density was 1.43 g cm^{-3}. Split-plot design with three replications was adopted to carry out the experiment. The treatments consisted of two methods of irrigation *viz.,* drip irrigation at 0.8 Pan evaporation fraction and check basin method at 1.0 IW/CPE as main plot treatments, three planting geometries *viz.,* plant population @ 3.33 lakh/ha (spacing 30 cm x 10 cm), plant population @ 4.00 lakh/ha (spacing 25 cm x10 cm) and plant population @ 5.00 lakh/ha (spacing 20 cm x10 cm) as sub-plot treatments and three fertility levels *viz.,* 75% RDF (18.75:37.50 NP kg/ha), 100% RDF (25.0:50.0 NP kg/ha) and 125% RDF (31.25:62.50 NP kg/ha) as sub sub-plot treatments. The groundnut variety 'GJG 31' was sown in first week of

February. A common surface irrigation was given to all the plots immediately after sowing for uniform germination. The laterals of drip system were laid in alternate inter rows (60 cm) and drippers of 2 LPH were spaced at 45 cm. The system was operated on alternate days at pan evaporation fraction (PEF) of 0.8 with a pressure of 1.20 kg/cm^2. In drip system, the irrigation was given on alternate days. The water meters were used to measure the volume of water applications. In surface method of irrigation, irrigation depth of 5.0 cm was applied at 1.0 IW/CPE. The cost of seeds, fertilizer and agro chemicals were taken following the recommended package of agronomic practices. The oil content of kernel was determined using Nuclear Magnetic Resonance Spectro Photometer (Oxford, 4000).

RESULTS AND DISCUSSION

Irrigation methods: The data pooled over three years (Table 1) revealed that the application of drip irrigation at 0.8 PEF (I_1) significantly recorded higher pod yield (2405 kg/ha), haulm yield (3550 kg/ha), kernel yield (1660 kg/ha), oil yield (815 kg/ha), number of branches per plant (5.58) , number of pods per plant (15.22), shelling per cent (68.97%), 100 kernel weight (42.04 g) and oil per cent (49.10%) as compared to check basin method of irrigation. The magnitude of increase in per cent pod yield, haulm yield, kernel yield and oil yield under I1 treatment of irrigation was to the tune of 18.94, 11.29, 22.33 and 24.43 per cent, respectively. Yield of a crop is a result of many physiological processes under which the crop is grown. The drip irrigation resulted in availability of higher soil moisture in the root zone throughout the crop period which resulted in higher relative leaf water content, growth parameters and dry matter production and subsequently in development of yield components and the yield (Chetti *et al.,* 1997). Similar findings were also reported by Manavadaria *et al.* (2004) and Mathukia *et al.* (2015).

Table 1 Effects of different treatments on growth, yield attributes and yield of groundnut (pooled data of three years)

Treatments	Plant height (cm)	No. of branches	Shelling (%)	100 kernel wt. (g)	No. of pods/ plant	Oil (%)	Pod yield (kg/ha)	Haulm yield kg/ha	Kernel yield (kg/ha)	Oil yield (kg/ha)
Main plot : Irrigation methods										
I_1: Drip irrigation at 0.8 PEF	27.69	5.58	68.97	42.04	15.22	49.10	2405	3550	1660	815
I_2: Check basin method at 1.0 IW/CPE	26.61	5.18	67.19	40.41	13.72	48.30	2022	3190	1357	655
CD (P=0.05)	NS	0.31	1.45	1.04	0.92	0.65	129	213	116	51
Sub-plot: Planting geometry										
P_1: Plant population @ 3.33 lakh/ha (spacing 30cm x10 cm)	27.17	5.34	68.19	41.32	14.80	48.92	2008	3189	1370	670
P_2: Plant population @ 4.00 lakh/ha (spacing 25cm x10 cm)	27.09	5.35	67.97	41.45	14.18	48.75	2204	3368	1499	731
P_3: Plant population @ 5.00 lakh/ha (spacing 20cm x10 cm)	27.19	5.45	68.06	40.90	14.44	48.43	2430	3553	1657	805
CD (P=0.05)	NS	NS	NS	NS	NS	NS	104	176	79	41
Sub-sub plot : Fertility levels										
F_1:75 % RDF	27.18	5.34	68.09	41.64	14.74	48.63	2297	3394	1528	744
F_2:100 % RDF	26.99	5.34	68.21	40.86	14.31	48.80	2166	3345	1490	728
F_3: 125 % RDF	27.28	5.47	67.94	41.16	14.36	48.67	2179	3371	1509	734
CD (P=0.05)	NS	NS	NS	NS	NS	NS	98	NS	NS	NS
Interaction										
I x P: CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	250	NS	NS
I x F: CD (P=0.05)	NS	NS	NS	NS	NS	0.59	NS	NS	NS	NS
P x F: CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I x P x F: CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Planting geometry: Different planting geometries significantly influenced the pod, haulm, kernel and oil yield (Table 1) and revealed that population @ 5.00 lakh/ha (spacing 20 cm x 10 cm, P_3) showed significantly higher pod yield (2430 kg/ha), haulm yield (3553 kg/ha), kernel yield (1657 kg/ha) and oil yield (805 kg/ha) as compared to the rest of treatments. Whereas, significantly the lowest pod yield, haulm yield, kernel yield and oil yield were observed under plant population @ 3.33 lakh/ha (spacing 30 cm x 10cm). An increase in pod yield in treatment P_3 was to the tune of 21.01 and 10.25 per cent and haulm yield 11.41 and 5.49 per cent over the treatments P_1 and P_2, respectively. This might be due to more plant population per unit area which ultimately reflected in yield of groundnut (Gunri *et al.,* 2015). The growth and yield attributes like plant height, number of pods/plant, shelling per cent and 100 kernel weights were not significantly influenced by various treatments (Table 1). These findings are in agreement with the results reported by Hirwe *et al.* (2006) and Soumya *et al.* (2011).

Fertility levels: The results furnished in Table 1 indicated that fertility levels (WSF) significantly influenced pod yield. Significantly higher pod yield (2297 kg/ha) was recorded by 75% RDF. The effect was significant in drip obviously due to high efficiency and easy availability of plant nutrients through the liquid fertilizers. In case of soluble fertilizers, the nutrients become available readily throughout the growth stages of crop which produces optimum yield. While, fertility levels were statistically comparable in respect of plant height, number of branches per plant, number of pods per plant, shelling, oil per cent, kernel and oil yield by different treatments. This might have resulted due to the fact that groundnut, being a leguminous crop, fixes atmospheric N and thus requires only a starter dose of N. Moreover medium status of P in experimental soil might be responsible for non-response of the crop to applied P. Similar results were also reported by Shinde *et al.* (2000) and Reddy *et al.* (2011).

Interaction: The effect of interaction between irrigation methods and plant geometry on haulm yield (Table 2) was significant. Application of drip irrigation @ 0.8 PEF (I_1) and plant population @ 4.00 lakh/ha (spacing 25 cm x10 cm, P_2) resulted in higher haulm yield (3770 kg/ha) which was remained at par with drip irrigation @ 0.8 PEF (I_1) and plant population @ 5.00 lakh/ha (spacing 20 cm x 10 cm, P_3). While interaction between drip irrigation @ 0.8 PEF (I_1) and fertility level of 125% RDF (F_3) recorded significantly higher oil per cent (49.32%), which were not significantly different from those with I_1 x F_2 and I_1 x F_1 (Table 3).

Table 2 Interaction effect of irrigation and plant geometry on haulm yield (pooled data of three years)

Irrigation/ plant geometry	Haulm yield (kg/ha) I_1	I_2	Mean	
P_1	3179	3199	3189	
P_2	3770	2967	3368	CD (P=0.05): 250
P_3	3700	3405	3553	
Mean	3550	3190		

Table 3 Interaction effect of irrigation and fertility levels on oil per cent (pooled data of three years)

Irrigation/ Fertility levels	Oil (%) I_1	I_2	Mean	
F_1	48.74	48.52	48.63	
F_2	49.23	48.38	48.80	CD (P=0.05): 0.59
F_3	49.32	48.01	48.67	
Mean	49.10	48.30		

Water use efficiency and water saving: The highest water use efficiency of 3.88 kg/ha/mm, was recorded with drip irrigation at 0.8PEF (I_1), plant population@ 5.00 lakh/ha (3.40 kg/ha/mm, P_3) and 75% RDF (3.18 kg/ha/mm, F_1). Nearly 23.5% water was saved due to drip irrigation (I_1) as compared to check basin method of irrigation (Table 4).

Economics: The results showed (Table 4) that the drip irrigation @ 0.8 PEF gave maximum gross return (₹105092/ha), net return (₹ 62954/ha) and B:C ratio (2.49). Among the plant geometries, plant population @ 5.0 lakh/ha (spacing 20 cm x 10 cm) recorded higher gross returns (₹106062/ ha), net returns (₹ 66163/ha) and B:C ratio (2.66). In respect of different fertility levels, application of 75% RDF recorded maximum grass return (₹ 99397/ha) and net return (₹ 62728 /ha) with B:C ratio of 2.71. This was mainly due to higher pod yield than rest of treatments.

On the basis of above findings, it may be concluded that summer groundnut should be irrigated through drip at 0.8 PEF on alternate day (lateral spacing 60 cm, dripper spacing 45 cm , dripper discharge 2LPH, operating time 1 hour and 5 minutes with pressure 1.2 kg/cm^2) and applied water soluble fertilizer @ 75% of RDF (18.75-37.50 kg NP/ha) in five equal splits through fertigation at an interval of 8 days starting from 20 DAS and maintain plant population @ 5.00 lakh/ha (spacing 20 cm x 10 cm) for higher productivity and net return, beside saving of 23.5 per cent water and 25 per cent fertilizer as compared to conventional practices.

Table 4 Effects of different treatments on economics and water use efficiency of groundnut (pooled data of three years)

Treatments	Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	BCR	Water applied (mm)	Water use efficiency (kg/ha/mm)
Main plot : Irrigation methods						
I_1: Drip irrigation at 0.8 PEF	42138	105092	62954	2.49	620	3.88
I_2: Check basin method at 1.0 IW/CPE	33379	88873	55494	2.66	810	2.50
Sub-plot: Planting geometry						
P_1: Plant population @ 3.33 lakh/ha (spacing 30cm x10 cm)	35879	88299	52420	2.46	715	2.81
P_2: Plant population @ 4.00 lakh/ha (spacing 25cm x10 cm)	37499	96587	59088	2.58	715	3.08
P_3: Plant population @ 5.00 lakh/ha (spacing 20cm x10 cm)	39899	106062	66163	2.66	715	3.40
Sub-sub plot : Fertility levels						
F_1:75 % RDF	36670	99397	62728	2.71	715	3.18
F_2:100 % RDF	37760	95008	57248	2.52	715	3.03
F_3: 125 % RDF	38848	96543	57696	2.49	715	3.08

Market price (₹/kg): Groundnut pod: ₹ 40, Groundnut haulm: ₹ 2.50; Cost of inputs (₹/kg) : Water soluble fertilizer (17-44-00) : 68 and Urea: 6.50, one season drip irrigation: ₹ 17500/ha and Surface irrigation: ₹ 8741/ha.

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Influence of different preceding crops and N levels on productivity and profitability of zero-till *rabi* castor (*Ricinus communis* L.)

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ABSTRACT

An experiment was conducted at College of Agriculture, Rajendranagar, Hyderabad during *kharif* and *rabi* 2010-11 and 2011-12. It was laid out in a split plot design, replicated thrice, with four preceding crops in main plots (green gram, groundnut, bajra and maize) and five nitrogen levels to *rabi* castor in sub plots (0, 40, 80, 120 and 160 kg N/ha) to find out the effect of preceding crops on system productivity and system profitability of zero-till *rabi* castor under different nitrogen levels. Among different systems, maize-castor with application of 120 kg/N/ha to castor gave greater system productivity in terms of castor equivalent yield (CEY) (6685 and 5828 kg/ha/year), higher system productivity/day (18.3 and 16 kg/ha/day) and system profitability (₹ 342 and 360 ha/day). However, it did not differ statistically with greengram-castor at the same level of 'N' with comparable CEY (6356 and 5515 kg/ha/year), system productivity per day (17.4 and 15.1 kg/ha/day) and system profitability (₹ 336 and 351 ha/day).

Keywords: Castor, Equivalent yields, Nitrogen, Preceding crop, Zero-till

Castor is a tropical crop cultivated around the world for its non-edible oilseed. In India, three states i.e. Gujarat, Rajasthan and Andhra Pradesh account for 96 per cent of the total castor seed production in the country. It is cultivated in an area of 8.39 lakh ha with a production and productivity of 10.62 lakh tonnes and 886 kg/ha, respectively (CSMAO, 2017). Castor when grown during *kharif* season, is threatened by drought and *Botryotinia* gray rot resulting in low productivity (500-600 kg/ha). But, India with 70 per cent share in world's castor trade, annually earns foreign exchange of about ₹2500 crores through export of oil and its derivatives (Ramanjaneyulu *et al*., 2014; Lakshmamma *et al*., 2016). Hence, there is an imminent need to enhance castor productivity by growing castor in *rabi* season during which *Botryotinia* gray rot is absent. However, information on preceding crops and their effect on *rabi* castor productivity is not available. Further, in view of short turnaround time between harvesting of preceding crops and succeeding castor, zero tillage is an option. Initial studies made at All India Co-ordinataed Research Project on Integrated Farming System, Hyderabad have revealed better performance of *rabi* castor under zero-till conditions following different *kharif* crops. Hence, it is felt essential to evaluate the performance of zero-till *rabi* castor under the influence of different preceding crops and N levels.

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MATERIALS AND METHODS

The field experiment was conducted during *kharif* and *rabi* seasons of the years 2010-11 and 2011-12 at College Farm, College of Agriculture, Rajendranagar, Hyderabad. The farm is situated at 18'50°N latitude, 77'-53°E longitude and an altitude of 542.6 m. The soil of the experimental site was sandy clay loam in texture with pH of 7.2, organic carbon of 0.59, available N of 264 kg/ha, 34 kg/ha available P_2O_5 and 236 kg/ha available K_2O. The experiment was laid out in split plot design with four preceding crops (greengram, groundnut, bajra and maize) in main plots and five nitrogen levels in sub plots (0, 40, 80, 120 and 160 kg N/ha) replicated thrice. The *kharif* crops were grown at the onset of monsoon with recommended package of practices. Castor was sown in zero-till plots by hand dibbling in the opened furrows immediately after harvest of *kharif* crops. Castor (PCH-111) was sown at a spacing of 90 cm x 60 cm. Before sowing, the seeds were treated with thiram @ 3g/kg seed as a prophylactic measure against seed borne diseases like alternaria leaf blight, seedling blight and wilt. The total rainfall of 681.0 mm in 42 rainy days was received during *kharif* and 251.6 mm (18 rainy days) in *rabi* crop growth period during 2010-11 and 377.1 mm (25 rainy days) during *kharif* and 121.5 mm in 9 rainy days in *rabi* crop growth period during 2011-12. The soil of the experimental site was sandy clay loam in texture with pH of 7.2. The experiment was laid out in split plot design with four preceding crops (green gram, groundnut, bajra and maize) in main plots and five nitrogen levels in sub plots (0, 40, 80, 120 and 160 kg N/ha) replicated thrice. The castor equivalent which indicates system productivity was calculated by the following formula.

$$\frac{Yp \times Pp}{Pc} + Pb$$

Where,

Yp and Pp indicates yield and price of preceding crop

Pc indicates price of castor

Pb indicates yield of castor

RESULTS AND DISCUSSION

A perusal of data in Table 1 indicates that among different preceding *kharif* crops, green gram registered an average productivity of 1332 and 1145 kg/ha seed yield and 2192 and 2015 kg/ha haulm yield; groundnut produced 1666 and 1496 kg/ha pod yield and 3173 and 2800 kg/ha haulm yield; bajra produced 1925 and 1840 kg/ha grain yield and 3940 and 3705 kg/ha of stover yield and maize gave 6890 and 6715 kg/ha grain yield and 8243 and 7920 kg/ha stover yield during 2010 and 2011, respectively. However, in terms of economics, maize gave highest mean net returns (₹ 73530/ha) with a mean benefit cost ratio of 4.32 followed by greengram (₹ 45452/ha; 3.99), groundnut (₹53250/ha; 3.28), and bajra (₹17021; 1.22).

Castor equivalent yield (Table 2) differed significantly due to differential yield potential of preceding *kharif* crops and market price. The castor equivalent yield of maize (3730 and 3161 kg/ha) was significantly higher over other *kharif* crops tested *viz.,* groundnut (2959 and 2347 kg/ha), green gram (2438 and 1906 kg/ha) and bajra (1291 and 1068 kg/ha) during first and second year, respectively. The system productivity in terms of CEY kg/ha/year of maize-castor (6208 and 5417) system was significantly higher over other systems. It was followed by greengram-castor (5575 kg/ha and 4781), groundnut-castor (5588 and 4720) and bajra-castor (4240 and 3782) systems. Among nitrogen levels, highest system productivity was observed with the supply of 160 kg N/ha (6120 and 5316) to castor over 120 kg N/ha (6023 and 5236) and other lower levels of nitrogen. The probable reason for such a positive response due to addition of higher rate of nitrogen might be tended to put more vegetative growth, better root development and resulted in efficient photosynthesis and finally produced more seed yield and system productivity. The former two were at par. The magnitude of increase in castor equivalent yield under maize-castor system was to the tune of 11.1, 11.4 and 46.4 per cent during first year and 13.3, 14.8 and 43.2 during second year, respectively over groundnut-castor, greengram- castor and bajra-castor systems. Similarly, highest castor equivalent yield was observed in maize-castor system at 120 kg N/ha by Patel *et al.* (2009) and Anonymous (2013). The system productivity per day due to preceding crops and N levels to castor followed similar trend as that of system productivity/year.

The interaction between preceding crops and nitrogen levels on system productivity of *rabi* castor based systems was found significant during both the years (Table 3) of experimentation. Significantly higher system productivity was recorded at 160 kg N/ha over lower nitrogen levels, irrespective of the preceding crops tested. However, it was statistically on par with that of 120 kg N/ha. Among different treatment combinations, greater values for system productivity were observed with maize as preceding crop at 160 kg N/ha as well as at 120 kg N/ha and greengram at 160 kg N/ha during first year; and maize with 160 and 120 kg N/ha during second year.

The system profitability of different cropping systems (Table 4) showed that maize-castor system at 160 kg N/ha (₹ 348 and 367/ha/day) and 120 kg N/ha (₹ 342 and 360 /ha/day) during first year; and greengram-castor system at 160 kg N/ha (₹ 338 and 354/ha/day) and 120 kg N/ha (₹ 336 and 351/ha/day) during second year were found more profitable. The results corroborate the findings of Anonymous (2013) and Patel *et al*. (2009).

It can be concluded that, maize-castor/green gram-castor cropping system with the application of 120 kg N/ha to zero-till *rabi* castor may be the better option for securing higher system productivity and profitability.

Table 1 Grain/seed (kg/ha), stover/haulm yield (kg/ha) and economics of *kharif* crops

Kharif crop	Grain/seed yield		Stover/haulm yield		Gross returns (₹./ha)		Net returns (₹/ha)		B:C ratio	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Greengram	1332	1145	2192	2015	58524	55280	47624	46115	4.37	3.61
Groundnut	1666	1496	3173	2800	71002	68048	55102	51398	3.46	3.09
Bajra	1925	1840	3940	3705	30980	30962	17480	16562	1.29	1.15
Maize	6890	6715	8243	7920	89508	91651	73008	74051	4.42	4.21

Market rate (₹) for different crops:
Greengram: ₹ 39 and 43 for seed in 2010 and 2011 year, respectively; ₹ 3 for straw in both years
Groundnut: ₹ 35 and 38 for pod in 2010 and 2011 year, respectively; ₹ 3 for straw in both years
Bajra: ₹ 12 and 12.80 for grain in 2010 and 2011 year, respectively; ₹ 2 for straw in both years
Maize: ₹ 10 and 10.70 for grain in 2010 and 2011 year, respectively; ₹ 2.50 for straw in both years

Table 2 Castor equivalent yield (kg/ha) of zero-till *rabi* castor as influenced by different preceding crops and nitrogen levels

Treatments	System productivity (kg/ha)						Mean
	2010-11			2011-12			
	CEY of *Kharif*	*Rabi*	Total	CEY of *Kharif*	*Rabi*	Total	
Preceding crop							
Greengram	2438 (1332)	3137	5575	1906 (1145)	2875	4781	5178
Groundnut	2959 (1666)	2630	5588	2347 (1496)	2373	4720	5154
Bajra	1291 (1925)	2949	4240	1068 (1840)	2714	3782	4011
Maize	3730 (6890)	2479	6208	3161 (6715)	2256	5417	5813
SEd ±	35	89	80	40	75	70	
CD (P=0.05)	86	218	195	99	182	170	
'N' levels (kg/ha)							
0	2635 (2986)	1598	4233	2057 (2727)	1566	3622	3928
40	2575 (2935)	2441	5016	2080 (2754)	2284	4364	4690
80	2604 (2948)	3019	5623	2103 (2783)	2735	4838	5231
120	2627 (2969)	3396	6023	2189 (2875)	3046	5236	5630
160	2581 (2930)	3539	6120	2173 (2856)	3144	5316	5718
SEd ±	41	76	67	38	78	58	
CD (P=0.05)	NS	155	137	78	158	119	
Interaction	NS	Sig.	Sig.	NS	Sig.	Sig.	

Figures in parentheses are actual yields of *kharif* crops (kg/ha)
Market rate of different crops
Greengram: ₹ 39 and 43 for seed in 2010 and 2011 year, respectively; ₹ 3 for straw in both years
Groundnut: ₹ 35 and 38 for pod in 2010 and 2011 year, respectively; ₹ 3 for straw in both years
Bajra: ₹ 12 and 12.80 for grain in 2010 and 2011 year, respectively; ₹ 2 for straw in both years
Maize: ₹ 10 and 10.70 for grain in 2010 and 2011 year, respectively; ₹ 2.50 for straw in both years
Castor: ₹ 24 and 29 for castor been in 2010 and 2011 year

Table 3 System productivity per day (kg/ha/day) as influenced by preceding crops and nitrogen levels to zero-till *rabi* castor during 2010-11 and 2011-12

N' levels to Castor	Preceding crop (year 2010-11)					Preceding crop (year 2011-12)				
	Greengram	Groundnut	Bajra	Maize	Mean	Greengram	Groundnut	Bajra	Maize	Mean
0 kg/ha	11.4	12.5	8.1	14.4	11.6	9.5	10.4	7.2	12.6	9.9
40 kg/ha	14.2	14.2	10.3	16.3	13.7	11.9	12.3	9.5	14.2	12.0
80 kg/ha	15.7	16.0	12.3	17.5	15.4	13.7	13.2	10.8	15.3	13.3
120 kg/ha	17.4	16.8	13.5	18.3	16.5	15.1	14.3	12.0	16.0	14.3
160 kg/ha	17.6	17.1	13.8	18.6	16.8	15.3	14.5	12.3	16.2	14.6
Mean	15.3	15.3	11.6	17.0		13.1	12.9	10.4	14.8	

	Preceding crop	N levels	N at same PC	PC at same or dft N	Preceding crop	N levels	N at same PC	PC at same or dft N
SEd±	0.22	0.18	0.37	0.47	0.16	0.15	0.30	0.35
CD (P= 0.05)	0.54	0.38	0.75	1.01	0.40	0.31	0.61	0.75

Table 4 System profitability (₹/ha/day) as influenced by preceding crops and nitrogen levels to zero-till *rabi* castor during 2010-11 and 2011-12

N levels to Castor	Preceding crop (year 2010-11)					Preceding crop (year 2011-12)				
	Greengram	Groundnut	Bajra	Maize	Mean	Greengram	Groundnut	Bajra	Maize	Mean
0 kg/ha	197	210	110	252	192	193	208	121	267	197
40 kg/ha	262	246	162	295	241	260	258	183	311	253
80 kg/ha	297	291	208	324	280	313	283	221	341	290
120 kg/ha	336	307	234	342	305	351	315	254	360	320
160 kg/ha	338	312	241	348	310	354	319	261	367	325
Mean	286	273	191	312		294	276	208	329	

	Preceding crop	N levels	N at same PC	PC at same or dft N	Preceding crop	N levels	N at same PC	PC at same or dft N
SEd±	4.9	4.4	8.7	10.6	5	4	9	11
CD (P= 0.05)	12.1	8.9	17.7	22.9	13	9	17	24

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Induction of defense mechanisms with chemical elicitors and *Alternaria brassicae* in mustard (*Brassica juncea*)

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ABSTRACT

Induction of resistance in plants by the application of various biotic and abiotic agents is well known, however, our understanding on the impact of such agents is still poor. Henceforth, effort has been made towards understanding of induced resistance in crop protection. Two promising combinations of benzothiadiazole (BTH) and salicylic acid (SA) *viz.,* T_1 (3.3ppm BTH + 33.3ppm SA) and T_2 (6.6ppm BTH + 16.6ppm SA), were tested with/without avirulent biotic inducer, *Alternaria brassicae* for their ability to induce changes in the activities of defense enzymes (peroxidase, superoxide dismutase and phenylalanine ammonia lyase) and phenolics that may help in boosting the defense mechanism of *Brassica juncea* (var. RLM 619) against the attack of *Alternaria* blight. The results revealed that both the combinations of elicitors showed increase in the activity of defense enzymes and phenolics on all days of observation as compared to control in four and five weeks old plants. It was observed that the bio-control agent, *A. brassicae* induced higher level of defense enzymes and phenolics in inoculated leaves than that of uninoculated leaves on all days of observation. In conclusion, this study will be useful in formulating *A. brassicae* and elicitors based formulations which may have effective defense responses in mustard.

Keywords: *Alternaria brassicae,* Benzothiadiazole, Defense enzymes, Phenolics, Salicylic acid

A range of infectious diseases are known that causes huge crop losses every year. The productivity of Indian mustard, second largest oilseed crop grown in the world, is highly hampered by the fungal disease, *Alternaria* blight and published reports account that it covers over a wide geographical area all over the world up to 47 per cent yield loss (Meena *et al.,* 2010). Their attack not only degrade the quality of seed but also reduces the oil content remarkably. Although a vast group of fungicides are available in market but their use is costly and application is burdensome. Therefore, the considerable efforts have been made to devise environmental friendly strategies for the check of such fungal diseases and thus to save human race from health hazard.

In 1900, it was accustomed that plants formerly infected by the pathogen become resistant to further infection which suggested the existence of immune system in plants (Ray, 1901). Resistance against pathogen infection can be aroused in plants by a broad range of biotic and abiotic agents (Lyon, 2007). In broad terms, induced resistance can split into two main types: systemic acquired resistance (SAR) and induced systemic resistance (ISR). SAR can be induced by treatment with a variety of biotic (avirulent pathogens) and abiotic agents certain chemicals (e.g. acibenzolar-S-methyl, ASM) and is mediated by a salicylic acid (SA)-dependent process. ISR develops as a result of colonization of plant roots by certain strains of plant growth-promoting rhizobacteria (PGPR) and is mediated by a jasmonate (JA)-and ethylene (ET)-sensitive pathway (Spoel and Dong, 2012). The first abiotic resistance activator, Probenazole, was registered in Japanas Oryzemate in 1975, and since then many other chemical and biological activators have been developed, including benzothiadiazole (BTH) by Novartis as a potent inducer of plant immune responses. Mellilo *et al.* (2014) showed that BTH application on tomato plants makes them more resistant to infection by nematodes by activating plants own defense response. Petersen *et al.* (2000) showed that injection of SA in tobacco elicited enhanced resistance to tobacco mosaic virus (TMV), and accumulation of SA triggered the accumulation of PR-proteins. SA has strongly been used to prompt resistance to a wide range of diseases in field crops (Karthikeyan *et al.,* 2009; Abdel-Monaim *et al.,* 2011).

These natural and synthetic compounds called elicitors induces similar defense response in plants as induced by the pathogen infection. Following elicitor perception, sensitized plants defend themselves against pathogenic attack by triggering various defense mechanisms including production of phytoalexins, accumulation of acid soluble pathogenesis related proteins (PR-proteins) and deposition of structural barriers. Some of the PR proteins such as chitinases (PR-3, -4, -8, -11) and β-1, 3-glucanases (PR-2) have the potential to hydrolyze chitin and β-1,3-glucan, respectively, which are major components of fungal cell walls, leading to the inhibition of fungal growth (Golshani *et al.,* 2015).The application of elicitors also increases the production of anti-oxidative compounds that protect the plants from oxidative damage due to biotic and abiotic stresses.

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Although, vast work has been done to study the effect of biotic and abiotic agents separately but it has become extremely important to made efficient formulations and promote their wide application in agriculture. Therefore, the main objective of the present investigation is to assess the effect of biotic (*A. brassicae*) and abiotic (combinations of BTH and SA) on the biochemical basis of disease resistance, by measuring the levels of defense compounds *viz.,* peroxidase (PO), phenylalanine lyase (PAL) and superoxide dismutase (SOD) and phenolics *viz,* total phenols, o-dihydroxy phenols and flavanol content from the leaves of four and five weeks old germinating seeds of *B. juncea* var. RLM619.

MATERIALS AND METHODS

Plant material and growth conditions: Seeds of *B. juncea* (var. RLM619) procured from Oilseed section, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana were sown in plastic trays (13"x 12"x 4") filled with soil in an incubator at 25±2ºC temperature under 16/8 h light/dark period. After the seeds started germinating, trays were then moved to fields. The experiment was conducted in *rabi* season during 2009-10 at the experimental farm of PAU, Ludhiana. Four and five weeks old Brassica plants grown in fields were sprayed with promising combination of elicitors *viz.,* T_1 [3.3ppm benzothiadiazole (BTH)+33.3ppm salicylic acid (SA)] and T_2 (6.6ppm BTH + 16.6ppm SA) solutions. Inoculation was done with fungal spores of *A. brassicae* (104/ml) after 24 h of elicitor application. The pots considered as control were sprayed with water only. Leaves were taken on 3rd, 5th and 7th day after inoculation. Biochemical analyses of all the parameters were carried out. Each experiment was repeated at least three times and the data were presented as means of all the representative experiments. Activities of defense related enzymes were determined using fresh samples, whereas, samples were dried at 70°C for estimation of phenols.

Preparation of fungal inoculums: Spores of *A. brassicae* were prepared by inoculating sterilized potato dextrose agar (PDA) slants with disk of fungal growth taken from infected leaf of *Brassica* plant. Tubes were incubated at 25°C. The fungus was sub-cultured every 15 days. Three weeks old cultures were flooded with sterilized distilled water and conidia were dislodged to yield spores. The spore concentration was determined with a haemocytometer and adjusted to $1x10^4$ spores/ml with sterile distilled water.

Extraction and assay of defense enzymes: In order to estimate defense enzymes, 0.15 g of fresh leaf samples were ground in pestle and mortar with 3.5ml of ice-cold 0.1 M sodium phosphate buffer (pH 7.5). The homogenates were centrifuged at 10,000 rpm for 25 min at 4°C and supernatants were used for determination of defense enzyme assays.

Peroxidase (PO, EC 1.11.1.7) activity was assayed by the method of Shannon *et al.* (1996) Enzyme activity was expressed as the change in absorbance at 470 nm min^{-1} g^{-1} fresh weight (total activity) and min^{-1} mg^{-1} protein (specific activity).

Superoxide dismutase (SOD, EC 1.15.1.1) activity was assayed by the method of Marklund and Marklund (1974). For the test, 0.1ml enzyme extract was added to inhibit the auto-oxidation of pyragallol to about 50%. One unit of enzyme activity has been defined as the amount of enzyme causing 50% inhibition of the auto-oxidation of pyragallol observed in blank.

Phenylalanine Ammonia Lyase (PAL, EC 4.1.1.5) activity was determined according to the protocol by Burrell and Rees (1974). The enzyme was assayed by following the appearance of t-cinnamic acid resulting from the deamination of L-phenylalanine. The enzyme activity was expressed as μg t-cinnamic acid formed h^{-1} g^{-1} fresh weight and μg t-cinnamic acid formed h^{-1} mg^{-1} protein. The concentration of t-cinnamic acid was read from standard curve prepared from t-cinnamic acid in the range of 5-40μg.

Extraction and estimation of phenolic compounds: Weighed (40mg), dried leaf samples and refluxed with 5ml of 80% methanol for 1h. The refluxed material was filtered and volume was made to 10ml by washing with hot 80% methanol (Khaled *et al.,* 2007). The extract thus prepared was used for estimation of phenolic content *viz.,* total phenols, o-dihydroxyphenols and flavanols.

Total phenols were estimated by the method of Swain and Hillis (1959). The absorbance of blue colour was read in a spectrophotometer at 760nm against the blank. The blank was prepared from water and reagents only. The concentration of total phenols was determined from standard curve prepared by using gallic acid (10-50μg).

O-dihydroxyphenols were estimated by the method of Nair and Vaidyanathan (1964). The light cherry colour developed, whose absorbance was read after 15min at 540nm against the blank, which consisted of water and reagents only. The concentration of o-dihydroxyphenols was determined from standard curve prepared by using catechol (6-40μg).

Flavanols were estimated by the method of Balabaa *et al.* (1974). Yellow colour was read at 420nm against 0.1M methanoilc solution of $AlCl_3$ as blank. The concentration of flavanols was determined from standard curve prepared by using Rutin (40-200μg).

Statistical analysis: The data was analyzed statistically, using the variance analysis. Student t-test was used for assessment of differences between the means, adopting the significant level α=0.01% and α=0.05% on excel sheet.

RESULTS AND DISCUSSION

Abiotic elicitors (chemical elicitors) and biotic elicitors (aviruent pathogen) are well known activators of defense response in plants. Many studies have shown positive effect of these biotic and abiotic elicitors in inducing SAR (Spoel and Dong, 2012). In this study, changes have been observed in the defense profile (defense enzymes activity *viz.,* PO, SOD, PAL and phenolic content) of four and five weeks old *B. juncea* (var. RLM 619) plants using two different promising combination of abiotic elicitor *viz.,* T_1 (3.3ppm BTH+33.3ppm SA) and T_2 (6.6ppm BTH+ 16.6ppm SA) with/without *A. brassicae* spores inoculation (Tables 1to 3).

Effect of treatment of elicitors with/without *A. brassicae* inoculation on defense enzymes activity: The results revealed that activities of all the three defense enzymes PO, SOD and PAL did respond to both the elicitor combinations *viz.,* T_1 and T_2 in the leaves of uninoculated and inoculated plants than the control. However, uninoculated plants showed less elevation in the defense enzymes activities as compared to the inoculated ones.

Peroxidase (PO): Both the combinations of elicitors *viz.,* T_1 and T_2 were found to be effective in eliciting the activity of PO (ΔA/min/g FW) in the leaves of uninoculated and inoculated plants than the control. However, activity of PO was less in the leaves of five weeks old plants as compared to that of four weeks old plants. Among the two combinations tried, maximum increase in the activity of PO was shown by T_2 in both four and five week's old *Brassica* plants. In four weeks old plants, significant increase (at 5% level) was shown by T_1 in inoculated leaves on 7th DAS whereas spray with T_2 showed significant increase in inoculated leaves on 3rd and 5th DAS and both uninoculated or inoculated leaves on 7th DAS as compared to control. In five weeks old plants, T_1 showed maximum increase in PO activity on 7th DAS. Spray with T_1 showed significant increase (at 5% level) in PO activity of inoculated leaves on 5th and 7th DAS whereas spray with T_2, showed significant increase on all days of observation in inoculated leaves (Table 1). When the results were expressed in ?A/min/mg protein similar trend was followed. Our results showed that both the combinations of elicitors elicited the activity of PO than that of control, however, T_2 was more effective than T_1 in both 4 and 5 weeks old plants except on 7th DAS in 5 weeks old plants where T_1 showed high increase in PO activity than T_2. Inber *et al.* (2001) reported that BTH applications markedly elicited peroxidase activity both locally and systemically in cotton seedlings and therefore, BTH acts as an excellent elicitor of the SA activated defensive pathway in cotton. PO and PPO are the important enzymes that play important role in defense mechanism against many biotic and abiotic stresses. Increase in the activity of these enzymes by exogenous application of SA and their role in plant defense against pathogens has been studied in many crops (Radhakrishnan and Balasubramanian, 2009; Rivas-San *et al.,* 2011). Increase in PO activity was observed in plants challenged with *A. brassicae* spores after both the combinations of elicitor treatment; however, the increase was more prominent in 5 weeks old plants. A significantly high concentration of PAL, PO, PPO and chitinase was observed in rice root tissue treated with *Pseudomonas fluorescens* in response to invasion by rice root nematode, *Meloidogyne graminicola* collectively contribute to induced systemic resistance and decrease in nematode infection (Anita and Samiyappan, 2012). PO, PPO and catalase are involved in the oxidation of phenolic compounds. The activities of these enzymes in diseased plants and the resistance offered by the hosts were attributed to the toxicity of their oxidation products such as quinone and hydrogen peroxide (Peng and Kuc, 1992) and are associated with secondary wall biosynthesis and lignification. Lignin is highly resistant to attack by microorganisms, and lignified cell walls are an effective barrier to pathogen entrance and spread. Therefore, it can be suggested that higher PO level in *Brassica* leaves may be responsible for inducing resistance against *A. brassicae* infection.

Superoxide dismutase (SOD): Activity of SOD showed an increase from 3rd to 7th DAS in both uninoculated and inoculated leaves. From our results it can be followed that inoculation of *Brassica* leaves with *A. brassicae* after 24 h of elicitor treatment resulted in significant increase in SOD activity as compared to their respective uninoculated control, however, increase due to inoculation was more notable in 5 weeks old plants (Table 2). Kong *et al.* (2000) reported induced SOD activity in roots of *Pinus massoniana* after infection with *Pislithu stinctorius.* In addition to the increase in SOD activity on infection with spores of *A. brassicae,* our results showed increase in SOD activity of the leaves treated with both the combinations of elicitors *viz.,* T_1 and T_2 as compared to control in 4 and 5 weeks old plants. In 4 weeks old plants, T_1 showed maximum increase in inoculated leaves on 3rd and 5th DAS, however, on 7th DAS, T_2 showed better elicitation than T_1. On the other hand in 5 weeks old plants, T_2 showed more elicitation in inoculated leaves on 3rd and 5th DAS whereas on 7th DAS, maximum increase in the activity of SOD was shown by T_1. Increase in the SOD activity in soybean seedlings sprayed with 200 ppm of SA has been reported (Shi and Chang, 1995). In plants treated with ASM, activities of antioxidant enzymes such as SOD and GST were estimated as markers of resistance. The results indicated that ASM treatment led to enhanced activities of SOD and GST in tomato leaves. A slight increase in SOD and GST activities was also found in *Clavibacter michiganensis* subsp. *michiganensis* (Cmm)-infected leaves. However, the increase in enzyme activities occurred much more rapidly and was more strongly enhanced in Cmm- infected leaves that were previously treated with ASM (Soylu *et al.,* 2003). SOD is likely to be the first enzyme able to scavenge O2* and its activity usually increases with overproduction of superoxide anions. Hence, higher activity of SOD in inoculated and elicitor treated *Brassica* leaves suggested their role in defense against invading pathogens.

Phenylalanine ammonia lyase (PAL): The PAL activity showed significant increase (at 5% level) over control on all days of observation after spray with T_1 in both uninoculated and inoculated leaves (Table 3) whereas spray with T_2 showed significant increase as compared to control on 3rd and 7th DAS. Spray with T_1 showed 1.5, 1.4 and 1.5 folds increase in PAL activity of inoculated leaves on 3rd, 5th and 7th DAS respectively, however, spray with T_2 showed 1.5, 1.4 and 1.6 folds increase on the same days of observation. Therefore, both the combinations showed almost similar fold increase in the activity but on 7th DAS, T_2 showed more effective results. In general, spray with T_2 showed significant increase in PAL activity of both inoculated and uninoculated leaves on 5th and 7th DAS whereas spray with T_1 showed significant increase on 7th DAS in inoculated leaves. Out of the two combinations tried, spray with T_2 showed maximum increase in the activity of PAL in uninoculated and inoculated leaves on all days of observation. Specific activity showed similar trend. The PAL activity was found to be more in the leaves of inoculated plants than in the uninoculated ones in all the treatments. Our results indicated that out of the two combinations of elicitor tried, T_2 was more effective in enhancing the activity of PAL in both uninoculated and inoculated leaves of 4 and 5 weeks old *Brassica* plants. However, both the combinations of elicitors effectively enhanced the activity of PAL in 4 and 5 weeks old *Brassica* plants than that of control. These results suggested that production of PAL, leading to phenylpropanoid biosynthesis in inoculated *Brassica* leaves, is an early defense response to infection and elicitor treatment. These results are supported by other reports like the PAL enzyme was progressively increased in elicitor treated yeast cells with up to a four-fold relative to control (Gomez-Vasquez *et al.,* 2004), high enzyme activity was observed in fungal treated cell cultures of carrot (Kurosaki *et al.,* 1986). It was also interpreted that inoculation with *A. brassicae* resulted in significant increase in PAL activity of both 4 and 5 weeks old inoculated plant as compared to their respective uninoculated leaves. Katoch (2005) showed increase in the PAL activity after treatment with different concentrations of elicitors *viz.,* SA and 4-ABA on pea plants and also it was observed that the treatment with *E.polygoni* resulted higher increase in PAL activity. Increased PAL activity was considered as an indicator of resistance in plants to pathogens.

Table 1 Effect of combinations of elicitors (BTH and SA) with/without *A. brassicae* spores inoculation on peroxidase activity in the leaves of 4 and 5 weeks old *B. juncea* (var.RLM 619) plants

Treatments (ppm)	Days after spray (DAS)					
	3rd		5th		7th	
	Uninoculated	Inoculated^{+}	Uninoculated	Inoculated^{+}	Uninoculated	Inoculated^{+}
	Peroxidase (ΔA/min/g FW)					
	Four weeks old plants					
C (water)	104.6±13.9 (0.3±0.1)	118.9±15.9 (0.5±0.1)	116.7±14.6 (0.5±0.2)	125.2±15.2 (0.5±0.1)	148.2±7.0 (2.3±0.3)	153.2±4.1 (2.3±0.3)
T_1 (3.3BTH+33.3 SA)	109.8±12.1 (0.5±0.1)	125.1±11.2 (0.5±0.1)	120.5±18.1 (0.7±0.2)	138.4±15.5 (0.4±0.1)	159.0±5.9 (2.2±0.3)	173.0±63.6^{ab} (2.4±0.5)
T_2 (6.6BTH+16.6SA)	130.8±18.7 (0.6±0.1)	147.4±22.8^{b} (0.7±0.2)^{b}	101.9±15.0 (0.5±0.0)	174.2±9.4^{ab} (0.7±0.0)^{ab}	166.4±6.8^{a} (2.5±0.3)	188.6±7.4^{ab} (2.5±0.3)
	Five weeks old plants					
C (water)	41.6±4.1 (0.4±0.0)	56.0±5.8^{b} (0.5±0.0)^{b}	99.2±17.6 (1.6±0.3)	142.7±3.4^{b} (2.3±0.0)^{b}	100.0±17.1 (1.3±0.3)	141.5±2.4^{b} (2.2±0.1)^{b}
T_1 (3.3BTH+33.3 SA)	45.9±9.7 (0.4±0.1)	59.1±2.4 (0.6±0.0)^{b}	111.6±10.6 (1.4±0.0)	200.3±7.8^{ab} (2.6±0.3)^{b}	103.3±10.1 (1.5±0.3)	182.0±20.7^{ab} (2.3±0.1)^{b}
T_2 (6.6BTH+16.6SA)	57.5±7.8^{a} (0.5±0.1)	75.0±2.4^{ab} (0.6±0.0)^{ab}	117.8±6.2 (1.6±0.1)	224.8±11.8^{ab} (3.1±0.1)^{ab}	87.8±4.8 (1.0±0.1)	132.6±5.3^{ab} (1.8±0.1)^{ab}

The results are mean ±SD of 3 replicates; BTH = Benzothiadiazole; SA=Salicylic acid
+Inoculation with *A. brassicae* spores was carried out 24h after treatment
*Specific activity (ΔA/min/mg protein) shown within parenthesis
a - Significant (at 5% level) difference between control and treatments (student's t - test)
b - Significant (at 5% level) difference between uninoculated and inoculated treatments (student's t - test)

Table 2 Effect of combinations of elicitors (BTH and SA) with/without *A. brassicae* spores inoculation onsuperoxide dismutase activity in the leaves of 4 and 5 weeks old *B. juncea* (var.RLM 619) plants

Treatments (ppm)	Days after spray (DAS)					
	3rd		5th		7th	
	Uninoculated	Inoculated+	Uninoculated	Inoculated+	Uninoculated	Inoculated+
	Superoxide dismutase activity(ΔA/min/g FW)					
	Four weeks old plants					
C (water)	113.8±22.5	159.8±34.5	177.9±60.0	207.6±23.4	216.1±43.7	288.7±38.4
	(0.3±0.1)	(0.6±0.1)^{b}	(0.8±0.3)	(0.8±0.1)	(3.3±0.7)	(4.4±0.9)
T_1 (3.3BTH+33.3 SA)	144.0±10.6	175.5±31.7	184.6±45.6	308.1±26.2^{ab}	255.4±37.3	329.3±24.7^{b}
	(0.7±0.0)^{a}	(0.8±0.2)	(1.0±0.2)	(0.9±0.2)	(3.5±1.0)	(4.6±0.6)
T_2 (6.6BTH+16.6SA)	108.9±4.8	161.6±47.2	198.5±15.1	267.5±29.5^{ab}	210.0±85.8	335.3±16.9
	(0.5±0.1)	(0.7±0.1)^{b}	(0.8±0.0)	(1.1±0.0) ^{ab}	(3.1±1.0)	(4.8±0.6)
	Five weeks old plants					
C(water)	208.3±23.9	216.7±18.8	143.8±14.9	221.9±11.8^{b}	257.8±40.3	278.0±22.2
	(2.0±0.3)	(2.2±0.1)	(1.9±0.3)	(3.5±0.1)^{b}	(3.4±0.6)	(4.4±0.4)
T_1 (3.3BTH+33.3 SA)	230.4±10.1	231.0±2.2	208.9±23.7^{a}	280.5±11.8^{ab}	267.2±11.5	315.1±57.1
	(2.2±0.4)	(1.9±0.2)	(3.0±0.6)^{a}	(3.6±0.3)	(3.9±0.5)	(4.1±1.0
T_2 (6.6BTH+16.6SA)	229.1±11.1	235.6±13.3	229.7±44.7^{a}	294.8±31.4^{a}	273.6±26.1	274.6±15.4
	(2.0±0.2)	(2.2±0.3)	(2.5±0.2)^{a}	(4.0±0.3)^{b}	(3.0±0.0)	(3.7±0.4)^{b}

\# The results are mean ±SD of 3 replicates
+Inoculation with *A. brassicae* spores was carried out 24h after treatment
* Specific activity (ΔA/min/mg protein) shown within parenthesis
a - Significant (at 5% level) difference between control and treatments (student's t - test)
b - Significant (at 5% level) difference between uninoculated and inoculated treatments (student's t - test)

Table 3 Effect of combinations of elicitors (BTH and SA) with/without *A. brassicae* spores inoculation on phenylalanine ammonia lyase activity in the leaves of 4 and 5 weeks old *B. juncea* (var.RLM 619) plants

Treatments (ppm)	Days after spray (DAS)					
	3rd		5th		7th	
	Uninoculated	Inoculated+	Uninoculated	Inoculated+	Uninoculated	Inoculated+
	Phenylalanine ammonia lyase (µg-t-cinnamic acid formed/hr/g FW)					
	Four weeks old plants					
C (water)	159.7±38.5	227.0±25.2	227.0±25.2	269.1±29.1	269.1±29.1	285.9±14.6
	(0.5±0.2)	(0.9±0.1)$_{b}$	(1.0±0.3)	(1.1±0.1)	(4.2±0.8)	(4.3±0.5)
T_1 (3.3BTH+33.3 SA)	243.8±29.1	344.7±38.5$_{ab}$	285.9±81.1	378.4±66.7	403.6±66.7$_{a}$	428.8±50.4$_{a}$
	(1.2±0.2)	(1.5±0.2)$_{a}$	(1.6±0.8)	(1.1±0.3)	(5.5±1.3)	(5.9±0.5)$_{a}$
T_2 (6.6BTH+16.6SA)	327.9±43.7$_{a}$	353.1±25.2$_{a}$	319.5±38.5$_{a}$	386.8±29.1$_{a}$	412.0±38.5$_{a}$	470.9±63.5$_{a}$
	(1.4±0.2)$_{a}$	(1.6±0.2)$_{a}$	(1.3±0.1)	(1.6±0.3)$_{a}$	(6.3±0.9)$_{a}$	(6.7±0.6)$_{a}$
	Five weeks old plants					
C (water)	218.6±38.5	243.8±77.1	227.0±50.4	269.1±29.1	210.2±58.2	235.4±14.6
	(2.1±0.4)	(2.5±0.8)	(3.0±0.8)	(4.3±0.4)	(2.8±0.8)	(3.7±0.3)
T_1 (3.3BTH+33.3 SA)	260.7±119.2	269.1±72.8	252.2±25.2	344.7±88.6	227.0±50.4	319.5±14.6$_{ab}$
	(2.4±0.9)	(2.2±0.4)	(3.7±0.7)	(4.5±1.4)	(3.3±1.0)	(4.1±0.3)
T_2 (6.6BTH+16.6SA)	277.5±90.9	277.5±66.7	344.7±38.5$_{a}$	370.0±29.1$_{a}$	285.9±72.8	361.6±38.5$_{a}$
	(2.4±0.9)	(2.5±0.6)	(3.8±0.2)	(5.0±0.6)b	(3.2±1.0)	(4.9±0.1)$_{ab}$

\# The results are mean ±SD of 3 replicates
+Inoculation with *A. brassicae* spores was carried out 24h after treatment
* Specific activity (µg-t-cinnamic acid formed/hr/mg protein) shown within parenthesis
a - Significant (at 5% level) difference between control and treatments (student's t - test)
b - Significant (at 5% level) difference between uninoculated and inoculated treatments (student's t - test)

Phenolic content: When combinations of elicitors were sprayed on the leaves of 4 weeks old *Brassica* plants and then inoculated with spores of *A. brassicae,* the phenolics *viz.,* total phenols, o-dihydroxyphenols and flavanols (mg/g DW) showed an increase over the control. Spray with T_2 showed more increase in the phenolic content than T_1 in the inoculated plants as well as in uninoculated plants on 5th and 7th DAS with the combinations of elicitors and also with control (Table 4). A significant increase (at 5% level) in the total phenolic content was observed in the leaves of uninoculated and inoculated plants sprayed with T_2 on 5th DAS whereas spray with T_1showed significant increase in total phenolic content of uninoculated leaves on 3rd DAS as compared to control. Significant increase in total phenols (at 5% level) on 5th and 7th DAS was reported in the leaves of inoculated plants than uninoculated plants sprayed with T_2. T_1 sprayed inoculated plants showed significant (at 5% level) increase in o-dihydroxyphenols content on 3rd DAS and in flavanol content on 5th DAS than their respective uninoculated plants. Similar changes were observed in phenolics *viz.,* total phenols, o-dihydroxyphenols and flavanols in 5 weeks old plants as that of 4 weeks old plants. Here also T_2 was more effective in increasing the phenolics over control on 5th and 7th DAS, however, on 3rd DAS, out of the two combinations of elicitors tried, T_1 was more effective. In leaves of inoculated plants, phenolics were found to be significantly (at 5% level) more than the uninoculated ones. Above results showed effective increase in phenolics *viz.,* total phenols, o-dihydroxyphenols and flavanols in the leaves *Brassica* plants treated with both the combinations of elicitors, whereas as non-significant decrease was observed in flavanols content of both uninoculated and inoculated leaves on 7th DAS in 5 weeks old plants. Out of the two combinations tried, T_1 showed maximum increase in total phenols on 3rd day, however, on 5th and 7th DAS, T_2 showed more effective increase in phenolic content in inoculated leaves of both 4 and 5 weeks old plants. Higher level of phenolics may be due to the higher activity of PO (Table 1) and PAL (Table 3) as these two enzymes are involved in the synthesis of phenolics. In tomato, PO is one of the enzymes believed to catalyze the last step in lignification pathway (Nicholson and Hammerschmidt, 1992).

Table 4 Effect of combinations of elicitors *(*BTH and SA) with/without *A. brassicae* spores inoculation on phenolic content in the leaves of 4 and 5 weeks old *B. juncea* (var.RLM 619) plants

Treatments (ppm)	Four weeks old plants					
	3rd DAS		5th DAS		7th DAS	
	Unioculated	Inoculated^{+}	Unioculated	Inoculated^{+}	Unioculated	Inoculated^{+}
	Total phenols (mg/g DW)					
C (water)	8.6±0.1	8.9±1.0	8.6±0.1	8.7±1.1	9.0±1.0	9.6±1.1
C_1 (3.3BTH+33.3SA)	9.3±0.3^{a}	10.2±1.0	9.7±0.9	9.8±0.7	9.5±0.7	10.0±1.6
C_2 (6.6BTH+16.6SA)	9.6±0.3^{a}	9.4±1.3	9.9±0.6^{a}	11.9±0.4^{ab}	7.8±0.8	11.2±0.2^{b}
	o-dihydroxyphenols (mg/g DW)					
C (water)	1.6±0.4	1.9±.1	1.8±0.4	1.9±0.6	2.6±0.1	2.9±0.1
C_1 (3.3BTH+33.3SA)	1.2±0.1	1.9±0.3b	1.9±0.1	2.0±0.1	2.7±0.3	3.1±0.1
C_2 (6.6BTH+16.6SA)	1.2±0.4a	1.5±0.1	2.2±0.1	2.6±0.2	2.9±0.1a	3.4±0.4
	Flavanols (mg/g DW)					
C (water)	1.6±0.1	2.0±0.4	2.4±0.6	3.1±1.0	2.9±0.4	3.0±0.7
C_1 (3.3BTH+33.3SA)	2.9±1.5	2.7±0.8	2.5±0.5	3.3±0.1b	3.1±0.0	3.4±0.6
C_2 (6.6BTH+16.6SA)	1.8±0.0a	1.6±0.1	2.4±0.2	3.6±0.8	3.0±0.2	3.3±0.2
	Five weeks old plants					
	3rd DAS		5th DAS		7th DAS	
	Unioculated	Inoculated^{+}	Unioculated	Inoculated^{+}	Unioculated	Inoculated^{+}
	Total phenols (mg/g DW)					
C (water)	7.7±0.9	9.6±0.3^{b}	9.5±0.3	10.0±0.7	7.8±1.8	8.6±0.2
C_1 (3.3BTH+33.3SA)	9.5±0.9	10.1±0.5	10.7±0.4^{a}	11.0±1.3	9.8±0.6	8.7±0.1^{b}
C_2 (6.6BTH+16.6SA)	8.2±0.8	10.0±0.4^{b}	10.2±0.8	13.0±0.6^{ab}	8.3±1.8	9.7±1.3
	o-dihydroxyphenols (mg/g DW)					
C (water)	2.4±0.3	2.5±0.3	2.3±0.4	2.6±0.2	2.2±0.0	2.8±0.7
C_1 (3.3BTH+33.3SA)	2.6±0.4	3.6±0.2^{ab}	2.8±0.3	2.9±0.4	2.5±0.1^{a}	3.1±0.4
C_2 (6.6BTH+16.6SA)	2.8±0.3	2.9±0.0	2.9±0.5	3.7±0.2^{ab}	2.4±0.1	2.9±0.2^{b}
	Flavanols (mg/g DW)					
C (water)	2.3±0.3	2.4±0.3	3.8±0.5	4.1±0.6	1.7±0.3	2.5±0.7
C_1 (3.3BTH+33.3SA)	3.5±1.3	2.8±0.2	4.2±0.4	4.4±0.5	1.4±0.6	1.7±0.4
C_2 (6.6BTH+16.6SA)	2.5±0.3	2.8±0.2	3.0±0.2	4.3±0.3^{b}	1.0±0.5	1.7±0.6

\# The results are mean ±SD of 3 replicates

\+ Inoculation with *A. brassicae* spores was carried out 24h after treatment

a - Significant (at 5% level) difference between control and treatments (student's t - test)

b - Significant (at 5% level) difference between uninoculated and inoculated treatments (student's t - test)

PAL activity is believed to determine the biosynthetic flux through the phenylpropanoid pathway and so higher PAL activity produces greater concentrations of phenolic phytoalexins in tissues (Orr *et al*., 1993). So, from pot field studies, it could be concluded that both the combinations of elicitors followed almost the similar trend in enhancing the level of phenolics. Since the production of phenolic compounds depends upon PAL activity (Graham and Graham, 1991), increased phenolic synthesis in treated tomato plants may be due to increased activity of PAL. The increased phenolic content in inducer-treated tomato leaves might have contributed to increased resistance to *A. solani.* In the plant cells, simple phenolics are believed to be scavengers of free radicals, protecting the cells from free radical damage. Phenolics are also involved in strengthening the plant cell walls during growth by polymerization into lignans and lignins (Huang *et al.,* 1992).Significantly higher level of total phenols, o-dihydroxyphenols and flavanols content in the *A. brassicae* inoculated leaves was observed in both 4 and 5 weeks old plants as compared to their respective uninoculated leaves i.e., infected leaves contain greater phenolic content than uninfected leaves. Similar observation have also been reported by Hoagland (1990) in *Cassia obtusifolia* where leaves contained higher concentration of phenolics than stems while infected leaves (with *Alternaria cassiae*) exhibited a greater phenolic contents than uninfected leaves.

In conclusion, our study suggested that treatment with the synthetic combination of elicitors *viz.,* BTH and SA along with inoculation with the pathogen increased the resistance of the plant by elevating the levels of defense enzymes *viz*., PO, PAL, SOD and phenolics content. Results of our experiments also emphasize that levels of these defense components could be used as an identity for analyzing the levels of resistance in *B. juncea* against *A. brassicae.* In this regard, it is recommended to use *A. brassicae* and elicitors based formulations as a promising alternate to chemical fungicides to minimize the adverse impact on the environment and ensuring plant disease management.

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Integrated management of *Alternaria* blight of safflower under field conditions

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ABSTRACT

Safflower (*Carthamus tinctorius* L.), is one of the oilseeds crop grown throughout the world. The crop suffers from many diseases, among that leaf spot/blight caused by *Alternaria carthami* (Chowdhury) has become one of the major constraints in the production and productivity of safflower all over India. The disease has been reported to cause 25 to 60 per cent yield losses in safflower. Management of safflower *Alternaria* blight with chemicals alone needs to be discouraged due to their ill-effects. Management trials were conducted with integration of the effective fungicides, bioagents and botanicals under natural epiphytotic condition during *rabi,* 2013 and 2014. The disease intensity was low (14.34%) with highest reduction (74.36%) with the combination of seed treatment with *T. viride* @ 10 g/kg + garlic clove extract ST @ 10 ml/kg followed by foliar spray hexaconazole FS @ 0.1 %. Seed treatment with hexaconazole ST @ 1 ml/kg followed by foliar spraying of same fungicide 0.1% also showed low disease intensity of 15.46 per cent and disease control of 72.37 per cent. Seed treatment of *T. viride* @ 1 ml/kg + garlic clove extract @ 10 ml/kg followed by spraying of mancozeb 0.25% reduced the disease by 69.16 per cent. Significant increase in seed yield up to 54.56 per cent and highest ICBR (3.22) was recorded in treatment of *T. viride* ST @ 10 g/kg + garlic clove extract ST @ 10 ml/kg + hexaconazole FS @ 0.1 %.

Keywords: *Alternaria carthami,* Efficacy, Integrated management, Safflower

Safflower (*Carthamus tinctorius* L.), is one of the world's oldest important oilseeds crop of the semi-arid regions belonging to the family Asteraceae (Compositae). The major safflower-producing countries of the world are India, Mexico, USA, Argentina, Canada and China. Safflower is also affected by many biotic and abiotic stresses. Of the biotic agents, fungi cause major diseases, followed by bacteria, viruses and nematodes (Bhale *et al.,* 1998; Suresh *et al.,* 2016). Among these diseases, leaf spot/blight caused by *Alternaria carthami* (Chowdhury) is widespread and have continued to be the major constraints in the production and productivity of safflower all over the country in general as well as in the state of Maharashtra in particular in recent times. The disease has been reported to cause 25 to 60 per cent yield losses all over India (Singh and Prasad, 2005) and 20 to 80 per cent in Maharashtra state (Anonymous, 2010), along with drastic reduction in seed size, seed volume, seed test weight as well as per cent oil content.

Safflower cultivars presently under cultivation do not posses proven field resistance or tolerance and majority of them are more or less prone to the leaf spot/blight disease (*A. carthami*), under such circumstances fungicides provide the most reliable means of controlling foliage diseases. Present day public perceptions and environmental hazards are compelling to search for alternative eco-friendly disease management strategies, for which integration of various cultural, biological and chemical methods might be the solution (Jagan *et al.,* 2013). Hence studies were conducted for integrated management of leaf blight with fungicides, biocontrol agents and botanicals as seed treatment and foliar sprays in different combinations.

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MATERIALS AND METHODS

The field experiments were conducted in the Research Farms of Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani during *rabi,* 2013-14 and 2014-15 to evaluate the efficacy of those fungicides, botanicals and bioagents which were found most effective against *A. carthami* in the *in vitro* studies. A total of 13 treatments, comprising three fungicides (systemic, non-systemic and combination fungicide one each), one fungal (*T. viride*) bioagent and one phytoextract (*A. sativum*) found most effective against *A. carthami* were integrated (alone or in combination) as seed treatment and or foliar sprayings for the management of *Alternaria* blight disease in safflower (cv. Manjira) during *rabi,* 2013-14 and 2014-15 seasons. Three sprayings of all the treatments were undertaken at an interval of 15 days, starting first spraying at first appearance of *Alternaria* blight disease symptoms. Ten plants were selected randomly per treatment per replication and tagged for recording observations on disease intensity. Three leaves (bottom, middle and top) from main branch on each plant were selected and *Alternaria* blight disease intensity were recorded following 0-9 disease rating scale (Mayee and Datar, 1986), one day before of each spraying and last observation at 15 days after last spraying. Per cent disease intensity was calculated as given below:

$$PDI = \frac{\text{Summation of numerical ratings observed}}{\text{No. of leaves / plants observed x maximum grade}} \times 100$$

Further, per cent disease control (PDC) was worked out applying the following formula.

$$\text{Per cent disease control (PDC)} = \frac{\text{PDI in control plot - PDI in treatment plot}}{\text{PDI in control plot}} \times 100$$

In both the field experiments (*rabi*, 2013-14 and 2014-15) after maturity the plants were harvested at maturity and cumulative seed yield data was presented (q/ha). To find out the most effective and economical treatment, the incremental cost:benefit ratio (ICBR) was worked out. For this the expenditure incurred on the inputs *viz.,* fungicides, bioagents, botanicals and labour charges on spraying were taken into account. The data obtained on per cent blight disease intensity, seed test weight and seed yield in both the seasons were subjected to pooled analysis and interpreted the results.

RESULTS AND DISCUSSION

The results obtained on per cent disease intensity, seed test weight, seed yield and incremental cost benefit ratio (ICBR) are presented in the Table 1 and 2. The pooled results (Table 1) revealed that all the treatments significantly influenced *Alternaria* blight disease intensity recorded at various intervals in safflower. The disease was found to appear first around 25 to 30 days and its mean intensity at first appearance ranged from 11.87 (T_4) to 29.87 (T_8) per cent, as against 30.08 per cent in untreated control; further, it was found to be increased steadily upto second spraying and decreased thereafter third spray treatment. The percent disease control was ranged from 74.36 (T_9) to 31.92 (T_8) per cent recorded with all the treatments. Comparatively low disease intensity (14.34 %) and highest reduction (74.36%) were recorded in treatment T_9 where seed treatment with *T. viride* + garlic clove extract followed by spraying of hexaconazole.

Table 1 Effect of various management treatments on *Alternaria* blight intensity of safflower at various intervals (*Rabi*, 2013-14 and 2014-15)

Tr. No.	Treatments	Disease Intensity* (%) At 1st Appearance	After 1st Spray	After 2nd Spray	15 days After 3rd Spray	Av. PDI (%)	Av. PDC (%)
T_1	Hexaconazole 5EC ST @ 1 ml/kg	19.50 (10.19)	27.58 (17.26)	32.04 (19.44)	23.31 (12.44)	25.61 (14.83)	54.24
T_2	Mancozeb 75WP ST @ 2.5 g/kg	19.96 (11.51)	31.46 (18.33)	34.83 (20.22)	24.52 (14.22)	27.69 (16.07)	50.51
T_3	Mancozeb 63% + Carbendazim 12% (SAAF) ST @ 2 g/kg	22.27 (12.87)	32.90 (19.21)	35.56 (20.67)	26.83 (15.59)	29.39 (17.09)	47.48
T_4	Hexaconazole 5EC ST @ 1 ml/kg + Hexaconazole FS @ 0.1%	11.87 (06.82)	16.74 (9.63)	21.07 (11.99)	12.16 (6.99)	15.46 (8.86)	72.37
T_5	Mancozeb ST @ 2.5 g/kg + Mancozeb FS @ 0.25%	16.12 (9.27)	22.46 (12.98)	26.87 (15.42)	15.21 (8.76)	20.16 (11.61)	63.97
T_6	SAAF ST @ 2 g/kg + SAAF FS @ 0.2%	17.69 (11.05)	25.60 (15.51)	30.67 (18.21)	16.39 (10.38)	22.59 (13.79)	59.63
T_7	*T. viride* ($2x10^7$cfu/g) ST @ 10 g/kg	25.92 (15.08)	37.42 (22.04)	42.75 (25.15)	30.48 (17.78)	34.14 (20.01)	38.98
T_8	Garlic clove extract 10% ST @ 10 ml/kg	29.87 (17.38)	41.37 (24.54)	46.70 (27.84)	34.43 (20.19)	38.09 (22.49)	31.92
T_9	*T. viride* ST @ 10 g/kg + Garlic clove extract (10%) ST @ 10 ml/kg + Hexaconazole 5EC FS @ 0.1%	13.43 (7.72)	13.67 (7.86)	18.99 (10.95)	11.30 (6.49)	14.34 (8.26)	74.36
T_{10}	*T. viride* ST @ 1 ml/kg + Garlic clove extract (10%) ST @ 10 ml/kg + Mancozeb 75 WP FS @ 0.25%	13.56 (7.79)	19.66 (11.34)	23.76 (13.74)	12.05 (6.93)	17.25 (9.95)	69.16
T_{11}	*T. viride* ST @ 1 ml/kg + Garlic clove extract (10%) ST @ 10 ml/kg + SAAF 75WP FS @ 0.2%	17.69 (11.05)	25.60 (15.51)	30.67 (18.21)	19.50 (10.31)	23.36 (13.77)	58.25
T_{12}	Hexaconazole ST @ 1 ml/kg+SAAF 75WP FS @ 0.2%	20.68 (12.30)	26.03 (14.77)	31.03 (17.78)	20.62 (12.29)	24.59 (14.29)	56.05
T_{13}	Mancozeb 75WP ST @ 2.5 g/kg+SAAF FS @ 0.2%	18.87 (11.56)	28.12 (15.41)	32.54 (18.38)	19.57 (11.99)	24.77 (14.34)	55.72
T_{14}	Control (Untreated)	30.08 (17.52)	43.67 (25.99)	64.72 (40.34)	85.34 (59.50)	55.95 (35.84)	--
	S.E.±	0.95	1.59	1.60	1.67	--	--
	C.D (P = 0.05)	2.77	4.61	4.66	4.84	--	--
	CV (%)	15.44	16.82	16.02	17.93	--	--

*:Mean of 2 replications, Figures in parentheses are arcsine transformed values; PDI:Per cent disease intensity, PDC:Percent disease control, , ST:Seed treatment; FS:Foliar spray.

Table 2 Effect of various management treatments on test weight, seed yield of safflower and incremental cost : benefit ratio (ICBR) (*Rabi*, 2013-14 and 2014-15)

Tr. No.	Treatments	Leaf blight (%)	Test weight (g)	Seed Yield (q/ha)	% Yield Increase over control	ICBR 2013-14	ICBR 2014-15	Pooled Mean
T_1	Hexaconazole 5EC ST @ 1 ml/kg	25.61 (14.83)	3.65	8.92	26.23	2.23	2.06	2.15
T_2	Mancozeb 75WP ST @ 2.5 g/kg	27.69 (16.07)	3.52	8.50	22.59	2.13	1.96	2.05
T_3	Mancozeb 63% + Carbendazim 12% (SAAF) ST @ 2 g/kg	29.39 (17.09)	3.38	8.14	19.16	2.05	1.86	1.96
T_4	Hexaconazole 5EC ST @ 1 ml/kg + Hexaconazole FS @ 0.1 %	15.46 (8.86)	4.94	13.63	51.72	3.04	2.99	3.02
T_5	Mancozeb ST @ 2.5 g/kg + Mancozeb FS @ 0.25%	20.16 (11.61)	4.45	12.38	46.85	2.88	2.81	2.85
T_6	SAAF ST @ 2 g/kg + SAAF FS @ 0.2%	22.59 (13.79)	4.30	10.73	38.68	2.43	2.32	2.38
T_7	*T. viride* (2x10^{7}cfu/g) ST @ 10 g/kg	34.14 (20.01)	3.23	7.93	17.02	2.00	1.81	1.91
T_8	Garlic clove extract 10% ST @ 10 ml/kg	38.09 (22.49)	3.17	7.60	13.42	1.93	1.73	1.83
T_9	*T. viride* ST @ 10 g/kg + Garlic clove extract (10%) ST @ 10 ml/kg + Hexaconazole 5EC FS @ 0.1%	14.34 (8.26)	5.10	14.48	54.56	3.33	3.31	3.32
T_{10}	*T. viride* ST @ 1 ml/kg + Garlic clove extract (10%) ST @ 10 ml/kg + Mancozeb 75WP FS @ 0.25%	17.25 (9.95)	4.67	13.02	49.46	2.90	2.84	2.87
T_{11}	*T. viride* ST @ 1 ml/kg + Garlic clove extract (10%) ST @ 10 ml/kg + SAAF 75WP FS @ 0.2%	23.36 (13.77)	4.14	10.45	37.03	2.36	2.24	2.30
T_{12}	Hexaconazole ST @ 1 ml/kg + SAAF 75WP FS @ 0.2%	24.59 (14.29)	4.00	10.10	34.85	2.16	2.16	2.16
T_{13}	Mancozeb 75 WP ST @ 2.5 g/kg + SAAF FS @ 0.2%	24.77 (14.34)	3.74	9.47	30.52	2.29	2.01	2.15
T_{14}	Control (Untreated)	55.95 (35.84)	2.79	6.58	--	1.71	1.48	1.60
	SE ±	--	0.08	0.64	--			
	C.D (P = 0.05)	--	0.23	1.86	--			
	CV (%)	--	5.44	9.48	--			

* : Mean of two replications, Conc.: Concentration, ST : Seed treatment, , Figures in parentheses are arc sine transformed values, FS : Foliar spray.

The second best treatment found was T_4 in which seed treatment with hexaconazole followed by spraying of the same fungicide with disease intensity of 15.46 per cent and reduction of 72.37 per cent. Seed treatment with *T. viride* + garlic clove extract followed by spraying of mancozeb also recorded low disease intensity of 17.25 per cent with reduction of 69.16 per cent. These were followed by the treatment T_5 of mancozeb ST followed by spraying of same fungicide recorded leaf blight of 20.16 per cent with reduction of 63.97 per cent. Seed treatment with *T. viride* + garlic clove extract followed by spraying of SAAF showed 23.36 per cent disease with disease control of 58.25 per cent. Rest of the treatments recorded disease intensity in the range of 24.59 (T_{12}) to 38.09 (T_7) per cent with disease reduction/control in the range of 31.92 (T_8) to 56.05 (T_{12}) per cent.

The results (Table 2) indicated that test weight of seeds and seed yield were significantly influenced with various treatments imposed to manage *Alternaria* blight disease in safflower crop, which were ranged from 3.17 to 5.10 g and 7.60 to 14.48 q/ha, respectively. In control plots test weight was low (2.79 g) with seed yield of 6.58 q/ha. The per cent increase in seed yield with various treatments, over untreated control was ranged from 13.42 to 54.56 per cent. Among the treatments, significantly highest test weight (5.10 g), seed yield (14.48 q/ha) and increase in seed yield (54.56%) were recorded with the treatment seed treatment with *T. viride* + garlic clove extract followed by foliar spraying of hexaconazole which is followed by the seed treatment with hexaconazole followed by spraying of same fungicide. Seed treatment with *T. viride* + garlic clove extract combined with foliar spraying of mancozeb recorded 4.67 g test weight and seed yield of 13.02 q/ha and 49.46 per cent, respectively and T_5 of mancozeb ST @ 2.5 g/kg + mancozeb FS @ 0.25% (4.45 g, 12.38 q/ha and 46.85%), respectively with test weight, seed yield and per cent increase in seed yield, over untreated control. Rest of the treatments compared to untreated control recorded also better weight in the range of 3.17 (T_8) to 4.30 (T_6), seed yield in the range of 7.60 q/ha (T_8) to 10.73 q/ha (T_6) and increase in seed yield in the range of 13.42 (T_8) to 38.68 (T_6) per cent.

Results indicated that on the basis of two years (2013-14 and 2014-15) pooled mean data, the most economical treatment with highest mean ICBR (3.32) was T_9 where seed treated with *T. viride* @ 10 g/kg + garlic clove extract @ 10 ml/kg combined with foliar spraying of hexaconazole @ 0.1%, followed by the treatment T_4 with ICBR of 3.02 in which seed treated with hexaconazole @ 1 ml/kg combined with spraying of the same fungicide @ 0.1 % (Table 2). Seed treatment with *T. viride* ST @ 1 ml/kg + garlic clove extract ST @ 10 ml/kg followed by spraying of mancozeb @ 0.25% also recorded ICBR of 2.87 followed by seed treatment with mancozeb @ 2.5 g/kg combined with spraying of same fungicide @ 0.25% with ICBR of 2.85 (T_5). The ICBR was 2.38 in seed treatment with SAAF @ 2 g/kg combined with spraying of SAAF @ 0.2 % (T_6) and the ICBR of 2.30 recorded in T_{11} where seed treatment with *T. viride* @ 1 ml/kg + garlic clove extract @ 10 ml/kg followed by foliar spraying of SAAF @ 0.2%.

These results are in conformity with the earlier findings of those workers who reported fungicides (systemic, non-systemic and combination fungicides), plant extracts/botanicals, bioagents along with or in combination ST or FS *viz., T. viride* ST @ 10 g/kg + garlic clove extract ST @ 10 ml/kg + hexaconazole FS @ 0.1%, hexaconazole ST + FS, *T. viride* ST + garlic clove extract ST + mancozeb FS, mancozeb ST + FS, SAAF ST + FS and *T. viride* ST + garlic clove extract ST + SAAF FS at various concentrations had showed significantly highest per cent disease control, seed yield and ICBR ratio of *A. carthami* infecting safflower. Anonymous (2009) reported that combi-fungicide carbendazim 12% + mancozeb 63% @ 0.2% recorded significantly least disease intensity, highest disease control and highest seed yield for the management of safflower *Alternaria* leaf spot disease, followed by carbendazim @ 0.1% and mancozeb @ 0.25% of disease intensity, disease control and seed yield, respectively. However, highest B:C ratio was reported with carbendazim (14.5), followed by mancozeb (10.3) and SAAF @ 0.2% (9.2). Basavarajappa *et al.* (2012) reported under field conditions for the management of sunflower leaf spot (*A. carthami*) disease, quintal (0.2%) recorded least mean disease intensity with highest seed yield, followed by difenconazole @ 0.05%, mancozeb @ 0.05%, chlorothalonil @ 0.2%, hexaconazole @ 0.1% and SAAF @ 0.2%, as against highest disease intensity (87.90%) in control. On the basis of B:C ratio the most economical treatments was quintal (3.67), followed by difenconazole (3.23) and hexaconazole (3.19). Pawar *et al.* (2012) reported that propiconazole gave significantly least mean disease severity (27.40%) and maximum disease control (64.73%) with highest seed yield (1522 kg/ha) and maximum B:C ratio (2.27) against *Alternaria carthami* of safflower. These results are in conformity with the findings of those reported earlier by several workers against, *Alternaria sesame* infecting sesame (Jeyalakshmi and Rettinassababady, 2009), *A. helianthi* infecting sunflower (Karuna *et al.,* 2012; Venkataramanamma *et al.,* 2014). Santhalakshmi Prasad *et al.* (2015) reported that seed treatment with iprodione + carbendazim 2g/kg followed by two sprays of propiconazole 0.1% at 15 days interval recorded low leaf blight with higher seed yield in sunflower.

Results of the present study obtained on integrated management of safflower Alternaria blight disease with the fungicides *viz.,* hexaconazole, mancozeb and SAAF, bioagents *T. viride* and botanical *A. sativum* which efficiently managed the disease with significant increase in seed yield and better ICBR are on the same line with the findings of those reported earlier by several workers (Murumkar *et al.,* 2009; Mesta *et al.,* 2011). Thus, for effective and economical management of safflower *Alternaria* blight disease, the integration of fungicides *viz.,* hexaconazole, mancozeb, SAAF, bioagent *T. viride* and botanical *A. sativum* could be exploited on large scale under field conditions.

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Economics and efficiency in groundnut *vis-à-vis* cotton cultivation: A DEA approach

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ABSTRACT

A significant change in groundnut and cotton acreage was observed in India and Gujarat since introduction of Bt-cotton in the country since 2002-03. The cotton acreage expanded whereas groundnut area shrunken at national as well as state level in post Bt-cotton period. The major cause of such transformation was higher returns in cotton cultivation than groundnut. In present study higher net returns in cotton (₹ 41,852/ha) was recorded than groundnut (38,721 ₹/ha). The overall technical efficiency was found higher at groundnut fields (95%) than cotton fields (91%). The year of schooling of the farmers and family size were found to improve the technical efficiency significantly in both crops along with farm size of groundnut fields. The decreasing area under groundnut needs policy support to make its cultivation more remunerative which will be helpful in providing edible oil security and also to cater feed demand of cattle in the country.

Keywords: Cotton, Data Envelopment Analysis, Groundnut, Gujarat, Technical efficiency

Groundnut and cotton are two important crops in agricultural economy of India as well as Gujarat state. Globally, India is the second largest producer next only to China in both the crops with contribution of 24.7 and 19.6 per cent to global production of cotton-lint and groundnut in-shell respectively in 2013 (GOI, 2015). In India, Gujarat was the largest producer of cotton as well as groundnut with 31 and 34 per cent share to the national production respectively, during 2014-15. These two crops jointly contribute about one-tenth of national and more than one-third of Gujarat's total cropped area (TCA). In India, a significant change in acreage under these two crops could be seen since 2003-04 (Table 1). The cotton acreage has increased to one and half times, from 8 million hectare (m.ha) in 2003-04 to 12 m.ha in 2012-13 at the compound growth rate (CGR) of 4.34 per cent in the country. The foremost credit for this area expansion under cotton goes to the introduction of Bt-cotton in March, 2002 (Singh, 2009). The Bt-cotton helped in expanding the share of cotton area to India's TCA from 4.24 per cent in 2003-04 to 6.11 per cent in 2012-13. On the other hand the reverse trend was seen in groundnut acreage. Its area in the country shrunken from 6.19 to 5.28 m.ha in the same period, resulted in groundnut area share to national TCA decreased from 3.26 to 2.71 per cent from 2003-04 to 2012-13, respectively.

The similar trend was also seen in Gujarat state where share of cotton area to state's TCA increased from less than 15 per cent in 2003-04 to 20 per cent in 2012-13. Whereas, groundnuts area share has decreased drastically from 18 to less than 15 per cent to state's TCA in the respective years. Groundnut is an important oilseed crop in the country and such an adverse transformation are worth studied and point to think over because India has turned over to largest importer of the edible oils in the world. It depends on imported edible oils to meet more than 50 per cent of domestic annual edible oil demand. Therefore such loss to the acreage under major oilseeds like groundnut is the big threat to edible oil security of the nation along with feed and fodder supply to cattle in the country.

There may be many reasons for such adverse drift in acreage but the foremost is comparative returns from the cultivation of a crop which motivates the farmers to switch over from one to other crop. The farming in present day scenario has become very competitive and opportunistic enterprise especially in state like Gujarat where farmers are very enthusiastic and leaning, comparative economics counts a lot. Alike other entrepreneurs, farmers also wish to secure maximum returns from his scarce resources, led him to shifts from lower to higher remunerative crop. Groundnut and cotton are mainly grown in same season i.e. *kharif* in the study area therefore there use to be though competition among both crop for area allocation under two crops, subject to available landholding with other necessary fixed and variable resources. Considering the fact, the present study have been undertaken to compare the economics of groundnut *vis-à-vis* cotton in the largest producing state for both the crops in the country. The outcome of the study will be helpful in policy formation such that sustainable cropping system can be maintained on the long term basis.

MATERIALS AND METHODS

The present study was purely based on primary data collected from *kharif* groundnut and cotton cultivators using multistage random sampling technique. The primary survey of 300 farmers (150 for each crop) of Gujarat was undertaken during 2012-13 by the personnel interview method because Gujarat is the largest producer of groundnut as well as cotton in the country. Further in Gujarat, Jamnagar, Junagadh and Rajkot districts were selected because these three districts jointly contributed about two-third of the states groundnut area and production, and the next most competitive crop to groundnut in these districts was cotton. So to study the comparative economics, costs and returns analysis was carried out using budgeting analysis. The cost component was comprised of all paid out costs *viz*., cost of seed, plant protection chemicals (PPC), FYM, fertilizer and irrigation charges, wages for hired labour, imputed family labour charges and imputed rental value of owned land. The net return per hectare was calculated by subtracting all the above cost components from the value of gross returns (including main and by-products value).

Different types of production functions using ordinary least squire (OLS) method were tried to measure the input-output relationship. Finally Cobb-Douglas functional form was preferred based on highest adjusted R^2. The specific Cobb-Douglas type of production function form given below was used; the coefficients were estimated using the Ordinary Least square (OLS) method.

$$\ln Y = \ln a + b_1 \ln X_1 + b_2 \ln X_2 + b_3 \ln X_3 + b_4 \ln X_4 + b_5 \ln X_5 + b_6 \ln X_6 + U$$

The efficiency measurement was carried out to evaluate and to compare the performance of groundnut and cotton farmers. Technical inefficiency measure of farmers indicates the amount by which all inputs could be proportionally reduced without a reduction in output. It is generally represented by some form of frontier function. Different methods are used to estimate frontiers. The two principal methods are Data Envelopment Analysis (DEA) and Stochastic Frontiers, which involve mathematical programming and econometric methods, respectively (Coeli, 1996). The technical efficiency of groundnut and cotton farmers was estimated with DEA technique using DEAP Version 2.1, a Data Envelopment Analysis (Computer) Program written by Tim Coelli (Coelli,1996). In present study input oriented, multi-stage DEA (DMS-DEA) approach to evaluate the technical efficiency of groundnut *vis-à-vis* cotton production was used.

Further, to assess the impact of socio-economic factor on technical efficiency in groundnut and cotton cultivation a linear regression analysis was carried out. The output of DEA efficiency measures was regressed against socio-economic factors like age, education, family size, experience, total land holdings and area under particular crop, to know their effect on efficiency level.

RESULTS AND DISCUSSION

Change in share of groundnut and cotton area to TCA: Groundnut and cotton are the major *kharif* crops grown in Gujarat and especially in the Junagadh, Jamnagar and Rajkot districts. These three districts jointly contribute almost 65 per cent area as well as production of groundnut and 17 and 25 per cent of cotton area and production respectively to the Gujarat's total. Table1 depicts that area under, CGR and instability index of groundnut and cotton crop at national and state level since adoption of Bt-cotton by farmers at commercial level in the country. The land use statistics of groundnut and cotton crops made it quite clear that scenario has changed a lot during last one decade, shifted in favor of cotton both at national as well as at state level. During this period area under cotton has expanded to one and half times (8.04 m.ha in 2003-04 to 11.88 m.ha in 2012-13) in India. It resulted in increased share of cotton to nation's total cropped area (TCA) from 4.24 to 6.11 per cent from 2003-04 to 2012-13, respectively. On the other hand, groundnut acreage in the country has shrunken from 6.19 to 5.28 m.ha in the same period resulted in decreased share of groundnut acreage to nation's TCA has from 3.26 to 2.71 per cent from 2003-04 to 2012-13, respectively. The cotton acreage in the country has increased at the CGR of 4.34 per cent per annum on contrary groundnut area decreased at CGR of -2.54 per cent per annum. The area share to TCA of both the crops and groundnut acreage had recorded higher instability at national level against state level whereas cotton acreage are more fluctuating in Gujarat compared to national level. Further, groundnut area in the country showed higher variation from normal trend (1.09) than cotton (0.61) because more than 70 per cent of the groundnut in the country is grown in rainfed conditions depends on rainfall under resource poor situations (Diop, 2004).

In Gujarat also, groundnut and cotton acreage performed similarly as national level. Cotton area in the state also expanded to one and half times from 1.69 m.ha in 2003-04 to 2.5 m.ha in 2012-13. Therefore share of cotton to state's TCA has increased from less than 15% in 2003-04 to almost 20% in 2012-13, even more than that during 2009-10 (22.21%), 2010-11 (21.48%) and 2011-12 (22.64%). On contrary, groundnut acreage share reduced from 17.89 to 14.65 per cent to state's TCA in same period because its cultivation has shrunken from 2.04 to 1.85 m.ha from 2003-04 to 2012-13, respectively. Cotton acreage in the state has expanded at higher CGR of 5.01% than national rate (4.34%) whereas the groundnut acreage decreased at slow CGR (-1.51%) than national rate (-2.54%). The instability index in groundnut cultivation in the state was measured low (0.64) compared to cotton (1.21) because groundnut is essential crop to meet the fodder requirement to the farm animals so farmer use to allocate minimum portion of their land holding at regular basis to the groundnut.

The changing trend in last one decade revealed a phenomenal transformation in groundnut and cotton acreage, can be well under stood with the findings of Vishanas and Lukka (2013). They studied the trends in cost of production, gross and net returns in cultivation of 22 crops in India from 2000-01 to 2010-11. The result of the study recorded the largest fall in real cost cultivation of cotton at the rate of ₹ 133 per year between 2000-01 and 2010-11 because of introduction of Bt cotton in 2002-03 due to low plant protection chemical requirements which forms a countable share in its cost of cultivation. On contrary the real cost of groundnut cultivation had increased at ₹ 11 per year, because 29 per cent of total cost in its cultivation is shared by human labor which has increased very much in recent years. More than this, per hectare gross returns in cotton cultivation has increased almost five times from 6,384 (average 2000-01 to 03-04) to 29,103 (average 2008-09 to 10-11) against just two times from 4,935 to 11,386 in case of groundnut cultivation in respective period. As a result net returns in rupees per hectare in cotton increased from 940 (average 2000-01 to 03-04) to 15,311 (average 2008-09 to 10-11) against 496 to 2,400 in groundnut in the respective periods. Net returns as per cent of C2 cost has increased from 3 to 36 per cent in cotton while in groundnut it increased meagerly from 2 to 7 per cent only (Table 2). These findings explained the above transformation of area shift under groundnut and cotton very well, which should be eye opener to the policy maker to safeguard the groundnut farmers in the country.

Comparative economics of groundnut *vis-à-vis* cotton cultivation: Based on the survey data collected through personnel interview of the farmers the costs and returns in groundnut and cotton cultivation was calculated and compared. Per hectare cost of cultivation was found higher by 5,369 in cotton (71,760 ₹/ha) than groundnut (66,391 ₹/ha). The higher yield in cotton (27 q/ha) than groundnut (18 q/ha) resulted in higher gross returns by 8,507 ₹/ha and net returns of 3,131 ₹/ha in cotton cultivation than groundnut (Table 3). The cost of production in groundnut main produce (3793.78 ₹/q) was higher by 1,130 than cotton main produce (2,664 ₹/q) but average market price received by groundnut farmer was higher only by 785 rupees per quintal than cotton farmers resulted in more returns per unit produced in cotton. The value of main produce in groundnut i.e. pod, was comparatively less (87,530 ₹/ha) than cotton-lint (1,13,602 ₹/ha) but the groundnut by-produce (known as haulm) was having good market demand as animal fodder in study area and fetched the average prices of 540 per quintal. It produced additional returns valued 17,582 ₹/ha resulted in increased total value of groundnut output to 1, 05,112 ₹/ha against 1, 13,612 ₹/ha in cotton. The further decomposition of total cost in groundnut pointed out seed as the major cost component (11,633 ₹/ha) which accounted for almost 18 per cent of total cost of cultivation. It was because of higher seed requirement, ranged from 100 to 120 kg kernel per ha. Seed cost was followed by harvesting cost (9,921 ₹/ha) accounted for 15 per cent of total cost. The harvesting in groundnut is more labor intensive operation mostly done with human labor due to low mechanisation of this operation. It was observed that land preparation cost was almost double on cotton farms compared to groundnut which pointed out farmers followed intensive tillage operation in cotton than groundnut cultivation. The seed requirement in cotton was comparatively very low (3 to 5 kg/ha for hybrid cotton) but still it contributed 4 per cent to total cost because of higher prices of Bt-cotton seeds coupled with farmers have to procure new seeds every year from market. The manual showing by dibbling in cotton resulted in higher showing cost than its seed cost and was more than double than groundnut sowing cost. It clearly pointed out need for mechanisation of showing operation in cotton crop. The fertiliser cost was one and half time higher in cotton (6,687 ₹/ha) than groundnut (4,402 ₹/ha) because of higher fertiliser application. Similar pattern in case of FYM application was also observed.

Table 1 Area under groundnut *vis-à-vis* cotton in India and Gujarat (in m.ha) with compound growth rate (CGR) and instability index from 2003-04 to 2012-13

Year	India					Gujarat				
	TCA	Groundnut		Cotton		TCA	Groundnut		Cotton	
		A	% to TCA	A	% to TCA		A	% to TCA	A	% to TCA
2003-04	189.66	6.19	3.26	8.04	4.24	11.42	2.04	17.89	1.69	14.84
2004-05	191.10	6.69	3.50	9.05	4.74	11.26	1.99	17.67	1.92	17.06
2005-06	192.74	6.82	3.54	8.71	4.52	11.49	1.96	17.03	2.01	17.44
2006-07	192.38	5.80	3.02	9.04	4.70	11.81	1.87	15.82	2.29	19.43
2007-08	195.22	6.35	3.25	9.39	4.81	12.21	1.85	15.12	2.42	19.80
2008-09	195.33	6.23	3.19	9.39	4.81	11.65	1.91	16.37	2.35	20.20
2009-10	189.00	5.43	2.87	9.98	5.28	11.09	1.82	16.42	2.46	22.21
2010-11	197.56	5.77	2.92	10.94	5.54	12.26	1.81	14.73	2.63	21.48
2011-12	195.63	5.20	2.66	12.17	6.22	13.09	1.69	12.88	2.96	22.64
2012-13	194.40	5.28	2.71	11.88	6.11	12.60	1.85	14.65	2.50	19.82
CGR	0.28	-2.54	-2.80	4.34	4.06	1.23	-1.51	-2.72	5.01	3.73
Instability index	0.17	1.09	6.96	0.61	3.65	0.56	0.64	3.16	1.21	2.79

Source: Directorate of Economics and Statistics, Department of Agriculture and Cooperation.
Note: TCA and A denotes total cropped area and area respectively in million hectare.

Table 2 Trend in gross and net returns in groundnut *vis-à-vis* cotton cultivation in India from 2000-01 to 2010-11

Particulars	Groundnut average during			Cotton average during		
	T_1	T_2	T_3	T_1	T_2	T_3
Gross returns (₹/ha)	4935	7236	11386	6384	11812	29103
Net returns (₹/ha)	496	1728	2400	940	4320	15311
Gross returns as % of A2+FL cost	40	49	48	45	63	103
Net returns as % of C2 cost	2	8	7	3	16	36
Gross margins over MSP as % of A2+FL cost	21	24	20	6	37	52
Net margins over MSP as % of C2 cost	-11	-9	-12	-23	-3	1

Source: Vishandass and Lukka (2013); Note: T1, T2 and T3 represents average during 2000-01 to 2003-04, 2004-05 to 2007-08 and 2008-09 to 2010-11, respectively

Table 3 Comparative costs and returns in groundnut *vis-à-vis* cotton cultivation in rupee per hectare during 2012-13 (N=300)

Particulars	Groundnut	Cotton
Land preparation	3085.22 (4.65)	5873.31 (8.18)
Seed	11633.13 (17.52)	2881.25 (4.02)
Sowing	1921.30 (2.89)	4607.40 (6.42)
Fertiliser	4402.17 (6.63)	6687.00 (9.32)
FYM	1996.92 (3.01)	3068.83 (4.28)
PPC	7371.67 (11.10)	9995.25 (13.93)
Weeding and intercultural operations	1932.54 (2.91)	2719.67 (3.79)
Irrigation charges	3496.71 (5.27)	5071.05 (7.07)
Harvesting	9921.00 (14.94)	10019.17 (13.96)
Interest on WC @ 4%	1830.43 (2.76)	2036.92 (2.84)
Rental value and land revenue	18800.00 (28.32)	18800.00 (26.20)
Total cost of cultivation	66391.08 (100.00)	71759.84 (100.00)
Yield of main produce(qtl/ha)	17.50	26.94
Average price of main produce	5001.73	4217.23
Yield of by-produce(qtl/ha)	32.56	--
Average price of by-produce	540.00	--
Gross returns	105112.40	113612.18
Net returns	38721.32	41852.34
Cost of production of main produce (₹/qtl)	3793.78	2663.69

Note: Figures in parenthesis indicates the % to total cost of cultivation.

Table 4 Results of Cobb-Douglas production function in groundnut *vis-à-vis* cotton; dependent variable-gross returns per hectare (N=300)

Particulars	Groundnut			Cotton		
	Coefficients	SE	t Stat	Coefficients	SE	t Stat
Intercept	-6.09***	1.67	-3.64	9.37***	1.00	9.37
Land preparation	0.54***	0.17	3.11	-0.01	0.07	-0.20
Seed and sowing	1.02***	0.23	4.35	-0.32**	0.11	-2.85
Weeding & intercultural	-0.30***	0.07	-4.32	0.25***	0.07	3.61
Irrigation charges	0.19***	0.04	4.32	0.00	0.02	-0.25
Fertiliser	0.27**	0.11	2.53	-0.10	0.10	-1.04
Harvesting	0.40***	0.11	3.75	0.20**	0.09	2.18
Adjusted R Square	0.49			0.25		

Note: *** and ** indicate significant at less than 1 and 5%, respectively.

In Bt-cotton also farmers are adopting more plant protection measures in cotton (9,995 ₹/ha) than in groundnut (7,371 ₹/ha) crop. Farmers also incurred more weeding and intercultural operation costs in cotton. The frequent irrigation requirement and application in cotton resulted higher irrigation charges by 1,575 ₹/ha than groundnut. There was not much difference in the harvesting cost in both the crops which shared about 14-15 per cent to total cost in both the crops. Therefore results showed that cotton cultivation was more labor and capital intensive but also yielded higher returns of about 26,000 ₹/ha if only main produce in both the crop was considered. The comparatively higher return in cotton cultivation was the foremost reasons for a tremendous growth in cotton acreage in the state in recent past. Otherwise, if overall economics including the value of by-product of groundnut i.e. haulm was considered the difference in gross returns was reduced to 8,500 ₹/ha. More than this groundnut is the leguminous crop which helps in soil enrichment on contrary to more water, PPC application in cotton which is challenge for natural resources and poor farmers. Therefore it can be said that groundnut cultivation should be promoted.

The functional relationship between gross returns and input costs was exercised using Cobb-Douglas production function, yielded adjusted R^2 of 0.49 and 0.25 in groundnut and cotton, respectively. It states that 49 per cent variation in gross returns in groundnut cultivation was explained by input cost used in its production against 25 per cent in case of cotton, rest explained by the factors not included in the model. Although, the coefficient of multiple determination i.e. R^2 does not tell the entire story it just tells how a model fits a set of observation. If R^2 is low but have significant predictor it can still draw important conclusion with cause and effect relationship between dependent and independent variable stating how much change in predictor values are associated with changes in response value. Same situation was encountered in present study as R^2 was less than 0.5 for both crops might be because of more dependence of *kharif* crops on environmental factor. In spite of low R^2 all the six factors included in model had significant effect on groundnut gross returns and three out of six explanatory variables in case of cotton were found significantly affecting the gross returns (Table 4). The expenditure on land preparation, seed and sowing cost, irrigation, fertiliser and harvesting cost influenced groundnut returns in positive and highly significant way at less than1 per cent except fertiliser cost at 5 per cent. There was negative and highly significant effect of weeding and intercultural expenditure on groundnut returns indicated over-expenditure on this component in groundnut cultivation and had inverse effect on income. The possible reason might be that intercultural operation at later stage of crop development may adversely affected the peg formation in groundnut followed by pod development. Investment in quality seed played very crucial role in groundnut returns, 1 per cent increase in seed investment raise the gross returns by 1.02 per cent over the mean level keeping other inputs constant. It was also found that 1 per cent expenditure on irrigation and fertiliser could increase the gross income by 0.19 and 0.27 per cent, respectively.

In cotton, only 25 per cent of the variation in gross returns was explained by input cost, rest is explained by the factors not included in the model. Gross returns in cotton cultivation, positively and significantly depends on weeding and intercultural and harvesting expenditures. But the investment on seed was found to affect returns inversely with negative elasticity of -0.32 which indicated the over-expenditure on seed component. Gross returns in cotton could be increased by 0.25 and 0.20 per cent with 1 per cent extra expenditure on weeding and intercultural and harvesting operation keeping other expenditure constant because returns in cotton cultivation depends significantly on efficient and proper picking of lint from the balls. Returns could be increased by 0.2 per cent with 1 per cent extra expenditure on harvesting operations. Income in both the crop was highly and very significantly explained by investment on inputs especially on harvesting component. In both the crops harvesting is mostly carried out with manual labor which forms the major cost component. Therefore it requires special attention for better returns through high level of mechanisation to bring down total cost of cultivation.

Technical efficiency and influence of socio-economic factor on technical efficiency: To evaluate and compare the performance to the farmers the technical efficiency in cultivation of both the crop was estimated. The input oriented technical efficiency was estimated using computer programme DEA version 2.1. The outcome of the progrmme provided technical efficiency under both constant returns to scale (CRS) and variable returns to scale (VRS) technologies along with scale measurement. The technical efficiency measured at VRS is relatively more precise estimate over CRS. The CRS assumption is only appropriate when all DMU's i.e. farmers in this study, are operating at an optimal scale. The various factors like: imperfect competition, availability of credit, irrigation, labour, inputs, social constraints etc. may cause farmers to be not operating at optimal scale. The use of the CRS specification when not all DMU's are operating at the optimal scale will result in measures of TE which are confounded by scale efficiencies (SE). The use of the VRS specification will permit the calculation of TE devoid of these SE effects (Coelli, 1996). Therefore, TE under VRS was considered and was found that TE efficiency in groundnut cultivation was higher (95%) compared to cotton cultivation (91%). More than 50 per cent of the groundnut farmers were operating at less than 90 per cent TE, whereas in cotton less the 50 per cent of farmers were found in this range. In groundnut only 47 per cent of the farmers were found 100 per cent technically efficient (TE=1) against 55 per cent in case of cotton. More of the groundnut farmers (35%) were operating at TE 90 and more but less than 100 per cent, than cotton farmers (12%). Because of above 35 per cent groundnut farmers the overall VRSTE was found higher in groundnut than cotton. All the groundnut farmers were operating at TE higher than 60 per cent against 2 per cent cotton farmers operated under 50 per cent level. Further the DEA results also spelt out that all the groundnut farmers who were operating at below 100 per cent TE were operating at increasing returns to scale which indicated that farmers could still increase their income with more use of inputs in groundnut cultivation. Whereas in cotton, 12 out of 150 farmers were found to operating at decreasing returns to scale indicated the overuse of the resources at cotton farms. The results of DEA pointed out that the resources were more efficiently used at groundnut farms compared to cotton farms resulted in higher technical efficiency at the groundnut farms.

Table 5 Frequency distribution and mean technical efficiency (VRSTE) in groundnut *vis-à-vis* cotton cultivation (N=300)

Range	Groundnut		Cotton	
	% farmers	Mean	% farmers	Mean
<0.5	0	--	0	--
0.5-0.6	0	--	2	0.59
0.6- 0.7	2	0.65	6	0.65
0.7- 0.8	3	0.78	10	0.74
0.8- 0.9	13	0.87	15	0.85
0.9 <1	35	0.95	12	0.94
1.00	47	1.00	55	1.00
Overall	100	0.95	100	0.91

Table 6 Socio-economic factor influencing technical efficiency (VRSTE) in groundnut *vis-à-vis* cotton cultivation (N=300)

Particulars	Groundnut			Cotton		
	Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat
Intercept	0.71***	0.10	7.26	0.91***	0.07	13.20
Years of experience	0.00	0.00	1.17	0.00	0.00	-0.03
Years to school	0.01**	0.00	-1.96	0.01**	0.00	-2.10
Members in family	0.02*	0.01	-1.83	0.02**	0.01	-2.31
Area under crop	0.00	0.00	-0.45	0.00	0.00	-1.22
Total land holding	0.01***	0.00	3.63	0.00	0.00	1.57
Age in years	0.00	0.00	0.58	0.00	0.00	0.99
Adjusted R Square	0.54			0.46		

Note: *** and ** indicate significant at less than 1 and 5%, respectively.

Further analysis to identify the factors which influenced the technical efficiency in groundnut and cotton farms, the technical efficiency of individual farmer was linearly regressed against farmers age, education, family size, land holding, area under crop and experience in the cultivation of particular crop. The OLS estimate indicated that above socio-economic factors explained 50 per cent of the total variation in technical efficiency (VRSTE) in groundnut and cotton cultivation (Table 6). Years of schooling and family size found to be significantly affecting the technical efficiency in both the crops and had positive effect. It was found that TE can be increased by 1 per cent with one year to additional schooling in groundnut and cotton cultivation. Similarly, TE can be increased by 2 per cent with one more member in the family. The total land holding of the farmer had positive impact on the TE in groundnut cultivation, which can be increased by 1 per cent with unit increase in farmers land holding.

The significant drift in area under groundnut and cotton crops in India as well as in Gujarat was observed during 2003-04 to 2012-13. The groundnut acreage in the country as well as in Gujarat has shrunken whereas cotton area shown tremendous expansion at both level. The drifting acreage away from groundnut is the big threat to edible oil security of the nation, which currently depends on import for more than 50 per cent of its annual edible oil demand. The foremost reason for moving away acreage from groundnut was comparatively low returns in its cultivation compared to cotton. The introduction of Bt-cotton has brought down cost of cotton production resulted in higher returns in this crop.

The resource use efficiency of the groundnut farmers was found higher than cotton and there is scope to improve it further with education and farm mechanization. It will cut down the costs and will increase returns. Policy supports are needed in the form of price support and procurement especially during price crash in markets below MSP, processing industry development with better capacity utilization in crushing industry and higher value addition in groundnut etc. are most required for the development of groundnut, will result in edible oil security in the country.

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Evaluation of mobile based agro-advisory services - A case of e-kapas and reliance information services

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ABSTRACT

A study was conducted in Telangana state to ascertain the knowledge gain and benefits attained by the farmers through Mobile Based Agro-Advisory Services (MBAS). Ex-post facto research design was used in the present investigation. Random sampling method was used to select the respondents. The study constituted of 60 respondents of cotton farmers and 90 respondents of oilseeds farmers. It was observed from the study that, both cotton and oilseeds farmers were middle aged, educated up to primary school, small farm holders, with medium level of information acquisition, information management and listening behaviours. Cotton farmers were having high-risk orientation whereas, oilseeds farmers were having low-risk orientation. Based on the study, it was concluded that cotton and oilseeds farmers possessed favourable attitude towards mobile based agro-advisory services (MBAS) and with medium level of knowledge on recommended cultivation practices. Oilseed farmers had low adoption and cotton farmers had medium level of adoption of recommended cultivation practices as a result of mobile based agro-advisory services. Majority of the farmers had positive followed by neutral and negative opinion on the timeliness of the messages, relevance, audio quality, message treatment, content adequacy and content usefulness.

Keywords: Agro-advisory services, Extent of adoption, E-kapas, MBAS

While involving in farming operations, farmers need different types of information during each stage of the development process, ranging from weather forecasts, pest attacks, inputs, cultivation practices, pest and disease management and prices (Mittal, 2012). This information will differ based on the landholding size of farmers or agro climatic region (Rivera, 1996). The farmer largely depends on the fellow farmers and input dealers to seek the advice on such problems (Bhaskar, 2012). The majority of farmers in India do not have access to any source of information (Claire *et al*., 2010). In this existing scenario, it is expected that the mobile phone networks and handsets in India presents an opportunity to make useful information more widely available and offers several advantages over other alternatives in terms of cost, geographic coverage and ease of use (Aker, 2010). In the present study two such projects were evaluated i.e., e-kapas and Reliance Information Service. In e-kapas projects voice messages on improved cotton production technologies and in Reliance Information Service voice messages improved oilseeds production technologies were sent to farmers.

MATERIALS AND METHODS

The *ex-post facto* research design was adopted for the study, since the variables chosen for the study have already occurred (Rao *et al*., 2017) (Table 1). Telangana state was selected purposively for the study since the two projects were implemented in this state. From Telangana state three districts were selected randomly. Among three districts two were e-kapas project implemented districts *viz*., Karimnagar, Adilabad and one district was Reliance Information Service project implemented district i.e. Mahabubnagar. A total of 150 project beneficiaries were selected randomly in which of 60 beneficiaries from e-kapas project implemented villages and 90 beneficiaries from Reliance Information Service project implemented villages.

RESULTS AND DISCUSSION

Profile characteristics of the farmers : It was observed from the study that, 44.4 per cent of oilseeds farmers were middle aged, having education up to primary school (33.3%), small farmers (44.4%), medium level information acquisition behaviour (53.3%), information management behaviour (42.2%), risk orientation (43.4%) and listening behaviour (51.1%).

Forty-five per cent of cotton farmers were middle age, having education up to primary school (35%), small farmers (38.3%), medium level information acquisition behaviour (60%), information management behaviour (55%), listening behaviour (46.6%) and high-risk orientation (58.3%).

Evaluation of mobile based agro-advisory services in terms farmers attitude, knowledge and adoption of recommended cultivation practices

Attitude: It was observed from the study that, 57.8 per cent oilseed farmers were found to possess favourable attitude

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towards mobile based agro-advisory services. This was followed by about (30%) of the respondents indicate their neutral attitude, few of the respondents (12.2%) exhibited unfavourable attitude towards mobile based agro-advisory services.

It was observed from the study that, 51.7 per cent cotton farmers were found to possess favourable attitude towards mobile based agro-advisory services. This was followed by about (33.3%) of the respondents indicate their neutral attitude, few of the respondents (15.7%) exhibited unfavourable attitude towards mobile based agro-advisory services. This result was in line with the findings of Ganesan *et al*. (2013).

Knowledge: The study reveals that 44.4 per cent of the oilseeds farmers were having medium level of knowledge on oilseeds recommended cultivation practices. The farmer belongings to low categories of knowledge were found (31.2%) followed by high (24.4%) level knowledge on oilseeds recommended cultivation practices.

The study reveals that (58.3%) of the cotton farmers were having medium level of knowledge on cotton recommended cultivation practices. The farmer belongings to low categories of knowledge were found (25%) followed by high (16.7%) level knowledge on oilseeds recommended cultivation practices. This result was in line with the findings of Vijai Babu and Asokhan (2010).

Adoption: It was evident from the study that most of the oilseeds farmers (44.4%) had low adoption of recommended cultivation practices, followed by medium (38.9%) and high (16.7%) adoption of recommended oilseeds cultivation practices respectively. The reasons for this are due to the low education, very short duration of voice message, message complexity, low information seeking behavior and poor information management behavior of oilseeds farmers.

It was evident from the study that, most of the cotton farmers (40%) had medium adoption of recommended cultivation practices, followed by low (38.3%) and high (21.7%) adoption of recommended oilseeds cultivation practices respectively. The same results were presented by Patil *et al*. (2008).

Assessment of opinion of farmers on mobile based agro-advisory services: It was noticed from the study that majority of the oilseeds farmers had expressed their opinion on Mobile Based Agro-Advisory Services messages are coinciding with the crop growth (75.2%), somewhat relevant (58.9%), good audio quality (82.2%), moderately technical (56.7%), content need more details (67.8%) and very useful content (70%). Whereas, majority of the cotton farmers had expressed their opinion on Mobile Based Agro-Advisory Services messages are coinciding with the crop growth (73.3%), somewhat relevant (58.3%), good audio quality (68.3%), moderately technical (51.7%), content need more details (55%) and very useful content (73.3%). These findings were in accordance with the results of Madan Singh *et al*. (2015), Kokate and Singh (2013).

The study has revealed that the information disseminated through voice messages has been very useful and helpful to the farmers. MBAS provided timely information which helped in solving many of the problems. This process can link the researcher with farmers and field extension workers in a systematic way to improve knowledge and adoption of improved practices. Extended duration of message, source of additional information, may further enhance the effectiveness of mobile services. Along with voice messages text messages in local language will be much helpful to the farmers. The same advisory system should be extended to other crops. To improve knowledge and adoption of improved practices, training sessions and demonstrations should be organized immediately after the broadcast of advisory in order to impart the required skills.

Table 1 Variables and their empirical measurement

Variables	Empirical Measurement
Socio-psychological Variables	
Attitude	Scale developed for the study
Knowledge	Knowledge test developed for the study
Adoption	Schedule developed for study
Information seeking behaviour	Schedule developed for the study
Information management behavior	Schedule developed for the study
Risk orientation	Scale developed by Supe (1969) used for the study with suitable modification.
Listening behaviour	Schedule developed for the study
Demographic Variables	
Age	Chronological Age
Education	Number of years of formal education
Land holding	Number of acres possessed

Table 2 Profile characteristics of the cotton and oilseeds farmers

Variable	Category	Oilseed farmers (n=90)		Cotton farmers (n=60)	
		F	P	F	P
Age	Young	28	31.1	17	28.3
	Middle	40	44.4	27	45.0
	Old	22	24.5	16	26.7
Education	Illiterate	21	23.3	14	23.3
	Primary School	30	33.3	21	35.0
	Upper primary school	18	20.0	11	18.3
	High school	10	11.1	8	13.3
	Intermediate	7	7.7	2	3.3
	Under graduate	4	4.4	3	5.0
	Post graduate	0	0	1	1.7
Land Holding	Marginal farmer	20	22.2	16	26.7
	Small farmer	40	44.4	23	38.3
	Large farmer	30	33.4	21	35.0
Information Acquisition Behaviour	Low	30	33.4	19	31.7
	Medium	47	52.2	36	60.0
	High	13	14.4	05	8.3
Information management behaviour	Low	34	37.8	10	16.6
	Medium	38	42.2	33	55.0
	High	18	20.0	17	28.4
Risk orientation	Low	28	31.1	07	11.7
	Medium	39	43.4	18	30.0
	High	23	25.5	35	58.3
Listening behaviour	Low	33	36.7	20	33.4
	Medium	46	51.1	28	46.6
	High	11	12.2	12	30.0

Table 3 Distribution of the farmers according to their level of attitude towards Mobile Based Agro-Advisory Services (MBAS)

Category	Oilseed farmers (n=90)		Cotton farmers (n=60)	
	Frequency	Percentage	Frequency	Percentage
Unfavourable	11	12.2	09	15.0
Neutral	27	30.0	20	33.3
Favourable	52	57.8	31	51.7

Table 4 Distribution of respondents according to their knowledge level on cotton and oilseeds cultivation practices

Category	Oilseed farmers (n=90)		Cotton farmers (n=60)	
	Frequency	Percentage	Frequency	Percentage
Low	28	31.2	15	25.0
Medium	40	44.4	35	58.3
High	22	24.4	10	16.7

Table 5 Distribution of respondents according to their adoption of recommended cultivation practices

Adoption	Oilseed farmers (n=90)		Cotton farmers (n=60)	
	Frequency	Percentage	Frequency	Percentage
Low	40	44.4	23	38.3
Medium	35	38.9	24	40.0
High	15	16.7	13	21.7

Table 6 Opinions of farmers on mobile phone based audio messages

Variables	Categories	Oilseed farmers (n=90)		Cotton farmers (n=60)	
		F	p	F	P
a. Timeliness of the messages					
	Coinciding with the crop growth	65	75.2	44	73.3
	Early	15	16.7	11	18.4
	Late	10	11.1	05	08.3
b. Relevance					
	Highly relevant	22	24.4	14	23.3
	Somewhat relevant	53	58.9	35	58.3
	Irrelevant	15	16.7	11	18.3
c. Audio quality					
	Good	74	82.2	41	68.3
	Fair	11	12.2	13	21.7
	Poor	05	5.6	06	10.0
d. Message treatment					
	Less technical	22	24.4	11	18.3
	Moderately technical	51	56.7	31	51.7
	Highly technical	17	18.9	18	30.0
e. Content adequacy					
	Adequate	20	22.2	17	28.3
	Needs more details	61	67.8	33	55.0
	Not at all adequate	09	10.0	10	16.7
f. Content usefulness					
	Very useful	63	70.0	44	73.3
	Little useful	23	25.6	10	16.7
	Not useful	04	04.4	06	10.0

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Investigation on Line x Tester analysis in sesame (*Sesamum indicum* L.)

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ABSTRACT

Line x Tester analysis in sesame using four lines and three testers was carried out to study the heterosis and combing ability for yield and yield components *viz*., days to maturity, plant height, number of primary branches per plant, number of capsules on the main axis, number of capsules per plant, length of capsule, number of seeds per capsule, 1000-seed weight and seed yield per plant. The variances due to crosses, lines, testers and line x tester were significant for all the characters except plant height and number of seeds per capsule for lines, number of seeds per capsule for testers and seed yield per plant for F_1s. The significant variances due to lines, testers and line x tester showed the involvement of both additive and non-additive gene actions in controlling the traits. General and specific combining ability (*gca* and *sca*) variances showed major contribution of additive gene action for all the nine characters studied except number of seeds per capsule. Lines DS-10 and PKVNT-11 were good general combiners for most of the characters including seed yield per plant. Highest magnitude of standard heterosis was recorded in the cross DS-10 x DS-5. Other promising crosses for high yield were DS-10 x RT-351, SVPR-1 x RT-351, PKVNT-11 x DS-5 and AKT-101 x GT-3 on the basis of *sca* effect. Heterosis and *per se* performance may be used to select superior heterotic crosses for exploitation of hybrid vigour in sesame.

Keywords: Combining ability, Heterosis, Line x Tester, Sesame

Sesame (*Sesamum indicum* L.) is an ancient indigenous oilseed crop cultivated in diverse agro ecological situations. It is called as the "Queen of oilseeds" because of its excellent qualities of the seed, oil and meal. Sesame is highly nutritive (oil 50%, protein 25%) and its oil contains an antioxidant called sesamol which imparts a high degree of resistance against oxidative rancidity. It is an important annual oilseed crop in the tropics and warm sub tropics. India ranks second in area (17.8 lakh ha) and production (7.69 lakh tonnes) among the sesame growing countries (DES, 2015; Kumhar and Meena, 2016). The crops, by virtue of its short duration, fits well into wide ranges of sequences and inter cropping systems. Development of short duration varieties in sesame is gaining importance due to their use as catch crop or relay crop and rice fallow crop. Apart from their wider use, they have several advantages like they require less crop management period, permits multiple cropping system, reduces overall production cost and allows escape from terminal drought. Nevertheless, the productivity of sesame in India is very low (421 kg/ha) in comparison with some other countries like China (705 kg/ha), Japan (700 kg/ha), Korea (635 kg/ha) and Thailand (575 kg/ha). There is an urgent need to augment the productivity levels. Unlike China, the hybrid technology, so far, remained an untapped resource for raising sesame productivity in India. The development of commercial hybrids could improve the productivity and thereby the production to a level of exportable surplus of sesame in the country. For breaking the present yield barrier and evolving varieties with high yield potential, it is desirable to combine the genes from genetically diverse parents. The success in identifying such parents mainly depends on the gene action that controls the trait under improvement, combining ability and genetic makeup. There are several techniques for evaluating the varieties or strains in terms of their combining ability and genetic makeup. In the present study, four lines, three testers and their twelve hybrids were evaluated for combining ability and heterosis for yield and its components.

Four lines *viz.,* AKT-101, PKVNT-11, DS-10 and SVPR-1 and three testers *viz.,* DS-5, RT-351 and GT-3 with varying agronomic and morphological characters were selected and crossed in Line x Tester fashion during summer season of 2013-14. Twelve hybrids along with seven parents were raised during *kharif* season of 2014. The present investigations were conducted during *kharif* season of 2014 in randomized block design and replicated twice at Main Agriculture Research Station, University of Agricultural Sciences, Dharwad. Seeds of each cross and their parents were sown in a row of 3 m in length in each replication with a spacing of 30 cm between the rows and 15 cm between plants. Observations were recorded on five plants selected at random in each replication for nine important characters *viz.,* days to maturity, plant height, number of primary branches/ lant, number of capsules on the main axis, number of capsules/plant, length of capsule, number of seeds/capsule, 1000-seed weight and seed yield/ plant. The data obtained for each character were analysed by the usual standard statistical procedure. The variation among the hybrids was partitioned further into source attributed to general combining ability and specific combining ability components in accordance with the standard procedure suggested by Kempthorne (1957). Relative heterosis, heterobeltosis and standard heterosis were estimated following the methods suggested by Hays *et al.* (1955). Variety DS-5 was used as the standard parental check.

The variances due to crosses, lines, testers and line x tester were significant for all the characters except plant height and number of seeds/capsule for lines, number of seeds/capsule for testers and seed yield/plant for line x tester (Table 1). The significant variances due to lines, testers and line x tester showed the involvement of both additive and non-additive gene actions in controlling the traits. However, all these characters except number of seeds/capsule appeared to be controlled predominantly by additive gene action as judged from the high GCA variance compared to SCA variance. For number of seeds/capsule, the estimate of sca was higher than the gca indicating the predominance of non-additive gene action for this trait. There are reports as indicated in literature (Mishra and Yadav, 1996; Babu *et al.,* 2004; Patel *et al.,* 2005; Singh *et al.,* 2007; Bharathi and Vivekanandan, 2009) that the number of seeds/capsule has shown the predominance of non-additive gene action for realizing higher yields.

A perusal of *gca* effects revealed that among the lines, AKT-101 and DS-10 were good general combiners for seed yield and PKVNT-11 were good general combiners for seed yield and its components with highly significant *gca* effects for these traits. Among the testers, DS-5 was good general combiner for seed yield per plant, number of capsules per plant and number of seeds per capsule while GT-3 was good combiner for days to maturity, number of primary branches per plant, number of capsule on main axis, number of capsules per plant and length of capsule. As regards to earliness RT-351, GT-3 and SVPR-1 were found to be the best general combiners (Table 2).

The performance of the F_1s derived from crosses PKVNT-11 x RT-351, SVPR-1 x RT-351 and DS-10 x GT-3 showed better performance for early maturity. The F_1s derived from DS-10 x DS-5 and SVPR-1 x DS-5 for number of capsules on main axis and number of capsules/plant, F_1s from AKT-101 x GT-3 for number of seeds/capsule and length of capsule, showed significant positive *sca* effects. Similarly crosses between PKVNT-11 x DS-5 and AKT-101 x RT-351 for 1000-seed weight and DS-10 x DS-5 for seed yield/plant were good specific combiners. Therefore, the parents, whose per se performance was good, were not necessarily good general combiners. Thus, for selecting good parents, both *per se* performance and *gca* effects of the parents may be more realistic. Similarly, best F_1's on the basis of *per se* performance were not in accordance to F_1s with respect to *sca* effects. It is observed that all the parents were not good general combiners for all the traits but when they were crossed with good general combiners, their *sca* effects were high, e.g. DS-10 x DS-5 for number of capsules/plant. Similarly, low x low combiners gave significant *sca* effects though they were not good general combiners, e.g., the performance of F_1s from the cross SVPR-1 x DS-5 for number of capsules on the main axis.

Heterosis was calculated as percent increase and decrease over mid-parent, corresponding better parent and standard parent (Table 3).

Table 1 Analysis of variance for combining ability in sesame

Source	d.f.	Mean sum of squares								
		Days to maturity	Plant height (cm)	No .of primary branches/ plant	No. of capsules on the main axis	No. of capsules/ plant	Length of capsule (cm)	No. of seeds/ capsule	1000 seed weight (g)	Seed yield / plant (g)
Crosses	11	21.23**	532.19**	0.726**	83.20**	175.31**	0.298**	51.98**	0.189**	11.82**
Lines	3	34.56*	629.12	1.25*	142.80**	326.89**	0.26*	76.19	0.29*	24.83**
Testers	2	39.35*	1297.39*	1.79*	176.59**	419.476**	0.86**	104.49	0.431**	19.88**
Line x Tester	6	4.12*	187.21**	0.201*	8.13**	19.38**	0.051**	23.39**	0.031**	1.09
Error	36	0.49	29.30	0.09	1.52	1.46	0.017	2.62	0.013	0.43
GCA variance	-	2.95	76.0	0.08	12.84	31.36	0.07	6.59	0.05	1.97
SCA variance	-	1.12	51.2	0.039	1.87	6.89	0.018	5.96	0.02	0.28
Add. variance	-	5.96	151.0	0.18	25.93	69.61	0.089	11.89	0.07	3.87
Dom. variance	-	1.12	51.2	0.039	1.87	6.89	0.018	5.96	0.02	0.28
Dom.variance/ Add. variance	-	0.14	0.28	0.36	0.07	0.19	0.13	0.49	0.161	0.08

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

Table 2 Estimates of general combining ability (*gca*) and specific combining ability (*sca*) effects in sesame

Parents	Days to maturity	Plant height (cm)	No. of primary branches/ plant	No. of capsules on main axis	No. of capsules/ plant	Length of capsule (cm)	No. of seeds/ capsule	1000 seed weight (g)	Seed yield/ plant (g)
Lines									
AKT-101	0.73**	9.89**	-0.33**	1.26**	1.70**	0.32**	4.12**	0.23**	3.12**
PKVNT-11	2.65**	-13.52**	0.13	-1.39**	-1.90**	-0.08*	-0.88	-0.08**	-1.89**
SVPR-1	-3.10**	5.60*	-0.42**	-4.53**	-5.28**	-0.19**	-2.89**	0.03	-0.89**
DS-10	-0.91**	-0.88	0.54**	4.96**	8.89**	-0.17**	1.89**	-0.24**	0.47*
SE(gi)	0.36	1.89	0.10	0.38	0.42	0.08	0.63	0.04	0.24
SE(gi-gi)	0.45	2.59	0.19	0.48	0.61	0.06	0.12	0.05	0.27
Testers									
DS-5	1.89**	-10.39**	0.43**	4.30**	5.98**	0.45**	-3.49**	0.17**	1.43**
RT-351	-1.93**	10.26*	-0.08	-2.98**	-5.01**	0.06	0.98	0.19**	-0.29
GT-3	0.22	1.79	0.48**	0.19	0.98**	-0.18**	4.32**	0.03	7.95**
SE(gi)	0.29	1.93	0.08	0.42	0.37	0.021	0.50	0.05	0.28
SE(gi-gi)	0.32	2.64	0.14	0.53	0.49	0.039	0.74	0.06	0.32
Crosses									
AKT-101x DS-5	0.46	-2.01	0.011	1.90*	4.23**	0.10	-2.26*	-0.04	-0.12
AKT-101x RT-351	-0.62*	-0.85	-0.09	-1.35	-2.21**	-0.09	1.66	-0.09	0.08
AKT-101x GT-3	0.42	3.80	0.07	-0.52	-1.80*	-0.04	0.74	0.14*	0.07
PKVNT-11x DS-5	-0.57	-0.74	0.23	-1.59*	-6.15**	0.10	1.93	-0.08	-0.19
PKVNT-11x RT-351	0.54	1.41	0.15	-0.36	0.38	0.07	1.67	0.26**	0.69
PKVNT-11x GT-3	0.61	-0.73	-0.23	2.13*	3.26**	-0.18**	-3.64**	-0.14*	-0.53
SVPR-1 x DS-5	2.60**	13.62**	0.22	-1.14	-1.59**	-0.04	0.53	0.09	0.04
SVPR-1 x RT-351	-1.14**	-5.89	-0.29	1.19	0.64	-0.09	-0.47	-0.15**	-0.89*
SVPR-1 x GT-3	-0.39	-7.23	0.027	-0.12	1.18	0.08	-0.07	0.05	0.84*
DS-10 x DS-5	2.26**	6.13	0.41	0.91	3.89**	-0.19**	3.16**	-0.02	0.79*
DS-10 x RT-351	-0.98**	-8.23**	-0.19	0.85	0.99	0.08	-2.81**	0.08	0.14
DS-10 x GT-3	-0.38	5.21	0.19	-1.32	-1.87**	2.08**	3.24**	-0.051	-0.34
SE (Sij)	0.47	3.19	0.17	0.72	0.74	0.06	0.93	0.05	0.29
SE (Sij-Sij)	0.63	5.17	0.24	0.89	0.84	0.09	1.42	0.07	0.34

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

Five crosses *viz.,* PKVNT-11 x RT-351, SVPR-1 x RT-351, AKT-101 x GT-3 and DS-10 x GT-3 recorded significant negative heterosis for maturity. Similar results were reported by Sankar and Kumar (2001). All the 12 crosses showed significant negative heterosis over standard check displaying dominance for earliness. The range of standard heterosis for seed yield/plant was -11.7 to 60.0 per cent and found maximum in the cross DS-10 x DS-5. The same cross had a high heterotic value for four other traits *viz.,* number of capsules on the main axis, number of capsule/ lant, number of seeds/capsule and 1000-seed weight. Heterotic behavior of crosses with respect to yield and component traits differs from character to character. However, a few crosses such as, SVPR-1 x RT-351, AKT-101 x DS-5 and DS-10 x RT-351 showed appreciable level of promising hybrid vigour for seed yield as well as over other major component traits. These findings got support from the views of earlier workers (Solanki and Gupta, 2000; Manivannan and Ganeshan, 2001; Senthil *et al.,* 2003; Vidyavathi *et al.,* 2005; Singh *et al.,* 2007; Ranjith *et al*., 2011; Padma Sundari and Kamala, 2012; Ramesh *et al*., 2014) regarding the heterosis in sesame.

Best three parents on the basis of *per se* performance and *gca* effect and best three crosses with respect to their *per se* performance, *sca* effects and standard heterosis have been presented in Table 4. The crosses showed significant *sca* and heterosis for yield/plant, in which both the parents were good general combiners that produced high *sca* effects indicating the predominance of additive gene interactions e.g. the performance of the cross DS-10 x DS-5. Where as other superior crosses, where both the parents were not good general combiners, showed the involvement of non-additive types of gene action. The crosses that exhibited high heterosis for seed yield and its contributing traits (DS-10 x RT-351, SVPR-1 x RT-351, PKVNT-11 x DS-5, AKT-101 x GT-3 and DS-10 x DS-5) could be used for commercial exploitation in sesame.

Table 3 Heterosis (in per cent) over mid parent (MP), better parent (BP) and standard variety DS-5 (SC) for different characters

Crosses	Heterosis (in per cent) over	Days to maturity	Plant height (cm)	No.of primary branches / plant	No.of capsules on the main axis	No. of capsules/ plant	Length of capsule (cm)	No. of seeds/ capsule	1000- seed weight (g)	Seed yield/ plant (g)
AKT-101x DS-5	MP	5.01*	-0.68	2.57	16.30**	8121**	9.40**	-5.43*	1.50	5.98
	BP	1.65-2.80**	-6.53	0.01	3.89	2.10*	7.54**	-12.96**	-5.62**	-9.40**
	SC		-9.94	9.10	27.09**	16.44**	29.27**	5.13	2.6	13.55**
AKT-101x RT-351	MP	0.62	9.58**	-14.43*	3.51	-0.71	0.53**	3.86*	12.94**	15.51**
	BP	-5.59**	7.73**	-15.62*	-6.76	-6.76	-4.87*	0..80	6.15**	-3.82
	SC	-8.28**	4.08	-6.93	-8.89*	-8.81*	13.09**	18.10**	15.40**	21.40**
AKT-101x GT-3	MP	2.62**	2.84	-21.10**	11.63**	5.95**	-1.05	5.03**	2.16	10.23**
	BP	-0.50*	1.94	-23.66*	10.34**	4.02**	-12.15**	1.03	0.0	5.63*
	SC	-4.92**	0.19	-10.98	7.85*	4.78**	3.30	17.02**	13.60**	29.78**
PKVNT-11x DS-5	MP	4.84**	-5.98*	28.48**	-9.43**	-7.31**	9.51**	3.28	-7.61**	-11.90**
	BP	0.50*	-5.25*	19.14**	-10.92**	-9.44**	5.81**	2.04	-11.67**	-16.51**
	SC	-2.53*	-18.85**	25.74**	9.85*	5.67**	19.05**	5.55	-8.6**	-12.74**
PKVNT-11x RT-351	MP	3.67**	-5.81**	9.42	-13.48**	-8.58**	6.84*	6.55*	18.23**	5.96
	BP	-2.87**	0.40	3.80	-23.23**	-13.93**	5.84*	2.95	14.07**	-3.48
	SC	-4.89**	-8.87**	9.90	-12.48	-7.89**	12.99*	10.96**	15.40**	-0.50
PKVNT-11x GT-3	MP	4.21**	-4.89	-10.04*	2.09	2.43	-8.32**	-0.93	-9.52**	-6.44*
	BP	0.02	-12.27**	-1.12**	-8.75**	-4.74**	-13.80**	-3.93	-13.79**	-9.86**
	SC	-2.01**	-13.79**	-9.01	7.74*	6.04*	-8.70**	4.88	-4.2	3.65
SVPR-1 x DS-5	MP	-3.80**	-8.26**	-4.97	-4.06*	-4.46**	-5.29*	-5.30*	-0.82	-3.03
	BP	-7.89**	-13.84**	-6.71	-12.76**	-11.10**	-12.00**	-6.30	-6.4*	-6.16
	SC	-5.90**	-12.84**	-3.15	8.59	5.93**	3.20**	-6.30	-5.4*	-6.18
SVPR-1 x RT-351	MP	-3.04**	9.25*	-3.88	-15.59**	-7.84*8	2.42	-6.54**	17.75**	8.51*
	BP	-7.52**	5.58	-6.60	-20.37**	-8.93**	-2.38	-8.98**	13.20**	-0.18
	SC	-7.53**	5.89	0.03	-21.37**	-9.93**	4.40	-2.82**	12.20**	-0.16
SVPR-1 x GT-3	MP	-5.38**	-0.20	-14.07*	-10.56**	-4.36**	2.68	2.61**	-5.49*	2.15
	BP	-6.05**	-0.92	-20.12**	-12.38**	-5.79**	-7.96**	3.81	11.21**	-5.52
	SC	-7.05**	-0.98	-9.01	-13.21**	-5.79**	-6.89**	11.01**	3.0	8.46*
DS-10 x DS-5	MP	3.01**	8.91**	23.83**	13.64**	8.06**	6.95*	1.90	-3.19	13.58
	BP	2.92**	7.89**	21.43**	6.64*	3.27*	-3.19	-2.91	-4.46	24.57**
	SC	3.78**	5.89**	35.42**	31.33**	16.81**	9.80**	6.17*	10.80**	33.58**
DS-10 x RT-351	MP	-4.67*	8.50**	1.01	19.68**	7.67**	0.28	3.40	4.31	7.51*
	BP	-7.26**	3.25	-0.91	4.10	0.90	-6.54	-0.90	1.26	-2.21
	SC	-8.57**	-5.58	7.90	15.34**	6.00	0.03	12.12**	-4.2	3.56
DS-10 x GT-3	MP	-2.80**	-2.89	5.85	19.69**	14.10**	0.80	6.83**	-6.70**	15.20**
	BP	-6.80**	-8.25	-8.64	12.35**	9.75**	-1.27	4.72**	-13.50**	12.20**
	SC	-6.82**	-12.12**	8.72	20.34**	13.34**	28.33**	12.35**	-5.0	23.95**
CD(P=0.05)	MP	0.99	7.20	0.39	1.61	1.84	0.14	2.49	0.09	0.89
CD(P=0.01)	MP	1.38	9.57	0.62	2.40	2.39	0.19	3.29	0.12	1.27
CD(P=0.05)	BP& SC	2.12	9.16	0.54	1.89	1.94	0.11	3.92	0.19	1.22
CD(P=0.01)	BP& SC	2.50	12.3	0.89	2.53	2.59	0.19	4.78	0.29	1.66

*. ** = significant at 5 % and 1% , respectively

Table 4 Three best parents, F_1s, general combiners and specific combiners for yield and component traits in sesame in line x tester experiment

	Days to maturity		Plant height		No of primary branches/ plant	No. of capsules on the Main axis	No. of Capsules/ plant	Length of capsule	No. of seeds/ capsule	1000-seed weight	Seed yield/plant
	Early	Late	Tall	Dwarf							
Best parent (*per se* performance)	SVPR-1 RT-351 DS-10	PKVNT-11 DS-5 AKT-101	AKT-101 SVPR-1 DS-5	PKVNT-11 RT-351 GT-3	DS-10 GT-3 DS-5	AKT-101 DS-10 DS-5	DS-10 DS-5 GT-3	AKT-101 DS-5 RT-351	GT-3 DS-10 AKT-101	RT-351 DS-5 GT-3	DS-5 AKT-101 DS-10
Best general combiners (*gca*)	AKT-101 DS-5 GT-3	PKVNT-11 SVPR-1 AKT-101	DS-5 DS-10 AKT-101	GT-3 RT-351 DS-10	GT-3 DS-10 DS-5	PKVNT-11 RT-351 DS-5	DS-5, DS-10, RT-351 DS-5	DS-5 RT-351 AKT-101	GT-3 DS-10 AKT-101	RT-351 AKT-101	GT-3 AKT-101 DS-5
Best F_1s with respect of *sca*	SVPR-1 x RT-351 AKT-101x RT-351 DS-10 x RT-351	SVPR-1 x DS-5 DS-10 xDS-5 PKVNT-11x GT-3	SVPR-1 x DS-5 AKT-101x GT-3 DS-10 x GT-3	DS-10 x RT-351 SVPR-1 x GT-3 SVPR-1 x RT-351	DS-10 x DS-5 PKVNT-11x DS-5 SVPR-1 x DS-5	PKVNT-11x GT-3 AKT-101x DS-5 SVPR-1 x RT-351	AKT-101x DS-5 DS-10 x DS-5 PKVNT-11x GT-3	DS-10 x GT-3 AKT-101x DS-5 PKVNT-11x DS-5	DS-10 x GT-3 DS-10 x DS-5 PKVNT-11x DS-5	AKT-101x GT-3 PKVNT-11x RT-351 SVPR-1 x DS-5	SVPR-1 x GT-3 DS-10 x DS-5 PKVNT-11x RT-351
Best F_1s with respect to *per se* performance and standard heterosis	DS-10 x RT-351 DS-10 x GT-3 SVPR-1 x RT-351	DS-10 x DS-5 AKT-101x DS-5 PKVNT-11x DS-5	SVPR-1 x RT-351 DS-10 x DS-5 PKVNT-11x DS-5	SVPR-1 x DS-5 PKVNT-11x RT-351 PKVNT-11x DS-5	PKVNT-11x DS-5 DS-10 x DS-5 PKVNT-11x RT-351	DS-10 x GT-3 DS-10 x DS-5 AKT-101x DS-5	DS-10 x DS-5 DS-10 x GT-3 AKT-101x DS-5	AKT-101x DS-5 PKVNT-11x DS-5 PKVNT-11x RT-351	DS-10 x GT-3 PKVNT-11x RT-351 AKT-101x GT-3	PKVNT-11x RT-351 SVPR-1 x RT-351 AKT-101x RT-351	DS-10 x GT-3 DS-10 x DS-5 AKT-101x GT-3

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Selection criteria of linseed (*Linum usitatissimum* L.) genotypes for seed yield traits through correlation and path coefficient analysis

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ABSTRACT

The experiment was conducted to study the different selection parameters for improving seed yield in 29 genotypes of linseed with two checks for 15 characters. Correlation study revealed that the genotypic correlation coefficients were higher in magnitude than the phenotypic correlation coefficients. Seed yield per plant had significant and positive correlation with number of capsules per plant, number of seeds per capsule,1000-seed weight, seed length and biological yield per plant, whereas, it had significant and negative correlation with bud fly infestation. Path analysis revealed that 1000-seed weight had moderate and positive direct effect on seed yield per plant and bud fly infestation had high and negative direct effect on seed yield per plant. Number of seeds per capsule, seed length, 1000-seed weight, biological yield per plant indirectly effected seed yield per plant *via* bud fly infestation.

Keywords: Bud fly infestation, Correlation, Linseed, Path analysis

Linseed commonly known as flax (2n=30) is a self pollinated crop but cross pollination can take place up to 2 per cent (Tadesse *et al*., 2009). It is grown worldwide for its oil and high quality fibre. Its oil demand is increased during last decade due to its richness in omega-3 fatty acid content which is used for different medicinal and industrial purposes. Linseed oil has anti-hypercholesterolemia effect, anti-carcinogenic effect and is also beneficial for development of brain and retinal tissues of infants (Payne, 2000; Biradar *et al*., 2016). Oil is also used in industries as drying agent for the manufacture of paints, varnish and printer ink etc and fibre is used for making clothes, bags, etc. In India, linseed is cultivated on about 2.63 lakh hectares with an annual production of 1.25 lakh tonnes and productivity of 477 kg/ha. It is mainly cultivated in Madhya Pradesh, Chhattisgarh, Jharkhand, Odisha, Uttar Pradesh, Maharashtra and Bihar. In Bihar, it is cultivated on about 0.15 lakh hectares with a production of 0.13 lakh tonnes and productivity of 859 kg/ha (Anonymous, 2017).

Selection is one of the key steps in plant breeding to exploit natural genetic resources for the benefit of mankind. The knowledge of correlation helps the breeder to understand the association of yield with different yield attributing characters and among themselves, whereas, path analysis gives information about the direct and indirect effect of different correlated characters on yield. These ultimately aids to selection of elite genotypes, breeding for the yield improvement. Hence, present study was carried out with objectives to find the correlation between yield and different yield attributing characters and effect of these characters on yield.

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Field experiment was carried out during *rabi* 2015-16 at Agricultural College farm of Bihar Agricultural University, Sabour, Bhagalpur, Bihar. It is situated at 52.73 meters mean sea level and 250 50' N latitude and 870 19' E longitude. Twenty nine genotypes (Ruchi, SLS-72, K. Selection, BRLS-101, BRLS-102, BRLS-103, BRLS-104, BRLS-105, H-49, EC-1424, Parvati, H-40, Sharda, Polf-23, JRF-5, NL-260, LBR-6, Meera, EC-537911, CI-1552, CI-1559,CI-1663, CI-2057, GS-202, GS-404, EC-1529, EC-537911A, LCK-7035, Neelum) along with two checks (T-397 and Shekhar) were grown in randomized complete block design with three replications in two rows of 5 metre length having row to row distance of 30 cm and plant to plant distance of 5 cm. Thinning was done to maintain the optimum plant population. The recommended agronomical packages and practices were followed to ensure good crop. The ten randomly selected plants from each entry and each replication was taken for recording data on fifteen characters, namely, days to 50% flowering, days to 50% maturity, plant height, flower diameter, number of primary branches per plant, number of capsules per plant, capsule diameter, number of seeds per capsule, 1000-seed weight, seed length, biological yield per plant, seed yield per plant, harvest index, oil content and bud fly infestation. Harvest index was calculated in percentage as the ratio of seed yield per plant to dried plant weight after harvesting. Oil content of each genotypes was analyzed using a bench top pulsed nuclear magnetic resonance (NMR)-Oxford-MQC-5 analyzer (London, UK), supplied with preloaded 'easy cal' software, calibrated with known oil castor seed samples (Yadav and Murthy, 2016). The mean data of the genotypes were subjected to statistical analyses using Windostat software service, Hyderabad.

The analysis of variances for each character was carried to test the difference among genotypes using *F-test*. Genotypic and phenotypic correlations were computed between pair of characters using formula (Al-jibouri *et al.,* 1958). Estimated values of correlation coefficients were compared with table values of correlation coefficient at treatment (n-2) degree of freedom at the 5% and 1% level of significance. Direct and indirect effect of characters on seed yield per plant were estimated using estimates of correlation coefficient in all possible combinations of various variables with dependent variable as suggested by Dewey and Lu (1959).

Selection of genotypes is the primary goal of any hybridization programme, which needs a better understanding of association among various yield attributing traits, and cause and effects of traits on seed yield. The analysis of variances (Table 1) showed that the mean sum of square due to genotypes were highly significant for all the traits studied, suggesting existence of significant variability among the genotypes.

Table 1 Analysis of variances for design of experiment for fifteen quantitative characters in linseed

Source of variation	Mean sum of squares														
	DF	DM	PH	FD	PBP	CP	BFI	DC	SC	TSW	SL	BYP	SYP	HI	OC
Replications (d.f.= 2)	1.88	2.03	26.96	0.35	0.55	51.06	24.12	0.05	0.08	0.03	0.003	2.01	0.04	3.69	0.02
Treatments (d.f.=28)	94.83**	49.35**	506.63**	36.51**	3.60**	1638.25**	523.88**	0.90 **	3.48 **	4.96 **	0.57 **	41.73**	1.43**	276.3**	26.86**
Error (d.f.=56)	2.12	1.93	13.29	0.29	0.33	27.995	8.79	0.09	0.12	0.05	0.02	5.34	0.02	3.25	0.01

Note: DF - Days to 50% flowering, DM-Days to 50% maturity, PH-Plant height, FD-Flower diameter, PBP- Number of primary branches per plant ,CP-Number of capsules per plant, BFI-Bud fly infestation, DC-Capsule diameter , SC- Number of seeds per capsule,TSW-1000 -Seed weight, SL-Seed length, BYP-Biological yield per plant, SYP-Seed yield per plant, HI-Harvest index, OC-Oil content

The correlation coefficients between different characters are presented in Table 2. The results indicated that the magnitude of genotypic correlation coefficients was higher than corresponding phenotypic correlation coefficients which could result due to little effect of environment in the expression of traits which is similar to the previous findings (Ranjanna *et al.,* 2014; Siddiqui *et al.,* 2016). The results revealed that the number of capsules per plant, number of seeds per capsule, 1000-seed weight, seed length, biological yield per plant had significant and positive correlation with seed yield per plant at phenotypic level, whereas, other characters, namely, days to 50% flowering, days to 50% maturity, plant height, flower diameter, capsule diameter, harvest index and oil content per cent showed non-significant correlation with seed yield per plant. However, bud fly showed significant and negative correlation with seed yield per plant. Harvest index showed significant positive correlation with oil content indicating that increase in harvest index results increase in the oil content. While, harvest index and oil content were significant and negatively correlated with days to 50% flowering, days to 50% maturity, plant height, flower diameter and biological yield per plant. It was revealed that the late flowering and maturity and increase in biological yield cause decrease in harvest index and oil content. These findings were in accordance with previous reports (Siddiqui *et al.,* 2016; Sahu and Sahu, 2016; Kumar and Paul, 2016; Ali *et al.,* 2014). On the basis of correlation analysis, it could be suggested that the selection based on characters *viz.,* number of capsules per plant, number of seeds per plant, 1000-seed weight, seed length, biological yield per plant and bud fly infestation could give a better results in yield improvement programme in linseed.

Simple correlation does not give the real picture of inter relation among different correlated traits which is further fulfilled by using path analysis. Path analysis separates the correlation coefficient into components of direct and indirect effects. In fact, selection of genotypes based on direct effects of characters will be effective (Copur and Oglakci, 1998). The path coefficients between different characters are presented in Table 3. The results indicated that positive and moderate direct effect of number of seeds per capsule, 1000-seed weight and biological yield per plant had on seed yield per plant. It indicated that these characters will be rewarding for selection of genotypes for high seed yield. While, bud fly showed negative and high direct effect on seed yield per plant, it revealed that less bud fly infestation should be given priority in selection of genotypes for yield improvement. Other characters *viz.,* number of capsules per plant and seed length had positive and low to negligible direct effect on seed yield per plant. However, capsule diameter and oil content had negative and low direct effect on seed yield per plant. All the characters had their higher indirect effect on seed yield per plant *via* bud fly infestation (Tiwari and Singh, 2012; Sahu and Sahu, 2016; Siddiqui *et al.,* 2016). The low phenotypic and genotypic residual effects of path coefficient analysis indicated that the most of the yield attributing characters were included in the study.

Table 2 Phenotypic and genotypic correlation coefficient between pairs of quantitative characters in linseed

Character	DF	DM	PH	FD	PBP	CP	BFI	DC	SC	TSW	SL	BYP	SYP	HI	OC
DF		0.837**	0.680**	0.245	0.432*	0.322	0.110	-0.281	-0.426*	-0.248	-0.050	0.439*	-0.064	-0.750**	-0.712**
		(0.896)	(0.715)	(0.263)	(0.487)	(0.344)	(0.112)	(-0.312)	(-0.462)	(-0.272)	(-0.085)	(0.455)	(-0.069)	(-0.779)	(-0.736)
DM			0.789**	0.465**	0.455**	0.332	0.134	-0.099	-0.415*	-0.020	0.196	0.585**	-0.030	-0.858**	-0.596**
			(0.821)	(0.516)	(0.542)	(0.354)	(0.152)	(-0.051)	(-0.451)	(-0.031)	(0.200)	(0.637)	(-0.037)	(-0.913)	(-0.631)
PH				0.478**	0.392*	0.469**	-0.081	0.056	-0.076	0.152	0.328	0.751**	0.253	-0.791**	-0.450*
				(0.507)	(0.451)	(0.479)	(-0.100)	(0.130)	(-0.088)	(0.161)	(0.331)	(0.762)	(0.254)	(-0.827)	(-0.463)
PBP					0.364*	0.396*	-0.171	0.330	-0.065	0.474**	0.476**	0.550**	0.240	-0.486**	-0.021
					(0.398)	(0.430)	(-0.175)	(0.373)*	(-0.080)	(0.488)	(0.516)	(0.572)	(0.262)	(-0.496)	(-0.022)
FD						0.366*	-0.036	-0.337	-0.213	-0.343	-0.182	0.461**	0.003	-0.588**	-0.433*
						(0.369)	(-0.039)	(-0.473)**	(-0.215)	(-0.376)*	(-0.187)	(0.504)	(0.004)	(-0.644)	(-0.457)
CP							-0.625**	0.111	0.251	0.256	0.279	0.719**	0.657**	-0.360*	-0.257
							(-0.670)	(0.119)	(0.298)	(0.263)	(0.293)	(0.742)	(0.669)	(-0.378)	(-0.265)
BFI								-0.250	-0.659**	-0.361*	-0.423*	-0.471**	-0.867**	-0.161	-0.079
								(-0.252)	(-0.710)	(-0.373)	(-0.463)	(-0.496)	(-0.933)	(-0.168)	(-0.081)
DC									0.261	0.806**	0.704**	0.159	0.295	0.121	0.497**
									(0.322)	(0.946)	(0.884)	(0.200)	(0.371)	(0.147)	(0.575)
SC										0.300	0.348	0.140	0.629**	0.367*	0.419*
										(0.334)	(0.375)	(0.142)	(0.667)	(0.397)	(0.441)
TSW											0.862**	0.276	0.467**	0.096	0.487**
											(0.901)	(0.282)	(0.489)	(0.105)	(0.492)
SL												0.422*	0.533**	-0.077	0.325
												(0.441)	(0.572)	(-0.078)	(0.337)
BYP													0.589**	-0.681**	-0.399*
													(0.590)	(-0.704)	(-0.406)
SYP														0.099	0.044
														(0.100)	(0.045)
HI															0.603**
															(0.615)
OC															

*,** significant at 5% and 1 % level of probability, respectively. Note:Genotypic correlation coefficient are shown under parentheses

Note: DF - Days to 50% flowering, DM-Days to 50% maturity, PH-Plant height, FD-Flower diameter, PBP- Number of primary branches per plant , CP-Number of capsules per plant, BFI-Bud fly infestation, DC-Capsule diameter , SC- Number of seeds per capsule, TSW-1000 -Seed weight, SL-Seed length, BYP-Biological yield per plant, SYP-Seed yield per plant, HI-Harvest index, OC-Oil content

Table 3 Direct (digonal) and indirect phenotypic and genotypic effects of eight quantitative characters on seed yield in linseed

Characters	CP	BFI	DC	SC	SL	TSW	BYP	OC	SYP
CP	0.078	0`.336	-0.012	0.053	0.015	0.059	0.107	0.02	0.657**
	(-0.081)	(0.520)	(0.006)	(0.038)	(-0.025)	(0.065)	(0.105)	(0.042)	(0.669)
BFI	-0.049	-0.537	0.028	-0.138	-0.022	-0.084	-0.070	0.006	-0.867**
	(0.054)	(-0.775)	(-0.012)	(-0.090)	(0.039)	(-0.092)	(-0.070)	(0.013)	(-0.933)
DC	0.009	0.134	-0.110	0.055	(0.037)	0.187	0.024	-0.041	0.295
	(-0.01)	(0.195)	(0.047)	(0.041)	(-0.074)	(0.234)	(0.028)	(-0.091)	(0.371)
SC	0.020	0.354	-0.029	0.21	0.018	0.070	0.021	-0.034	0.629**
	(-0.024)	(0.55)	(0.015)	(0.126)	(-0.031)	(0.083)	(0.019)	(-0.07)	(0.667)
SL	0.022	0.227	-0.078	0.073	0.053	0.20	0.063	-0.027	0.533**
	(-0.024)	(0.358)	(0.042)	(0.047)	(-0.084)	(0.223)	(0.062)	(-0.053)	(0.572)
TSW	0.02	0.194	-0.089	0.063	0.045	0.232	0.041	-0.04	0.467**
	(-0.021)	(0.289)	(0.045)	(0.042)	(-0.075)	(0.248)	(0.04)	(-0.078)	(0.489)
BYP	0.056	0.253	-0.018	0.029	0.022	0.064	0.149	0.033	0.589**
	(-0.060)	(0.385)	(0.010)	(0.017)	(-0.037)	(0.07)	0.141	0.064	(0.589)
OC	-0.02	0.0424	-0.055	0.088	0.017	0.113	-0.060	-0.082	0.044
	(0.021)	(0.063)	(0.027)	(0.056)	(-0.028)	(0.122)	(-0.057)	(-0.159)	(0.045)

Phenotypical residual effects; 0.404; Genotypical residual effects; 0.284 : *,** significant at 5% and 1 % level of probability, respectively.

Genotypic direct and indirect effect are shown under parenthes

Note: CP-Number of capsules per plant, BFI-Bud fly infestation, DC-Capsule diameter , SC- Number of seeds per capsule, SL-Seed length, TSW-1000 -Seed weight, BYP-Biological yield per plant, SYP-Seed yield per plant, OC-Oil content

The present investigation indicates that the characters, number of capsules per plant, number of seeds per capsule, 1000-seed weight and biological yield per plant had significant and positive correlation and exerted major direct and indirect effect on seed yield per plant indicating that these characters should be given due weightage during selection of elite genotype for the improvement of seed yield in linseed. Further, bud fly resistance genotypes should also be considered in linseed breeding programme.

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Influence of sulphur application on oil content and productivity of soybean [*Glycine max* (L.) Merrill] in Malwa Nimar of Madhya Pradesh

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ABSTRACT

An on-farm study was conducted in fifteen farmers fields at Nimar area in Madhya Pradesh. Analysis of soil samples collected in year of 2015 (without sulphur application) and 2016 (with sulphur application) revealed that sulphur level in all soil samples were low (2.5 to 14.2 mean 9.23 kg/ha). Further, demonstrations showed increase in yield of soybean from 2.11 to 2.27 t/ha and oil content from 19.93 to 21.60 per cent with application of sulphur fertilizer.

Keywords: Oil content, Productivity, Soil, Soybean, Sulphur

Soybean [*Glycine max* (L.) Merrill] is one of the most important *kharif* crops of Nimar area in Madhya Pradesh. In the last few decades, the crop has become a cash crop in Nimar. It is a sulphur loving crop and its requirement is much more than any other crop for better growth and development. Sulphur is an essential element for all biological systems and has been recognized as a major nutrient for optimal plant growth (Moris *et al.,* 1988). It also increases oil content in grain, control some soil borne diseases and ultimately higher yield. Available sulphur level is generally low in the Nimar area due to hot and humid climate, high likelihood of sulphate leaching and continuous cultivation of oily crops like cotton, soybean and groundnut without sulphur containing fertilizers, less S deposition to soil from the atmosphere and decreased use of organic manures (Pradip *et al*., 2011). Keeping in view importance of S, demonstrations were conducted in farmers fields to showcase and improve awareness of farmers about sulphur nutrition in Soybean.

Total 15 farmers fields were selected in Nimar area in Madhya Pradesh (Table 1 and Fig. 1). The surface soil samples (0-20 cm depth) were collected from different farmers fields before soybean cultivation in 2015. These were completely air-dried and passed through 2 mm sieve and stored in properly labelled plastic bags for analysis. Processed soil samples were analyzed for physicochemical properties like pH, EC, Organic Carbon (Jackson, 1973; Walkley Black, 1934) and available sulphur using standard methods (Chesin and Yien, 1950).

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Soybean yield data were collected after harvesting during the year 2015. Yield dada were recollected after application of sulphur fertilizer (@12 kg/ha) in the year 2016. The sulphur fertilizer, containing 90% elemental sulphur and 10% bentonite clay was applied with basal dose of NPK fertilizer at showing time. Rushkovsky gravimetric method was used for determination of oil content in dry soybean seeds (Yermakov, 1987).

On the basis of the data presented in Table 2, soil pH ranged from 7.36-7.90 with mean of 7.60. In case of EC, all samples are in normal range. Organic carbon of samples varied from 0.2-0.86%, Available sulphur varied from 2.50 to 14.2 kg/ha, which is very low but it should be 20-30 kg/ha for soybean crop. Demonstrations in the farmers fields showed soybean grain yield ranged from 1.71 to 2.51 t/ha with a mean of 2.11 t/ha during the year 2015 before S application (Table 3). However, the grain yield increased from 1.90 to 2.63 t/ha with a mean of 2.27 t/ha due to application of sulphur fertilizer (12 kg/ha) during the year 2016 (Fig. 2). Similar findings were also reported in groundnut (Chaubey *et at*., 2000) and linseed (Dubey *et al*., 1997). In this study we also fund that the oil content in soybean seeds which ranged from 17.08 to 23.54 increased to (19.44 and 24.94, respectively with a mean of 21.60 per cent with the application of sulphur containing fertilizer (Fig. 3). Such results were reported by Sonune *et al*. (2001) who recorded highest oil (20%) content due to application of 40 kg S/ha in soybean. On farm demonstrations clearly indicated improvement in oil content and yield of soybean due to sulphur nutrition. Hence, sulphur @ 12 kg/ha in the form of either gypsum, superphosphate or elemental sulphur can be applied to soybean crop during *kharif* season.

Table 1 Details of farmer's field selected for study

Name of farmer	Village	District
Purushottam Sohani	Kasrawad	Khargone
Amish Jaiswal	Gujari	Khargone
Subhash Patel	Rengwa	Khargone
Bhawarsingh Sisodiya	Ekaldhariya	Khargone
Ramratan Patidar	Ghotiya	Khargone
Mahesh Patidar	Ghotiya	Khargone
Santosh Patidar	Ghotiya	Khargone
Ghisilal Patidar	Ghotiya	Khargone
Krishnalal ji	Icchapur	Khargone
Mukesh Patidar	Ghotiya	Khargone
Bhagwan Patidar	Ghotiya	Khargone
Ashutosh Sohani	Tandaojhar	Khargone
Sukhram Choudhary	Rengwa	Khargone
Kamal Namdev	Dogava	Khargone
Gorishankar Mori	Multhan	Khargone
Purushottam Sohani	Kasrawad	Khargone

Table 2 Physicochemical parameter of soil samples

Sample No.	pH	EC (dS/m)	Organic Carbon (%)	Available S (kg/ha)
1	7.54	0.40	0.70	14.2
2	7.60	0.36	0.72	7.4
3	7.72	0.39	0.81	10.5
4	7.36	0.48	0.39	11.2
5	7.57	0.6	0.69	10.8
6	7.78	0.81	0.63	8.5
7	7.72	0.55	0.61	5.0
8	7.42	0.50	0.60	11.5
9	7.51	0.32	0.51	11.1
10	7.80	0.86	0.75	7.0
11	7.90	0.22	0.54	8.0
12	7.60	0.27	0.72	2.5
13	7.55	0.47	0.87	14.0
14	7.38	0.71	0.57	9.5
15	7.56	0.48	0.88	7.3

Table 3 Statistical analysis of data on physico-chemical parameters, oil content and yield parameters

Parameter	pH	EC (dS/m)	Organic Carbon (%)	Available S (kg/ha)	Oil content in Seed (%)		Yield (t/ha)	
					2015	2016	2015	2016
Mean	7.60	0.49	0.67	9.23	19.93	21.60	2.11	2.27
Maximum	7.90	0.86	0.88	14.20	23.54	24.94	2.51	2.63
Median	7.57	0.48	0.69	9.50	19.78	21.52	2.11	2.22
Min	7.36	0.22	0.39	2.50	17.08	19.44	1.71	1.90
S. D.	0.16	0.19	0.14	3.18	1.86	1.72	0.25	0.22
Std. Error	0.04	0.05	0.03	0.82	0.48	0.44	0.06	0.06

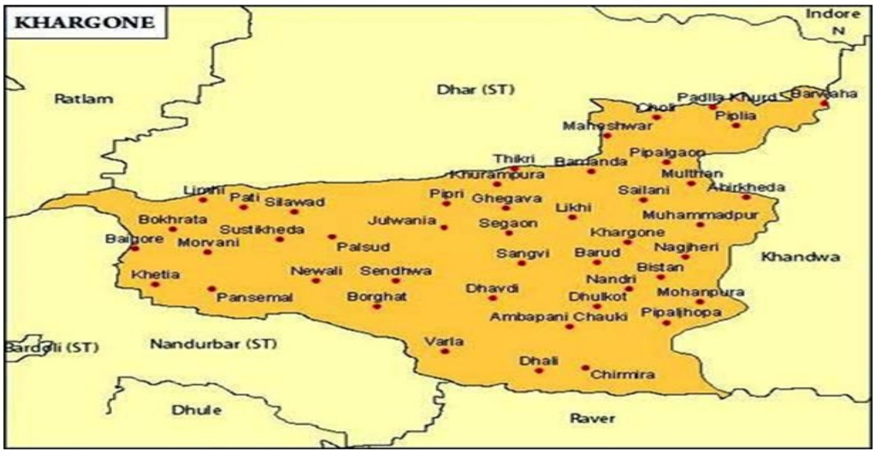

Fig.1. Study Area

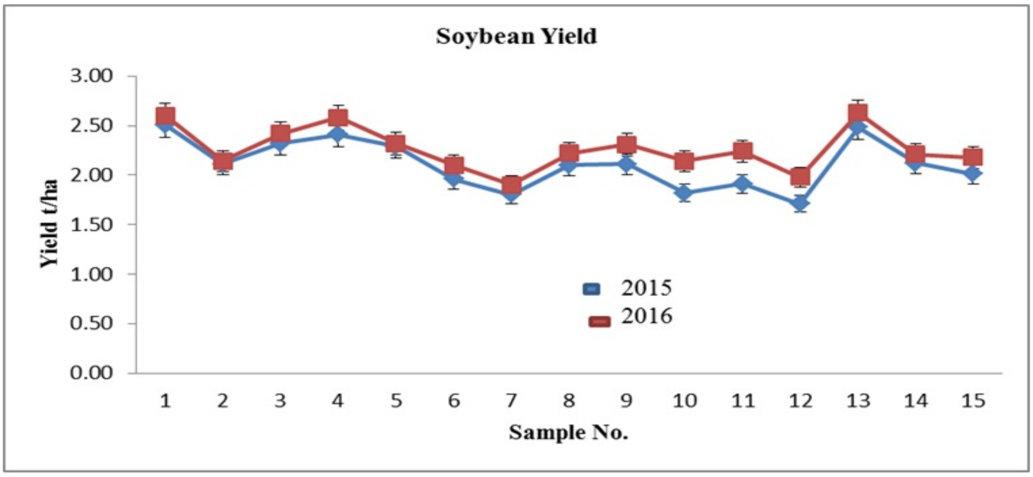

Fig. 2. Effect on soybean yield with and without sulphur application

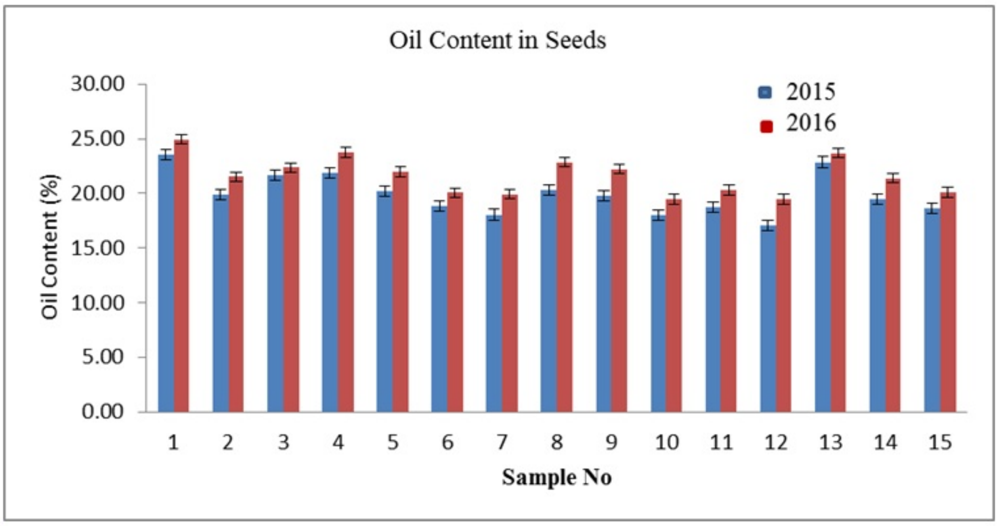

Fig. 3. Effect of oil content with and without sulphur application

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Oilseed based cropping systems productivity in response to land configuration practices in Vertisols under rainfed conditions

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ABSTRACT

Five oilseed based cropping systems [fallow-safflower; pearl millet-chickpea + safflower (3:1); fallow-sunflower; soybean-sunflower and soybean + pigeonpea (4:2)] which are popular in Vertisols were evaluated in four land configuration practices in broad bed and furrow system. The amount of rainfall received during cropping season (June-March) was 1009 mm. Crops did not suffer from moisture stress. Land configuration practices did not differ statistically in influencing the cropping systems productivity. Among the different oilseed based cropping systems, soybean + pigeonpea (4:2) recorded significantly the highest system productivity (4625 kg/ha). The system productivity of other four were in the order of double cropping of soybean-sunflower (3175 kg/ha) > millet-chickpea+safflower (1513 kg/ha) > fallow-sunflower (1488 kg/ha) > fallow-safflower (1200 kg/ha).

Keywords: Cropping systems, Land configuration, Oilseeds

The Vertisols and associated soils of Peninsular India are located in the heartland of the dry farming region of India where majority of oilseed area is present. Vertisols have high moisture storage capacity because of the high clay content (40-60% or more), high bulk density (1.5-1.8 Mg m^{-3}) and related properties. Conversely, these soils become very hard when dry and very sticky when wet. Management of these soils through harnessing the beneficial attributes as well as overcoming the production constraints is a challenge. Apart from soil related constraints, erratic behaviour of monsoon rains and droughts affect crop production with respect to their onset, distribution, intensity and withdrawal. Further, in the changing climatic conditions, declining rainfall amount as well as rainy days affects soil moisture availability which is a concern for sustainable oilseed production (Padmavathi and Virmani, 2013). Land configuration is one of the approaches to improve soil moisture availability and moisture use by the cropping system (Deshmukh *et al.,* 2016). Therefore different oilseed based cropping systems were evaluated on different land configuration practices to quantify the impact on oilseed based cropping systems.

Field experiment was conducted in Vertisols under rainfed conditions at ICAR-Indian Institute of Oilseeds Research Farm at ICRISAT in 2013-14 with four land configuration practices and five oilseed based cropping systems. The four land configuration practices *viz*., broad beds of 1.2 m, 1.5 m, 1.8 m and 2.1 m with uniform furrow of 0.3 m were evaluated in different blocks (500 m^2). The five oilseed based cropping systems *viz.,* fallow-safflower; pearl millet-chickpea + safflower (3:1); fallow-sunflower; soybean-sunflower and soybean + pigeonpea (4:2) were evaluated in each block (100 m^2). The trial was unreplicated. *Kharif* crops were sown on 4th July 2013 while *rabi* crops were sown on 31st October, 2013. The recommended levels of nitrogen, phosphorus and potassium were applied as basal to *kharif* as well as *rabi* crops. In case of intercropping systems (soybean+pigeon pea; chickpea+safflower), the area occupied by each crop was the basis for amount of total fertilizer applied. The details of variety used and recommended fertilizer was presented in Table 1 and crop spacing followed in different land configuration practices was presented in Table 2.

The amount of rainfall received during cropping season was 1009 mm. The crops did not suffer from moisture stress. *Rabi* crops were sown immediately after harvest of *kharif* crops. The seed yield of other crops *viz.,* millet, soybean, pigeonpea, chickpea and sunflower were converted into safflower equivalent yield which was calculated as under.

Safflower equivalent yield (kg/ha)=
Yield of other crop (kg/ha) x Price of other crop (₹/kg)/ Price of safflower (₹/kg)

The data was statistically analyzed using analysis of variance technique as applicable to factorial design without replications. The mean differences between treatments were compared using the least significant difference (LSD).

Land configuration practices did not influence safflower equivalent yield significantly. Good rainfall year might be the reason for non-significant effect. Besides providing adequate surface drainage to *kharif* crops, the land configurations were also useful during prolonged dry-spell thereby, minimizing any adverse effect of soil moisture stress at flowering and seed development stages of rainy season crops (Tomar *et al.,* 1996). Post-rainy season crops were successfully grown with sufficiently high yields. Oilseed cropping systems differed statistically with respect to safflower equivalent yield. Among the different systems, soybean + pigeonpea recorded significantly the highest safflower equivalent yield (4625 kg/ha) across four land configuration practices. Soybean-sunflower double cropping system (3175 kg/ha) was in next place, however it was significantly lower than soybean+pigeonpea intercropping system. The two cropping systems, millet-chickpea+ safflower (1513 kg/ha) and fallow-sunflower (1488 kg/ha) were statistically on par to each other but significantly lower than that of soybean+pigeonpea and soybean-sunflower cropping systems. Fallow-safflower recorded the lowest safflower equivalent yield (1200 kg/ha) nearly 1/4th of soybean+pigeon pea system. In a Vertisols of south India, sorghum/ pigeon pea intercropping on broad bed and furrow produced greater grain/seed yield compared to flat bed method of sowing in low rainfall year (Selvaraju *et al.*, 1999). The systems, maize-chickpea, soybean/ maize intercropping chickpea and maize/ pigeonpea intercropping on broad-bed and furrow system would hold the promise for increasing productivity in Vertisol soils (Mandal *et al.*, 2013).

Table 1 Cultivars and recommended fertilizer of different crops

Crop	Cultivar	Recommended fertilizer (kg/ha)		
		N	P_2O_5	K_2O
Kharif				
Pearlmillet	HHB 67	30	30	20
Soybean	JS 335	20	60	20
Pigeonpea	Asha	20	50	0
Rabi				
Chickpea	Vihar	20	50	40
Safflower	Annigeri-1	40	25	25
Sunflower	DRSH-1	90	90	20

Table 2 Number of crop rows and plant spacing followed in each broadbed and furrow

Crop	Land configuration							
	1.2 m broadbed		1.5 m broadbed		1.8 m broadbed		2.1 m broadbed	
	Number of rows	Plant spacing (cm)	Number of rows	Plant spacing (cm)	Number of rows	Plant spacing (cm)	Number of rows	Plant spacing (cm)
Kharif								
Pearlmillet	3	45 x 10	4	40 x 10	4	50 x 10	5	45 x 10
Soybean*	4	30 x 10	5	30 x 10	6	30 x 10	7	30 x 10
Rabi								
Safflower	3	45 x 20	4	40 x 20	4	50 x 20	5	45 x 20
Sunflower	3	45 x 40	3	60 x 30	3	75 x 25	4	60 x 30
Chickpea**	4	30 x 10	5	30 x 10	6	30 x 10	7	30 x 10

*Soybean+pigeonpea: two rows of soybean was replaced by pigeonpea; **Chickpea+safflower: one row of chickpea was replaced by safflower

Table 3 Effect of land configuration practices on oilseed systems productivity

Cropping system	Safflower equivalent yield (kg/ha)				Mean
	Land configuration (Broad Bed and Furrow)				
	1.2 + 0.3 m	1.5 + 0.3 m	1.8 + 0.3 m	2.1 + 0.3 m	
Fallow – Safflower	1200	1300	1100	1200	1200
Millet – Chickpea + Safflower	1300	1350	1650	1750	1513
Fallow – Sunflower	1750	1500	1400	1300	1488
Soybean – Sunflower	2800	3000	3500	3400	3175
Soybean + Pigeonpea	4400	5000	4600	4500	4625
Mean	2290	2430	2450	2430	
	Cropping system	Land Configuration	Interaction effect		
SEm±	88	70			
C.D ($P \leq 0.05$)	243	NS			

Price of the produce (₹/kg): Safflower 30; Sunflower 35; Soybean 32; Millet 13.5; Chickpea 33; Pigeonpea 37.5

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An analysis of changing pattern in area, production and productivity of oilseeds in Karnataka

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ABSTRACT

The analysis of growth is usually used in economic studies to find out the trend of a particular variable over a period of time and used for making policy decisions. The growth in the area, production and productivity of different oilseed crops in Karnataka was estimated using the compound growth function. The necessary secondary data were collected for a period of 15 years (2000-01 to 2014-15). Oilseed crops contribute a significant proportion to the agricultural GDP. In 2014-15 the area under nine oilseed crops in Karnataka was 13.73 lakh ha with production of 9.59 lakh t, with productivity of 505.4 kg/ha. The results showed that the compound growth rate of total oilseed crop in Karnataka during the period of 2000-01 to 2014-15 was declined to -3.30 per cent with area, -1.93 per cent with production and productivity increased to 0.43 per cent. In order to increase the oilseed production, it is necessary to make available of physical (fertilizers, pesticides and high yielding varieties), financial (credit facilities, crop insurance) and technical inputs (extension services) to the farmers there by increase in productivity of oilseeds in Karnataka.

Keywords: Area, Karnataka, Oilseeds, Production, Productivity

India is the largest producer of oilseeds in the world and oilseed sector occupies an important position in the agricultural economy of the country. Oilseeds are among the major crops that are grown in the country apart from cereals. In terms of acreage, production and economic value, these crops are second only to food grains. India is the fifth largest vegetable oil economy in the world, next only to USA, China, Brazil and Argentina, and has an annual turnover of about ₹ 80,000 crores. India accounts for 12-15 per cent of oilseeds area, 7-8 per cent of oilseeds production, 6-7 per cent of vegetable oils production, 9-12 per cent of vegetable oils import and 9-10 per cent of the edible oils consumption. Nine oilseeds are the major source of vegetable oil in the country. Among nine oilseeds, soybean (39%), groundnut (26%), Rapeseed and Mustard (24%) contributes >88% of total oilseeds production in the country (2014-15). In India, oilseeds follow cereals, sharing 14 per cent of the country's gross cropped area and accounting for nearly 3 per cent of the gross domestic product and 5.98 per cent of the value of all agricultural products (Teja *et al.*, 2017). Despite being the largest cultivator of oilseeds in the world, India imports about 50 per cent of the requirements because of the life style changes in dietary pattern and increasing *per capita* income. India grows oilseeds on an area of 27.02 million hectares, with productivity of 1108 kg/ha for the quinquennium ending 2013-14.

Karnataka is one of the major states in the country in area and production of important edible oilseed crops in India. Groundnut, soybean and sunflower and non-edible oilseed crop such as castor are the major oilseed crops grown in the state. Karnataka is known for its rich biodiversity in India. The State has been identified as one of the 10 agro-climatic zones, suited for the majority of agricultural and horticultural crops. Despite a paradigm shift in economic activities from agriculture to non-agriculture sectors in recent years in the State, the growing need for increase in agricultural production and productivity has been greatly felt with the growth of the population not only for food security but also for generating employment. The sector still plays an important role in the overall development of the State and supports nearly 65 per cent of the State's population (GoK, 2014). The state of Karnataka is blessed with varied agro-climatic conditions which permits the farmers of the state to cultivate not only a variety of crops in a season but also a number of crops like cereals, pulses, oilseeds, commercial crops and horticultural crops across different seasons of the year. In 2014-15 the area under nine oilseed crops in Karnataka was 13.73 lakh ha with production of 9.59 lakh t, with productivity of 505.4 kg/ha.

Oilseed cultivation in Karnataka is predominantly dependent on rainfall and this leads to a higher magnitude of instability in production of oilseeds. Often, the marginal lands are earmarked for cultivation of oilseed crops. Such inherent disadvantages ensure that a level playing field is not provided to the oilseed crops even when they are being compared increasingly with their competing crops in terms of production, productivity and profitability. Therefore, an attempt has been made to study the growth trend of area, production and productivity of oilseeds in Karnataka. The study also attempts to formulate strategies to boost oilseeds production in future.

To study the growth in area, production and productivity of selected oilseed crops in the Karnataka state. The study is based on time series data on area, production, and productivity of selected oilseed crops was available from 2000-01 onwards. Hence the analysis was covered for the period from 2000-01 to 2014-15. Data used for the study was collected from published sources from the Directorate of Economics and Statistics (DES), Bangalore, Karnataka, Department of Agriculture and Cooperation, Government of India.

The growth in the area, production and productivity of selected oilseed crops was estimated using the compound growth function of the form:

$$Y_t = Ab^t \mu_t$$

Where,

Y_t = data on area, production and productivity in the year 't'

A = intercept indicating Y in the base period (t-0).

t = time period

μ_t = error term b = (1+g)

g = average compound growth rate to be estimated

The equation was transformed into log linear form for estimation purpose. The compound growth rate (g) in percentage was then computed using the relationship g = (10^b-1)*100. (Veena, 1996).

From 2000-01 to 2014-15 area, production and productivity total oilseed crops in Karnataka was declined and presented in Table 1. In 2000-01 the area under nine oilseed crops was 18.94 lakh ha with production of 15.44 lakh t, with productivity of 611.4 kg/ha (Fig. 1). During 2014-15 the area under nine oilseed crops in Karnataka was 13.73 lakh ha with production of 9.59 lakh t, with productivity of 505.4 kg/ha. In 2000-01 the area under soybean crops was 0.63 lakh ha with production of 0.65 lakh t, with productivity of 1098 kg/ha. But it increased to 2.56 lakh ha, 1.89 lakh t and 779 kg/ha during 2014-15. The overall performance of groundnut, sunflower, safflower, sesame and mustard is not encouraging as the modest growth in production in the state is mainly due to area expansion. The productivity growth showed a decreasing trend.

The reasons for declining in area, production and steady productivity of oilseed crops are related to biophysical factors, socio-economic conditions, institutional and policy factors, levels of technology transfer and post-harvest management and market linkages. Lack of suitable varieties, high-costs and timely availability of inputs, incidence of diseases and insect pests, low and fluctuating prices, shortage of human labour, poor irrigation facilities, weak linkages between oilseeds producers and processors and markets leading to exploitation by market intermediaries, poor extension services, are major constraints in increasing oilseeds production (Sonnad *et al*., 2011).

From the Table 2, it is noticed that the area under total oilseed crop during the period of 2000-01 to 2014-15 was declined to -3.30 per cent with production of -1.93 with productivity increased to 0.43 per cent in Karnataka. The growth rate of area under groundnut, sunflower, safflower, sesame and rapeseed and mustard have been negative at -2.93; -5.53, -6.59, -3.71 and -7.40 per cent respectively, this indicates that the area under groundnut, sunflower, safflower, sesame and rapeseed and mustard crops has been decreasing year by year, farmers were shifting their cropping pattern from oilseed crops to other crops. But the growth rate of area under soybean was increased to 10.51 per cent during the study period from 2000-01 to 2014-15. This indicates that the area under soybean crops has been increasing year by year.

The growth rates of production of groundnut, sunflower, safflower, sesame and rapeseed and mustard are negative at -2.76, -3.63, -5.45, -3.39 and -5.07 per cent, respectively this shown the production of groundnut, sunflower, safflower, sesame and rapeseed and mustard are also decreasing year by year. The growth rates of production of soybean crop were positive trend of 12.36 over the years in Karnataka.

The growth rates of yield of all the above said crops are positive in Karnataka. Soybean, sunflower and safflower crops show the positive trend 1.66, 2.01 and 1.26 per cent, respectively. Groundnut, rapeseed and mustard and sesame yield was steady during the study period from 2000-01 to 2014-15. This indicates the productivity of all the oilseed crops is also increasing year by year (Fig. 2).

Analysis of secondary data on area, production and productivity of oilseeds over the years reveal that, there has been a slowdown in oilseeds sector in the state. Further, it is impressive to note that cultivation of soybean has made a remarkable progress even after confronting a number of technological, economic and infrastructural constraints. It was observed that the yield levels of groundnut in the state as a whole were declining over time and that of sunflower, safflower, sesame and mustard was not encouraging. Hence, there is an immediate need to take appropriate yield raising measures for sustained production of oilseeds in the state. It thus comes out that to further promote growth in the cultivation of oilseeds, such constraints need to be addressed in future intervention schemes, particularly relating to price risks and economic uncertainties.

The previously-evolved varieties have failed to bring the desired effect in production of oilseeds. Such poor performance is further aggravated by the lack of any technological breakthrough in developing high-yielding varieties (HYVs) of oilseeds. There is lack of supply of quality seeds due to constraints in their large-scale production. Also, farmers are hesitant to adopt improved varieties of seeds; it requires high doses of fertilizers and pesticides, which require high investment. Thus, there is a kind of virtual stagnation in the yield levels of most oilseed crops.

Table 1 Area, production and yield of total oilseeds of Karnataka (2000-2001 to 2014-2015)
(Production: Lakh tonnes; Area : Lakh hectares; Yield : Kg/ha)

Crops/Year	Total oilseeds		
	Area	Production	Yield
2000-01	18.94	15.44	611.4
2001-02	17.37	10.20	489.0
2002-03	20.05	10.74	489.8
2003-04	22.66	9.34	381.0
2004-05	26.73	14.46	455.7
2005-06	28.62	15.28	530.7
2006-07	23.55	9.44	457.9
2007-08	22.75	14.18	551.0
2008-09	21.78	10.29	519.8
2009-10	20.01	8.99	429.2
2010-11	16.22	10.93	564.0
2011-12	14.14	8.84	508.7
2012-13	14.22	9.00	467.1
2013-14	14.10	11.62	604.8
2014-15	13.73	9.59	505.4

Source: www.indiasat.com

Table 2 Growth rates of area, production and productivity of selected oilseed crops in Karnataka (2000-2001 to 2014-2015)

Crops	CAGR (%)		
	Area	Production	Yield
Soybean	10.51	12.36	1.66
Groundnut	-2.93	-2.76	0.18
Sunflower	-5.53	-3.63	2.01
Safflower	-6.59	-5.45	1.26
Rapeseed and mustard	-7.40	-5.07	0.30
Sesame	-3.71	-3.39	0.39
Total oilseeds	-3.30	-1.93	0.43

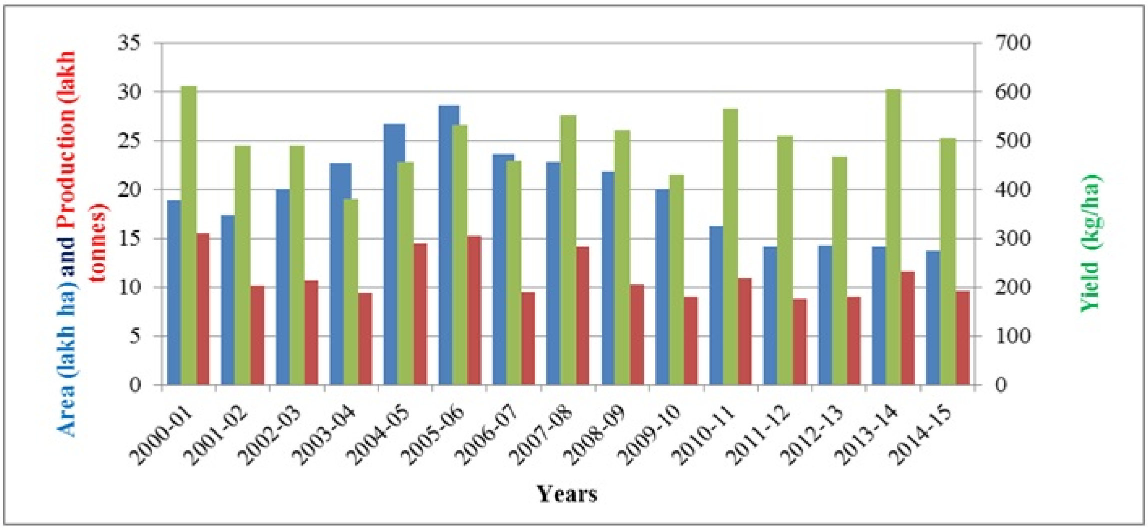

Fig 1. Area, production and productivity of selected oilseed crops in Karnataka from 2000-2001 to 2014-2015

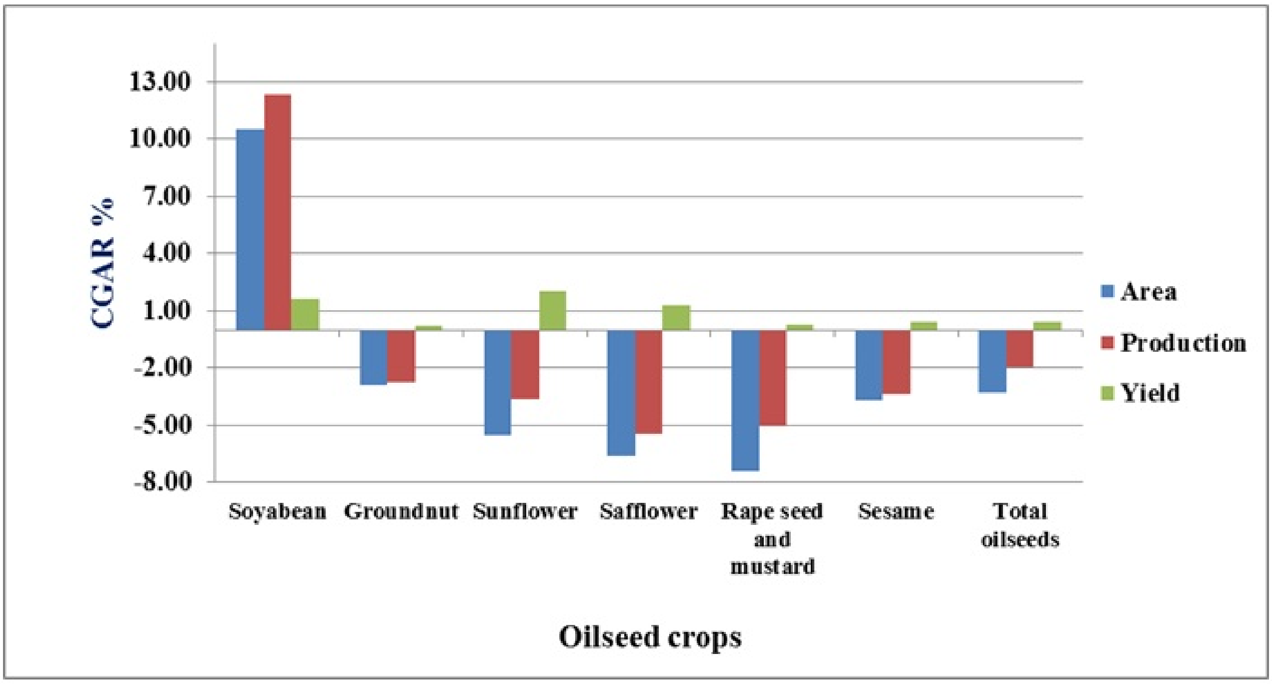

Fig. 2. Growth rates of area, production and productivity of selected oilseed crops in Karnataka 2000-2001 to 2014-2015

Based on the observations of the present study, a few policy suggestions can be made, which are briefly stated as below:

- In an attempt to promote dynamic outlook of the farmers toward adoption of modern cultivation practices, there is a felt need to further promote farmers awareness regarding various government schemes and policies.
- Bringing additional oilseeds areas under irrigation, promotion of modern crop technology and better dry farming and promoting oil palm cultivation.
- Further, there is a need to enlarge the scope of research, technology diffusion and institutional intervention to re-energize the oil sector. This would include increase public research spending in oilseed crops for development of biotic and abiotic stress tolerant varieties.
- Strengthen the oilseed crop seed chain, particularly in groundnut to match the variety specific demand for higher yield.
- Provide incentives to private sector participation in processing and value addition in oilseed crops. Also, constraints for low capacity utilization should be addressed.
- An action plan including popularization of improved technology, production and supply of quality seeds, provision for irrigation at critical stages, ensuring availability of critical inputs, mechanization, special pilot projects in high productivity zones and policy support - value chain, export-import, etc.,
- Development of short duration varieties and hybrids in castor, photo and thermo insensitive varieties in sesame and safflower. Development of ideal genotypes suited for prevailing cropping systems in newer areas. Characterization of production environment for oilseeds with the help of GIS and satellite imageries; comparative assessment of oilseeds profitability, factor productivity and sustainability with competing crops.
- Development of agro-technology for extension of oilseeds cultivation in paddy fallows to utilize residual moisture and fertility. Extension of castor cultivation to non-traditional areas and for newer ecosystems. Development of efficient and profitable intercropping and production systems involving sunflower, safflower and castor either as base crop or as component crop in the major crops of the region. Promoting oilseed crops as contingency crops to harness short season resources in many rainfed cropping systems.
- Strong political will and positive government policies to encourage the production and utilization of oilseed crops through fiscal incentives like soft loan and tax rebate / concessions.
- Ensures the availability of physical (fertilizers, pesticides), financial (credit facilities, crop insurance) and technical inputs (extension services) in major crop ecological zones of oilseed crops.

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Rice bran oil, a hitherto untapped source to meet the edible oil deficit in India

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ABSTRACT

India is the world's fourth largest edible oil producer, it is the world's leading importer and consumer of edible oils in the world. The annual *per capita* consumption of edible oil in the country shot up from around 3 kg in 1950 to 15.9 kg during 2015-16. The continued demand for edible oils by the ever increasing population makes edible oil deficit as a perennial national problem. Therefore, it is pertinent to explore new, unconventional edible oil sources to meet country's ever growing edible oil demands. Of several available options, rice bran oil has potential to jazz up the edible oil deficit, thus making India self-sufficient. Nutritional and toxicological evaluations of rice bran oil proved that this is a healthier option and an attempt has been made in this direction to assess the available untapped rice bran oil reserves at state and county level for rapidly filling up the edible oil supply-demand deficit.

Keywords: Edible oil deficit, Production, Rice bran oil, Vegetable oils

With 21 per cent of the world's area and 15 per cent of world's production, India is the fourth largest oilseed producing country in the world, next to the USA, China and Brazil. Oilseeds in India account for the second largest agricultural commodities after cereals, sharing 13 per cent of the country's gross cropped area, nearly 5 per cent of gross national product and 10 per cent of the value of all agricultural products (Hedge, 2009). The diverse agro-ecological conditions in the country are favourable for growing all the nine annual oilseeds, which include seven edible oilseeds *viz.,* groundnut (*Arachis hypogaea*), rapeseed (*Brassica napus*), mustard (*Brassica juncea*), soybean (*Glycine max*), sunflower (*Helianthus annuus*), sesame (*Sesamum indicum*), safflower (*Carthamus tinctorius*) and niger (*Guizotia abyssinica*), and two non-edible oilseeds *viz.,* castor (*Ricinus communis*) and linseed (*Linum usitatissimum*). Apart from annual oilseeds, a wide range of perennial tropical oil crops of horticulture origin including in particular coconut (*Cocos nucifera*) and oilpalm (*Elaeis guineensis*) are also cultivated in the country. In addition, substantial quantity of vegetable oils is also obtained from non-conventional sources *viz.,* ricebran, cotton seed, corn and tobacco seed (Hedge, 2012).

India is the world's leading importer and consumer of edible oils in the world (Table 1). India currently plays an important role in the global edible oil market, accounting for ~11 per cent share of consumption; 7 per cent share of oilseed production; 5 per cent share of edible oil production and 14 per cent share of world edible oil imports. The *per capita* consumption of edible (= vegetable oils) in the country shot up from around 3 kg annually in 1950 to 15.9 kg during 2015-16 (ICRA, 2015). This increasing trend of edible oil demand has begun to ring alarm bells owing to its severe health implications in the form of a rising tide of cardiovascular complications. Further, experts also fear shortages in the future if the consumption continues to grow at the current pace. Therefore, the present scenario calls for some urgent measures to be taken to step-up edible oil production on a sustainable basis for the growth in oilseeds production has not kept pace with their increasing domestic demand. Thus, intensifying the use of land also seem to be a feasible option, if there are limited chances of area expansion under oilseed crops (Jha *et al.,* 2012). Under these circumstances, exploiting the other alternative, non-conventional edible oil sources will provide realistic options to meet the country's vast supply-demand deficit in the edible oil sector. Of several alternative non-conventional edible oil sources, rice bran oil, a byproduct of rice (staple food for a large part of the world's human population, especially in Asia) offers potential solution that could sustainably close the edible oil gap.

Table 1 Domestic edible oil production and imports (in lakh tonnes)

Year	Production of edible oils	Imports
2005-2006	83.16	40.91
2006-2007	73.70	46.05
2007-2008	86.54	54.34
2008-2009	84.56	74.98
2009-2010	79.46	74.64
2010-2011	97.82	72.42
2011-2012	89.57	99.43
2012-2013	92.19	106.05
2013-2014	100.80	109.76
2014-2015	89.78	127.31

Source: Department of Food & Public Distribution (http://dfpd.nic.in/oil-division.htm#)

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Rice Bran Oil (RBO) is an excellent substitute for vegetable oil. This oil is notable for its high smoke point of 232°C (450°F) and its mild flavour, making it suitable for high-temperature cooking methods such as stir frying and deep frying and popular as a cooking oil in several Asian countries, including Bangladesh, Japan, India and China (www.wiki/ricebranoil). The viscosity of RBO is very light and food cooked with RBO absorbs up to 15 to 20 per cent less oil (ricela.com). It's not just delicate and flavorful, it can help lower cholesterol, fight diseases, enhance the immune system, fight free radicals and more (niir.org).

RBO is unique among edible oil due to its rich source of commercially and nutritionally important phytoceuticals such as oryzanol, lecithin, tocopherols and tocotrinols. However, most of these phytoceuticals are removed from the RBO as waste byproducts during the refining process. γ-oryzanol is one of such component having the potential to be used in nutraceutical, pharmaceutical and cosmoceutical preparations. It is a mixture of ferulic acid esters of sterol and triterpene alcohols and occurs at a level of 1-2 per cent where it serves as natural antioxidant (Patel *et al.,* 2004). Globally, the RBO is very popular and called as 'Heart Oil' in Japan and is being sold as 'World's Healthiest Oil' in the USA. In Europe, RBO has acquired the status of 'Functional Food' and it is also accepted as a 'Premium Cooking Oil' in Japan, Thailand and in India.

RBO, a byproduct of rice is actually the oil extracted from rice bran-the outer layer of rice kernels. Rice bran refers to the thin coating removed from the brown rice during the process of milling. Rice bran removed during milling is about 7.5 to 8 per cent. Rice bran contains anything between 15 to 20 per cent oil depending on the rice variety and the milling process utilized (Atul Chaturvedi, 2013).

Rice, the initial raw material for RBO is grown in more than a hundred countries, with a total harvested area of approximately 158 million hectares, producing more than 700 million tonnes annually. Rice being the major food crop in Asia nearly 90 per cent of the world's rice is produced and consumed in this region (fao.org). Nearly 640 million tonnes of rice is grown in Asia, representing 90 per cent of global production (ricepedia.org). Today, the world's largest rice producers are from Asian countries and the majority of all rice produced comes from China and India followed by Indonesia, Bangladesh, Vietnam, Thailand, Philippines etc. (www.wikipedia.org) (Fig. 1).

India is among the leading rice producers in the world and stand at 2nd position in the world. Apart from being the leading rice producer, India is also the largest exporter of rice in the world and in the last financial year, India exported more than 8 million tonnes of rice to many countries. Rice is grown widely across the nation in more than 20 states and in an area of over 400 lakh hectares. Out of these states, top 10 rice producing states accounts for more than 80 per cent of total rice production in India (Fig. 2). West Bengal is the leader among all rice producing states with more than 13 per cent contribution in India's rice production with 146.05 lakh tonnes (Fig. 3). Rice is grown in a large area in West Bengal in more than 50 lakh hectares of land, which is about 50 per cent of total cultivated land of the state. In terms of yield, Tamil Nadu stands on top with yields of more than 3,900 kg per hectare (listz.in).

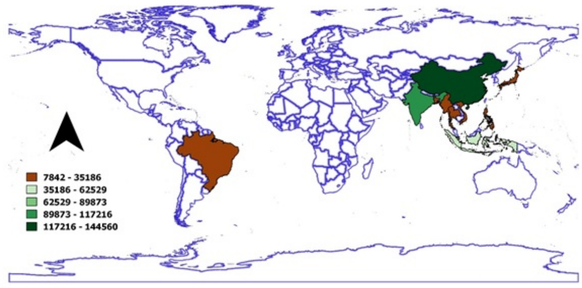

Fig.1. Top ten rice producing countries in the world

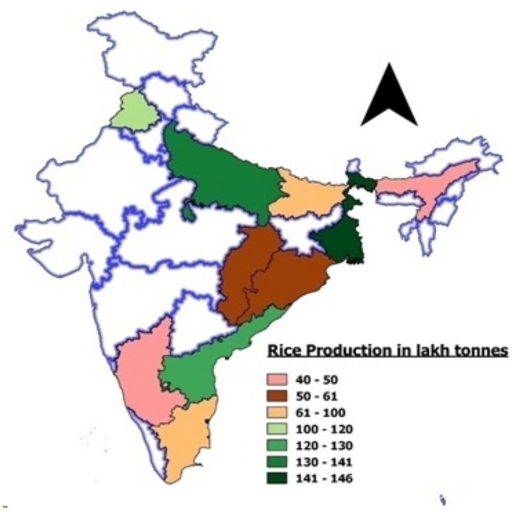

Fig. 2. Top ten rice producing states

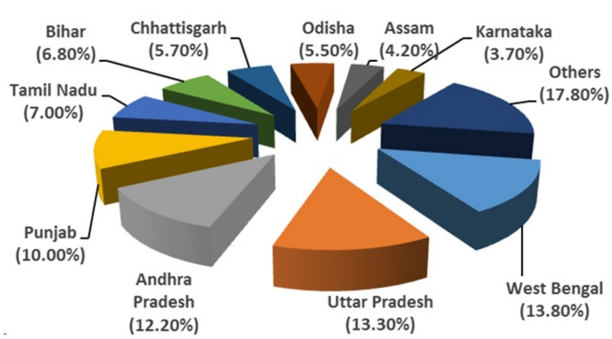

Fig. 3. State-wise contribution of rice production

Rice has been cultivated several years in India and there is a tremendous growth rate in terms of production. During 1950-51 there was 20.58 million tonnes production and as today we crossed more than 100 million tonnes (Fig. 4). The major contribution comes from West Bengal (13.8%) followed by Uttar Pradesh (13.3%), Andhra Pradesh (12.2%), Punjab (10.0%), Tamil Nadu (7.0%), Bihar (6.8%), Chhattisgarh (5.7%), Odisha (5.5%), Assam (4.2%), Karnataka (3.7%) and other states are contributing around 17.8 per cent of the country's rice production.

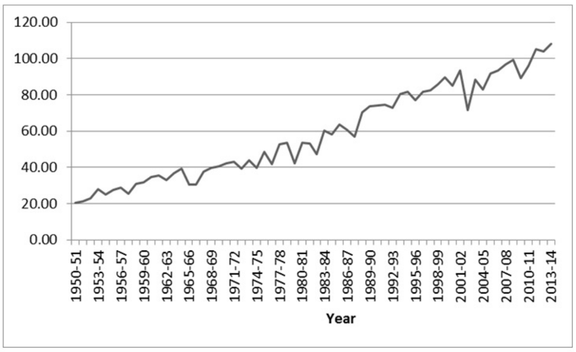

Fig.4. Rice production (million tonnes) trend from 1950-51 to 2013-14

The current potential of RBO in the world is 3.5 million tons, against which the current production is only about 1.5 million tonnes. The major producers are India (9,50,000 T), China (2,00,000 T), Japan (80,000 T) and Thailand (50,000 T). India represents nearly 2/3rd of the world production and is number one in the world. Last one decade, India RBO production increased from 0.68 to 0.93 million tonnes. But in India potential for RBO production is 1.61 million tonnes. Current production is 0.93 million tonnes. This leaves an unrealized potential of 0.68 million tonnes (Table 2). In fact, last one-decade, there is an increasing trend can be seen in RBO production in India, which around 5 per cent of average growth rate except in the year 2009-10. At the same time, un-utilized potential RBO is more than 57 per cent.

Table 2 RBO Production, potential and untapped RBO
(quantity in million tonnes)

Year	RBO Production	RBO Potential	Untapped RBO
2004-05	0.68	1.28	0.60
2005-06	0.73	1.40	0.67
2006-07	0.75	1.43	0.68
2007-08	0.80	1.40	0.60
2008-09	0.85	1.51	0.66
2009-10	0.80	1.36	0.56
2010-11	0.83	1.45	0.62
2011-12	0.88	1.52	0.64
2012-13	0.90	1.58	0.68
2013-14	0.93	1.61	0.68

Source: http://seaofindia.com/cdn/gallery/2409.pdf

As per the rice production data in the country during 2013-14, state-wise potential RBO was calculated and presented in Table 3. West Bengal was leading with 0.21 MT of potential RBO followed by Uttar Pradesh (0.20 MT), Andhra Pradesh (0.19 MT), Punjab (0.15 MT), Tamil Nadu (0.11 MT), Bihar (0.10 MT), Chhattisgarh (0.09 MT), Odisha (0.08 MT), Assam (0.06 MT), Karnataka (0.06 MT) and other states contribution was around 0.27 MT. But during 2013-14 RBO production in India was around 0.93 MT and untapped RBO was around 0.68 MT.

India is expected to produce rice about 125 and 160 MT by 2025 and 2050 respectively, and which has the potential to yield 1.80 and 2.30 MT of RBO (www.taas.in) (Table 3). The projections are based on the assumptions that the per capita consumption would be increasing annually at 3 per cent till 2013-14, followed by an increase in a declining rate of 2.5 per cent from 2013-14 to 1.75 per cent in 2025, with a further decline in the incremental consumption to negligible levels by the year 2050. The estimated per capita consumption is accordingly placed at 17.50 and 19.16 kg/annum in the year 2025 and 2050, respectively. The total edible oil requirement is estimated at 24.50 and 32.19 MT during 2025 and 2050 respectively (Table 4).

Table 3 State-wise potential RBO production (2013-14)
(quantity in million tonnes)

State	Rice Production	RBO Potential
West Bengal	14.90	0.21
Uttar Pradesh	14.36	0.20
Andhra Pradesh	13.18	0.19
Punjab	10.80	0.15
Tamil Nadu	7.56	0.11
Bihar	7.34	0.10
Chhattisgarh	6.16	0.09
Odisha	5.94	0.08
Assam	4.54	0.06
Karnataka	4.00	0.06
Others	19.22	0.27

Source: Directorate of Economics and Statistics

Table 4 Projection of rice and RBO for year 2025 and 2050
(quantity in million tonnes)

	Year		
	2013-14	2025	2050
Rice	108	125	160
RBO Potential	1.61	1.80	2.30
Population (billion)	1.25	1.40	1.68
Per capita consumption (kg/annum)	14.40	17.50	19.16
Edible oil requirement	18.00	24.50	32.19

Projected values based on the study

Based on the historical data growth rates, state-wise rice production is predicted for West Bengal which is leading with 17.25 and 22.07 MT followed by Uttar Pradesh (16.62 and 21.27 MT), Andhra Pradesh (15.25 and 19.53 MT), Punjab (12.50 and 16.00 MT), Tamil Nadu (8.75 and 11.20 MT), Bihar (8.50 and 10.87 MT), Chhattisgarh (7.13 and 9.13 MT), Odisha (6.88 and 8.80 MT), Assam (5.25 and 6.73 MT), Karnataka (4.63 and 5.93 MT) and others states contribution will be around 22.25 and 28.47 MT for the year 2025 and 2050, respectively. According to rice production estimations, state-wise potential RBO is estimated and presented in Table 5. West Bengal is leading with 0.25 and 0.32 MT followed by Uttar Pradesh (0.24 and 0.31 MT), Andhra Pradesh (0.22 and 0.28 MT), Punjab (0.18 and 0.23 MT), Tamil Nadu (0.13 and 0.16 MT), Bihar (0.12 and 0.16 MT), Chhattisgarh (0.10 and 0.13 MT), Odisha (0.10 and 0.13 MT), Assam (0.08 and 0.10 MT), Karnataka (0.07 and 0.09 MT) and other states contribution will be around 0.32 and 0.41 MT for the year 2025 and 2050, respectively.

India is one of the world's largest producers of oilseeds and consumers of edible vegetable oil, producing around 8.2 million tonnes and importing around 11 million tonnes annually to meet domestic demand. In this context, the growing popularity of rice bran oil in the country is a welcome development for the government, which is keen to reduce dependency on edible oil imports. It also provides an incentive to boost rice farming in the country. The health benefits associated with the consumption of rice bran oil will be a boon to promote its production and popularize its consumption nationwide.

Table 5 State-wise projection of RBO for year 2025 and 2050 (quantity in million tonnes)

	2025		2050	
State	Rice Production	RBO Potential	Rice Production	RBO Potential
West Bengal	17.25	0.25	22.07	0.32
Uttar Pradesh	16.62	0.24	21.27	0.31
Andhra Pradesh	15.25	0.22	19.53	0.28
Punjab	12.50	0.18	16.00	0.23
Tamil Nadu	8.75	0.13	11.20	0.16
Bihar	8.50	0.12	10.87	0.16
Chhattisgarh	7.13	0.10	9.13	0.13
Odisha	6.88	0.10	8.80	0.13
Assam	5.25	0.08	6.73	0.10
Karnataka	4.63	0.07	5.93	0.09
Others	22.25	0.32	28.47	0.41

Projected values based on the study

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