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Vol. **37**, No. 4 Dec., 2020

CONTENTS

Research Papers

Short Communications

Wide hybridization between wild and cultivated species of *Helianthus annuus* and morphological characterization of interspecific hybrids

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ABSTRACT

The present study was undertaken to understand cross-compatibility between two genotypes of cultivated *Helianthus annuus* L. and three accessions of wild annual diploid *H. annuus* accessions, ANN-61, ANN-98 and ANN-114. The derived six interspecific hybrids were evaluated for morphological characters and *Alternaria* blight incidence under field conditions. The six interspecific crosses were recorded with anthocyanin pigmentation on petiole, stem and stigma and leaf serration resembling wild parents whereas some of the characters like cordate leaf shape resembled cultivated parents. Stem pubescence was intermediary between wild and cultivated parents confirming the hybrid nature of crosses. The interspecific crosses recorded medium resistant reaction to *Alternaria* leaf spot which has been transferred from resistant wild accessions into susceptible cultivated genotypes. The meiotic abnormalities were not observed in interspecific crosses resulting in higher pollen fertility of 95%. The present study represents successful crossing between cultivated and diploid wild species and possibility of developing *Alternaria* resistant inbred lines with high self fertility in sunflower.

Keywords: Interspecific hybrids, Morphological Characterization, Pollen sterility, Sunflower, Wide hybridization

Oilseeds occupy a place of pride in the Indian economy. Oilseeds are among the major crops grown in the country apart from cereals and pulses. In terms of acreage, production and economic value, oilseed crops are second only to food grains. Sunflower originated in Southern United States and Mexico from where it was introduced into Europe and later into former USSR. It is the second most important oilseed crop in the world after soybean. Sunflower is an oilseed crop introduced in the country during 1969. In India, it is cultivated on an area of 3.02 lakh hectares with a production of 2.27 lakh tons and productivity of 667 kg/ha. The major sunflower producing states are Karnataka (62%), Odisha (6.7%), Andhra Pradesh (5.3%), Maharashtra (5%) and Bihar (4%) (Anonymous, 2019). However, over the last decade, sunflower cultivation in India is limited severely by the heavy yield losses due to diseases like necrosis, *Alternaria* leaf spot, downy mildew and powdery mildew and insect pests like leafhoppers. *Alternaria* blight is known to reduce seed yield by 27-80% and oil yield by 17-33% and even disease can significantly reduce seed germination, head diameter and number of seeds per head (Reis *et al*., 2006).

The genus *Helianthus* is composed of 51 species and 19 subspecies with 14 annual and 37 perennial species (Seiler, 2007). Chromosome number in somatic cells of the cultivated sunflower (2n=34) was determined by Tahara (1915) and confirmed by Wagner (1932), and Kostoff (1939). Studying the chromosome number in different *Helianthus* species by Geisler (1931) found species with n=17, 34 and 51 chromosomes. This finding was later on corroborated by Heiser and Smith (1955) and Georgieva-Todorova (1976). While the basic chromosome number in the genus *Helianthus* is n=17, the genus is a polyploidy complex composed of diploid (2n=2x=34), tetraploid (2n=4x=68) and hexaploid (2n=6x=102) species (Rogers *et al*., 1982).

Management of disease through synthetic chemicals will increase cost of cultivation and also has environmental concerns. Hence, bio-intensive management involving host plant resistant is one of the best alternatives for managing diseases in a sustainable manner. So there is a need to identify reliable sources of resistance for various diseases either to recommend directly for cultivation in endemic area or as a possible donor for resistance breeding. Wild *Helianthus* species represent a valuable reservoir of genes for several biotic stresses which have been successfully introgressed into cultivated sunflower (Seiler, 2007).

Interspecific hybridization has played a pivotal role in the genetic improvement of sunflower (Korell *et al.,* 1996). Interest in interspecific hybridization in sunflower is mainly for transfer of characters such as disease and insect resistance, salt tolerance, drought tolerance, fatty acid composition, protein quality, cytoplasmic male sterility and fertility restoration. Interspecific hybridization offers a lot of scope for creating variability and broadening the genetic base of cultivated sunflower. But the derived hybrids exhibits partial sterility due to ploidy level differences, genomic incompatibilities, cytoplasmic imbalances or other factors. The narrow genetic base of cultivated sunflower has been broadened by the infusion of genes from the wild species,

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which have provided a continued source of agronomic traits, insect and disease resistance and seed quality factors (Thompson *et al.,* 1981; Seiler, 1992). Morphological characterization helps to screen germplasm lines resistant to pests such as leaf and stem hairiness inhibiting oviposition (Zimmerman and Fick, 1973), leatheriness of leaves, seed color and size (Balakrishnan *et al.,* 1994) and also attraction to insects for pollination (Sinha and Atwal, 1996). Phenotypic characterization can be used as marker to identify parents or lines in hybrid seed production and cultivar purity testing. Investigation on different morphological characters in any crop is a pre requisite for plant breeding particularly when it involves wide hybridization to trace introgressed traits and for further selections. Keeping in view the importance and urgency of utilizing wild genome, present study was aimed at synthesis and screening of sunflower interspecific hybrids to *Alternaria* disease resistance and for their use in future breeding programme.

MATERIALS AND METHODS

The experimental material for present investigation consisted of three wild accessions of *Helianthus annuus* (accessions ANN-61, ANN-98 and ANN-1114 supplied by ICAR-Indian Institute of Oilseeds Research, Hyderabad) as male parents and two genotypes of cultivated species (CMS-B and R-83), that are morphologically different used as female parents. Crosses between these chosen genotypes yielded six interspecific hybrids. The CMS-B line is a mono headed broad spectrum maintainer line used to maintain the male sterility in CMS-A lines. Another line R-83 is a multi-headed restorer line used for restoration of male fertility when crossed with male sterile lines.

All inter-specific hybrids along with cultivated species were planted in *kharif* 2016 at Main Agricultural Research Station, University of Agricultural Sciences, Raichur. The interspecific hybrids were characterized by recording 17 morphological traits and 11 quantitative characters along with wild parental species. As per PPVFRA's DUS guidelines phenotypic characterization was carried out.

For screening against *Alternaria* leaf spot, all plants derived from six interspecific crosses along with susceptible check were planted in field for morphological evaluation and advancement. The incidence of *Alternaria* leaf spot disease infection was favored by intermittent rains during *kharif* season with humid micro climate under crop canopy. The incidence of *Alternaria* leaf spot disease was recorded in all plants of each interspecific crosses at 45 days after sowing by using 0-9 as scale (Mayee and Datar, 1986).

RESULTS AND DISCUSSION

The morphological characterization is very important for selection, identification and classification of various germplasm/inbred lines. Morphological characterization helps to screen lines/parents resistant to insect pests based on the morphological traits such as leaf and stem hairiness which inhibit oviposition (Zimmerman and Fick, 1973) leatheriness of leaves, seed color and size (Balakrishnan *et al*., 1994) if their association with agronomic traits are esatblished. Besides, morphological traits are also helpful for screening of diseases (Pathak *et al.,* 2000) and sometimes for attracting the insects for pollination (Sinha and Atwal, 1996). The wild accessions and cultivated genotypes of *H. annuus* belongs to same annual diploid group having chromosome number 2n=34. However, morphologically they differ significantly (Fig. 1). In spite of the differences in both the species, both species are easily crossable. In the present study, a multi-headed restorer line 'R-83' and a mono-headed maintainer line 'CMS-B' belonging to cultivated species were used as female parents to cross with wild annual diploid *H. annuus* Accessions used as pollen parent. Wide hybridization, through hand emasculation and pollination, was successful because of good percentage of seed setting in cultivated female parents.

Interspecific hybrid plants observed with characters approximating the characters of either parent, individuals with a completely new phenotype or those similar to related species indicating genetic recombination. This large level of genomic recombination creates phenotypic variability with exchanged genetic base which helps to select better recombinants (Encheva and Christov, 2006). Seventeen morphological and eleven quantitative characters of 3 accession of wild and 2 cultivars of *H.annuus* and their interspecific hybrids were recorded and are presented in Table 1 and 2.

Leaf characters such as leaf shape, leaf angle play an important role in identification and are often associated with yielding ability of plant species. Erect orientation of leaves permit greater penetration and more even distribution of light into the crop canopy and thus higher photosynthetic activity. Thicker and dark green leaves usually have higher densities of chlorophyll per unit area and hence have greater photosynthetic abilities. Leaf serration provides tolerance to the plant against invading pests. All three wild accessions and R-83, showed triangular leaf shape whereas while CMS-B showed cordate leaf shape. Among 6 interspecific crosses, only one cross (R83 X ANN-1114) recorded triangular leaf shape remaining all crosses showed cordate leaf shape. These results are in accordance with the results of Terzic *et al.* (2006) they reported cordate type of leaf shape in interspecific hybrids. While Prashanth *et al.* (2014) reported cordate leaves in interspecific crosses between cultivated species and diploid perennial wild species (*Helianthus occidentalis* and *Helianthus maximiliani*). Wild *H. annuus* accessions recorded medium leaf serration while cultivated lines showed low serration. Interspecific crosses showed medium serration similar to wild parents.

With respect to anthocyanin pigmentation on hypocotyl, petiole and stem was absent in cultivated genotypes while it was present in wild annual diploid *H. annuus* accessions. The interspecific crosses recorded medium anthocyanin pigmentation on hypocotyl and petiole similar to wild accessions indicating it to be dominant character (Fig. 1).

The stem and leaf pubescence have adaptive significance and play important role in plant defense mechanism. There is a negative correlation between trichome density and insect feeding and oviposition responses. The leaf pubescence of cultivated genotypes R-83 and CMS B was low while wild annual diploid *H. annuus* accessions were densely pubescent and the interspecific crosses recorded dense hairiness. Encheva and Christov (2006) reported interspecific cross between *H. annuus* × *H. salicifolius* showed intermediary with regard to the indices for leaf hairiness. The stem hairiness in cultivated genotypes R-83 and CMS B were very sparse compared to wild annual diploid *H. annuus* accessions which had dense hairs on its stem. However, interspecific crosses recorded medium amount of hairs on the stem. Valkova and Christov (2004) observed stem covered with short, sharp hairs in their interspecific cross between cultivated and wild *H. annuus* L. While Meena *et al.* (2017) reported similar medium level of stem hairyness in interspecific crosses between cultivated sunflower and a wild species *H. argophyllus* (PI-468649).

Table 1 Comparative morphological features of accession of wild species and genotypes of cultivated species used as parents and their interspecific crosses obtained

Traits	Wild accessions			Interspecific Crosses						Cultivated lines	
	ANN-61	ANN-98	ANN-1114	R83 x ANN-61	CMS-B x ANN-61	R83 x ANN-98	CMS-B x ANN-98	R83 x ANN-1114	CMS-B x ANN-1114	R-83	CMS -B
Hypocotyl anthocyanin pigmentation	Strong	Strong	Strong	Medium	Medium	Medium	Medium	Medium	Medium	Absent	Absent
Leaf shape	Triangular	Triangular	Lanceolate	Cordate	Cordate	Cordate	Cordate	Triangular	Cordate	Triangular	Cordate
Leaf serration	Medium	Medium	Low	Medium	Coarse	Medium	Medium	Low	Low	Low	Coarse
Vein leaf lateral angle	Acute	Acute	Acute	Acute	Acute	Acute	Acute	Acute	Acute	Acute	Acute
Leaf pubescence	Dense	Dense	Medium	Dense	Dense	Dense	Dense	Dense	Dense	Low	Low
Petiole pigmentation	Present	Present	Present	Present	Present	Present	Present	Present	Present	Absent	Absent
Stem colouration	Light Green	Light Green	Light green	Dark green	Light-dark green	Light green	Light-medium green	Dark green	Medium-dark green	Light green	Green
Stem pubescence	Dense	Dense	Dense	Medium	Medium	Medium	Medium	Medium	Medium	Sparse	Sparse
Plant type (Branching/ Non Branching)	Branching	Branching	Branching	Branching	Branching	Branching	Branching	Branching	Branching	Branching	Non branching
Ray floret –shape	Ovate	Ovate	Ovate	Ovate	Ovate	Ovate	Ovate	Ovate	Elongated	Elongated	Elongated
Ray floret –colour	Orange yellow	Orange yellow	Yellow	Orange yellow	Orange yellow	Light yellow	Orange yellow	Light yellow	Orange yellow	Yellow	Yellow
Stigma colour	Brown	Brown	Brown	Brown	Brown	Brown	Brown	Brown	Brown	Yellow	Yellow
Pollen colour	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Head angle	Inclined	Inclined	Inclined	Vertical	Vertical	Vertical	Vertical	Vertical	Vertical	Half-turned down	Half-turned down
Seed shape	Small ovate	Small ovate	Small ovate	Narrow elongate	Bold ovate	Elongated	Bold elongated	Small ovate	Small ovate	Elongated	Ovoid elongated
Seed colour	Light brown	Light brown	Light brown	Black	Black	Black	Black	Brown	Brown	Black	Black
Seed coat stripes	White with black spots	White with black spots	Black spots	Absent	Absent	Grey	Absent	Absent	Absent	Grey	No

Table 2 Mean quantitative characteristics of wild, cultivated species and their interspecific crosses in sunflower

Genotypes	Characters										
	Number of leaves/ plant	Days to 50% flowering	Days to maturity	Plant height (cm)	Leaf width (cm)	Leaf length (cm)	Stem girth (cm)	Head diameter (cm)	Seed length (mm)	Test weight (g)	Yield/ plant (g)
ANN-61	207**	69.6	102.4	157.8**	11.94	14.56	3.16**	3	4.03	0.81	6.16*
ANN-98	230**	76.6	111.4	170.2**	17.26**	19.8**	3.28**	3.44	4.48	0.99	4.86
ANN-1114	103	96.2**	125**	56.2	8.58	10.98	2.28	2.92	4.03	0.78	4
Mean of wild parents	180	80.80	112.93	128.07	12.59	15.11	2.91	3.12	4.18	0.86	5.01
R83	47	54.2	79.2	101	13.2	17.4	2.02	13.04	8.26	3.26	15.04**
CMS-B	46	53.4	75	94.4	17.2	16	1.9	14.16	9.84**	4.05**	9.48
Mean of cultivated parents	46.50	53.80	77.10	97.70	15.20	16.70	1.96	13.60	9.05	3.66	12.26
R83 X ANN-61	53	59.8	91	120	21.8	19.6	1.9	7	7.93	2.8**	7.44*
CMS-B X ANN-61	26.8	57.2	87.8	173**	32.6**	33.4**	2.96**	6.5	9.36**	3.64**	8.58**
R83 X ANN-98	69.4**	54.2	83	151.4**	26.4**	24.6*	2.62*	7	7.32	2.5	8.42**
CMS-B X ANN-98	67.2**	53.6	86.6	141.6*	26.7**	24.5	2.24	6.92	9.04**	3.32**	8.48**
R83 X ANN-1114	77.4**	59.8	90.4	80	15.5	16.7	1.48	4.3	5.94	1.24	2.56
CMS-B X ANN-1114	29.4	61.4	91	87.5	15	13.5	1.5	8.1	5.92	1.18	2.88
Mean of interspecific crosses	53.87	57.67	88.30	125.58	23.00	22.05	2.12	6.64	7.59	2.45	6.39
SEm	3.4829	1.5004	1.6484	5.0187	0.7058	0.911	0.1489	0.2664	0.1753	0.092	0.316
C.D @5%	9.95	4.28	4.71	14.34	2.01	2.6	0.42	0.76	0.5	0.26	0.9
C.D. @1%	13.32	5.73	6.3	19.19	2.69	3.48	0.56	1.01	0.67	0.35	1.2

Plant branching is a dominant character for most wild sunflower species. Wild annual diploid *H. annuus* showed dominant branching where cultivated sunflower CMS B had no branching (Fig.1) and R-83 had branching. The interspecific crosses recorded plant branching in all 6 crosses similar to wild parent. Profuse branching in interspecific hybrids between *H. annuus* × *H. maximiliani* (Hristova-Cherbadzi *et al.,* 2011) and between *H. annuus* × *H. tuberoses* (Prabakaran and Sujatha, 2004) have been reported.

Seed size is an important objective in breeding programmes because larger seeds contain more of biomass and oil content and test weight. Wild annual diploid *H. annuus* had brown colour with rough texture and most of the interspecific crossed seeds showed light black seed coat colour indicating the intermediate character (Fig. 2). These results were in accordance with Vishnutej *et al.* (2016) in a cross between cultivated sunflower LSF-8 X wild annual diploid *H. argophyllus.* In contrast Hristova and Cherbadzi (2004) obtained pale gray-brownish to dark brown seed colour, in their interspecific crosses involving annual diploid *H. bolanderi* Gray, *H. neglectus* Heiser and *H. petiolaris.* For seed shape, small ovate type of seed shape was recorded in wild parents whereas elongated type in cultivated lines. Variation for seed shape observed among crosses varied between small ovate to narrow elongated.

These results confirmed that wide hybridization between wild *Helianthus* species and cultivated sunflower creates diversity for different traits as reported earlier by others (Satziperov, 1916; Georgieva-Todorova, 1972; Christov, 1988).

Table 3 Screening for Alternaria leafspot disease under natural field conditions

Genotype	Alternaria leaf spot	
	Score	Host reaction
ANN-61	3	R
ANN-98	3	R
ANN-1114	1	HR
R83	7	S
CMS-B	7	S
R83 X ANN-61	5	MR
CMS-B X ANN-61	5	MR
R83 X ANN-98	5	MR
CMS-B X ANN-98	5	MR
R83 X ANN-1114	5	MR
CMS-B X ANN-1114	5	MR
Morden ©	9	HS

MR- moderately resistant, R- Resistant and S- susceptible, HS-highly susceptible

Quantitative characters are of prime importance to evaluate potentiality of parents and crosses in sunflower (Table 2). Seed yield/plant is less in wild accessions and interspecific crosses compared to cultivated lines. There is a negative transgression for this trait but yield is not a simple character as it involves contribution from more than one characters towards it. In contrast, Nikolova *et al.* (2004) reported high seed yield in interspecific crosses between *H. annuus* × *H. laevigatas.* The average test weight of cultivated sunflower seeds was 3.65 grams and wild annual diploid *H. annuus* accessions was 0.86 grams. Interspecific cross had an average test weight of 2.45grams. Hristova and Cherbadzi (2004) reported improvement in test weight in interspecific crosses involving annual diploid *H. bolanderi* Gray, *H. neglectus* Heiser and *H. petiolaris.* These results are also in accordance with the results obtained by Whelan and Dorrell (1980) for 100 seed weight in the interspecific derived hybrid between *H. annuus* × *H. maximiliani.*

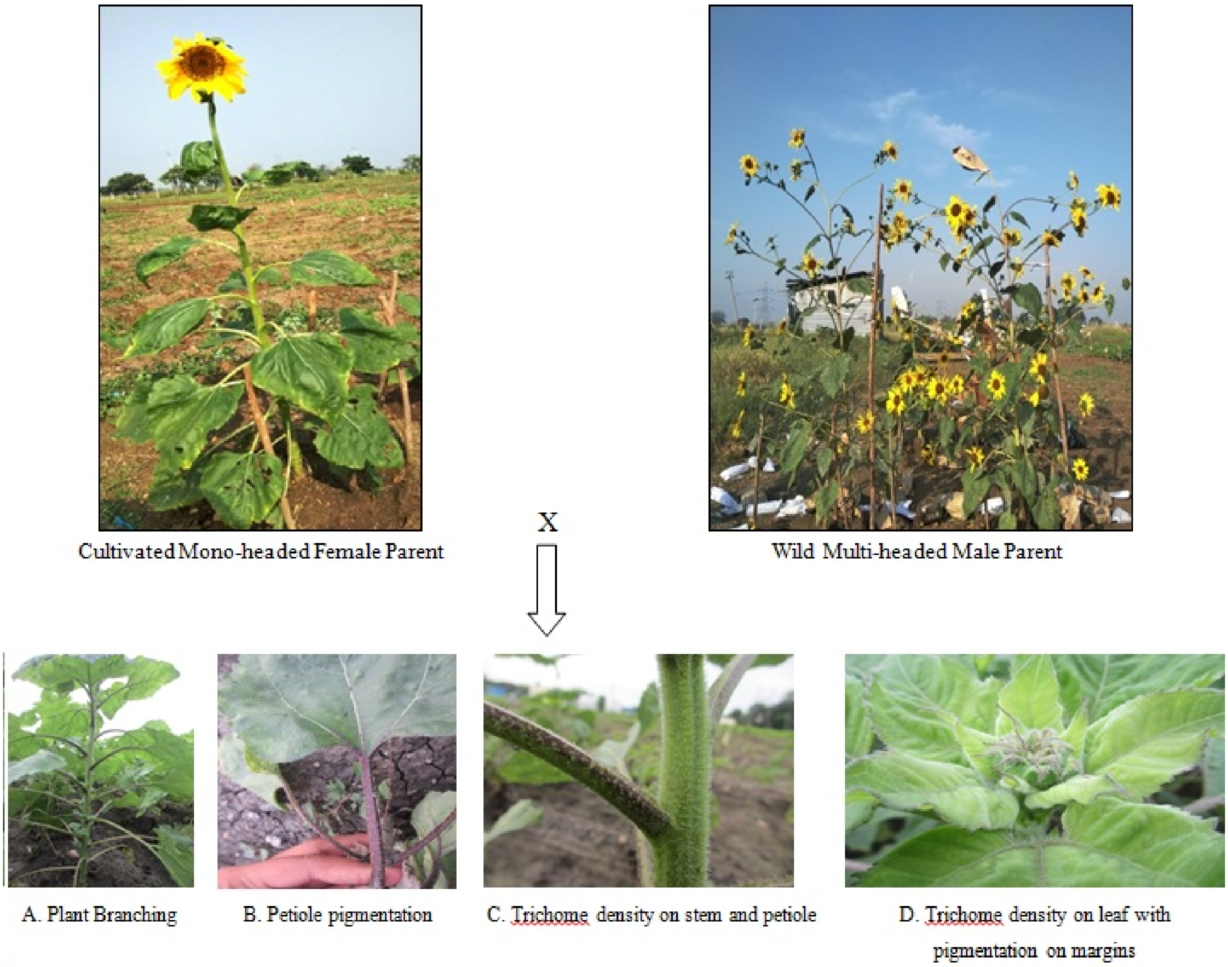

Fig. 1. Morphological features of cultivated and wild parents and their interspecific hybrids

Head diameter in sunflower is an important agronomic trait. Bigger heads have more number of seeds and also contribute towards better yield potential. However, in addition to head size, other factors like number of heads/plant, number of filled seeds, seed size are also important. Head diameter in the cultivated sunflower is larger compared to that of wild annual diploid *H. annuus.* The cultivated lines had average head diameter of 13.6 cm and the head diameter of wild *H. annuus* was 3.12 cm. The interspecific cross showed an average of 6.63 cm head diameter indicating intermediate type of head diameter. Several earlier studies have reported intermediate head diameter for the interspecific hybrids; between *H. annuus* x *H. maximiliani* (Hristova-Cherbadzi *et al.,* 2011); between *H. annuus* x *H. simulans* (Prabakaran and Sujatha, 2004); between *H. annuus* x *H. argophyllus* (Nikolova and Christov, 2004); and between *H. annuus* (hybrid Albena) x *H. salicifolius* (Encheva and Christov, 2006).

The number of days required to 50 percent of the plants in a genotype to flower is a definite indication of the duration of the genotype. The days to maturity is often closely related with days to flowering, although genetic differences in the period or duration required for flowering to maturity exists (Kandalkar, 1997). There is considerable difference in days to 50% flowering. The cultivated sunflower flowered early in 54 days while wild annual diploid *H. annuus* took 81 days to flowering. The six interspecific crosses recorded days to 50% flowering ranging from 54 to 61, intermediary in flowering with a mean of 58 days.

In our study, the wild annual diploid *H. annuus* accessions were taller than cultivated female genotypes. The average height for wild *H. annuus* accessions recorded a mean of 128.07 cm and the cultivated showed 97.7 cm. The interspecific crosses recorded 125.88 cm. Hristova and Cherbadzi (2004) reported interspecific crosses involving annual diploid *H. bolanderi* Gray, *H. neglectus* Heiser and *H. petiolaris* that all plants reached a height of up to 150 to 160 cm, and individual plants from the cross *H. neglectus* x *H. annuus* being as tall as 195 cm. Nikolova and Christov (2004) observed reduced plant height in a cross between wild and cultivated lines of *Helianthus* spp., *H. argophyllus* (E-007) x L.1234, indicating similar results.

Cultivated *H.annuus* parent

Interspecific Hybrid

Wild *H. annuus* parent

Fig. 2. Seed characteristics of cultivated and wild parents and their interspecific hybrids

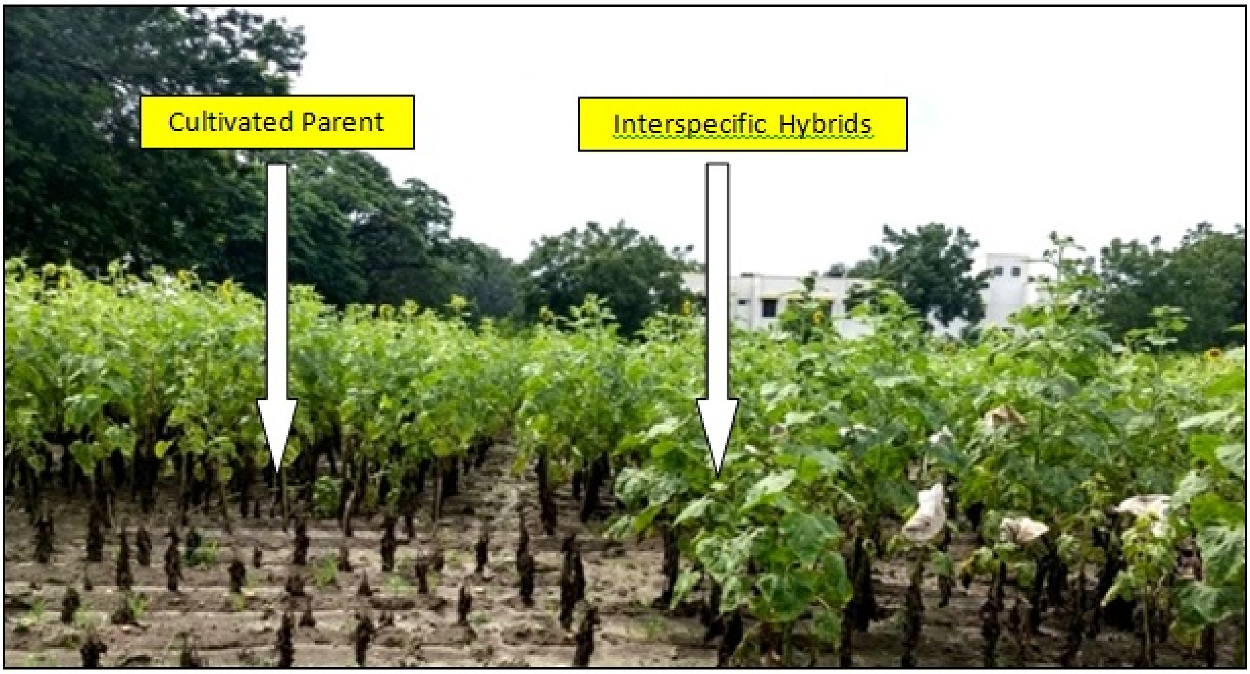

Fig.3. Differential incidence of Alternaria blight in cultivated parents and interspecific hybrids

Nine *Alternaria* species have been reported on sunflower, among them *A. helianthi* (Hansford) has been recognized as the most prevalent and damaging species worldwide (Kolte, 1985). *Alternaria* leafblight occurs in all sunflower producing areas and is currently a potential disease threat to sunflower production particularly in *kharif* season which receives more of intermittent rains. Initially *Alternaria* leaf spot symptoms appear as dark brown to black circular lesions with concentric rings. In younger leaves, lesions may appear as distinct yellow halos which later enlarge to coalesce resulting in leaf blighting. In severe incidence of blight plants may be defoliated prematurely and die or lodge causing heavy losses upto 80% (Reis *et al.,* 2006).

In the present study six interspecific crosses along with parents and susceptible check Morden were evaluated for *Alternaria* disease incidence with 1-9 scale (Datar and Mayee, 1986). Natural infections occurred each year, resulting in low to medium levels of disease intensity during rainy (*kharif*) season. Out of three wild accessions ANN-1114 recorded highly resistant reaction with a score of 1 whereas remaining two wild accessions ANN-61 and ANN-98 recorded resistant reaction with a score of 3 while cultivated parents R-83, CMS-B and susceptible check Morden recorded susceptible (score 7) and highly susceptible (score 9) reactions (Fig. 3), respectively. All six interspecific crosses showed medium resistance with a disease score of 5, which has might have been transmitted from wild species. Similarly resistance genes have been transferred from wild *H. annuus, H. praecox, H. argophyllus* and *H. debilis* ssp. *cucumerfolius* to cultivated species (Miller and Fick, 1997). Two wild sunflower populations *H. tuberosus* and *H. resinosus* showed resistance to *Alternaria* leaf blight (Alternaria), Septoria leaf blight (Septoria) and powdery mildew which have been used to introgress resistance genes into cultivated species (Block, 2005).

In the present study, the pollen fertility was very high in parents as well as the interspecific hybrids which indicated compatibility between wild *H. annuus* and cultivated *H. annuus*. Hence interspecific cross caused least abnormalities. Cytological investigations revealed no laggards and chromosome bridges during Anaphase I and no micronuclei during tetrad formation indicating normal meiotic division and seed setting. Similar results have been reported earlier (Kulshreshtha and Gupta, 1979; Binsfeld *et al.,* 2001; Kesavaraman *et al.,* 2006) in interspecific crosses. On the contrary Georgieva-Todorova (1976), Chandler *et al.* (1986) and Manjula *et al.* (1999) reported the appearance of chromosome bridges, fragments and laggards during Anaphase I in the interspecific hybrids of sunflower.

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Identification of superior parents and hybrids for yield improvement in castor (*Ricinus communis* L.)

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ABSTRACT

An experiment was conducted to determine the nature and magnitude of heterosis in castor for seed yield and its yield attributing traits. Forty hybrids were synthesized involving five lines and eight testers through line x tester (L×T) mating design and were evaluated for yield and its components. Among 13 parental lines, JP-96, VP-1, DPC-9, RG-2661-1, RG-109 and RG-3160 were identified as good general combiners for seed yield and its components, which can be directly exploited in heterosis breeding. The cross combination, DPC-18 × RG-2661-1 was good specific combiner for early maturity. High seed yield per plant was recorded for hybrids: VP-1×RG-109 (105.04 g), DPC-18×RG-1771 (98.26g) and DPC-18×RG-2661-1 (97.97 g). These promising crosses involved parents with high × high and high × low GCA effects and were found promising for high yield potential in castor.

Keywords: Castor, Combining ability, Heterosis, Gene action, Standard heterosis

Castor (*Ricinus communis* L.) is one of the most important non-edible oilseed crops of tropical, sub-tropical and warm temperate parts of the world (Weiss, 2000). It is cultivated in several countries; India, Brazil, China, Russia, Thailand and Philippines are the major castor growing countries. India is the world leader in castor area (7.62 lakh ha), production (12.2 lakh tonnes) and productivity (1600 kg/ha) (ICAR-IIOR, 2020). The seeds of castor contain about 40 to 60 per cent oil rich in ricinolein an unusual fatty acid found only in castor. The castor oil has great industrial value as it is used for the manufacturing of soaps, refined and perfumed hair oil, printing inks, varnishes, synthetic resins, carbon paper, lubricant, ointments, cosmetics and processed leather. Castor is largely grown as a rainfed crop and the seed yield is affected due to vagaries of the climatic factors which in turn influence crop traits including sex expression (Aher *et al.*, 2015). It is a highly cross-pollinated species with a complex sex mechanism that is influenced by environment (Lavanya *et al.*, 2006). Therefore, development of hybrids with high femaleness is needed to exploit the heterosis effectively.

With the availability of complete pistillate lines, exploitation of hybrid vigour commercially has become feasible and economical in castor (Lavanya *et al.*, 2006). The *per se* performance of parental lines provides clues about hybrid performance; however, information on magnitude of heterosis and combining ability of parents for yield and its component traits would aid in selecting appropriate parents and desirable cross combinations.

Similarly, information on type of gene action for different traits is important in formulating an appropriate breeding programme for yield improvement. Heterosis for various agronomic traits has been reported in castor (Dangaria *et al.*, 1987; Ramesh *et al.*, 2013; Aher *et al.*, 2015; Patel *et al.*, 2015; Sapovadiya *et al.*, 2015). Line × Tester (L × T) analysis suggested by Kempthorne (1957) is widely used to study gene action and combining ability among parents for different traits. In this context, the present investigation was carried out in castor with the twin objectives of estimating the magnitude of heterosis for seed yield and its component traits and to identify the superior parents and hybrid combinations for commercial exploitation.

MATERIALS AND METHODS

The investigation was conducted during *kharif* 2018 at Zonal Agricultural Research Station (All India Coordinated Research Project, AICRP-Castor), University of Agricultural Sciences, GKVK, Bengaluru. The materials were obtained from the ICAR-Indian Institute of Oilseeds Research (ICAR-IIOR), Hyderabad and Castor and Mustard Research Station (AICRP-Castor), Sardar Krushinagar Dantiwada Agricultural University, Gujarat, India. Five pistillate lines (VP-1, JP-96, M-574, DPC-18 and DPC-9) and eight testers (RG-43, RG-1771, RG-109, RG-2661-1, RG-392, RG-72, RG-3160 and RG-1608) were crossed using L ×T mating design and the 40 experimental hybrids were generated during *kharif* 2018-2019. Thus, the experimental materials consisted of 56 entries including 5 lines, 8 testers, 40 hybrids and 3 checks (DCH-177, DCS-9 and DCS-107). While crossing work, racemes of the female parents were bagged before opening of the flower. In the male parents all opened flowers in the spike were removed prior to bagging in order to obtain pure pollen for pollination. At the time when stigma became receptive, the pollen collected in a labelled Petri

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plate from the desired male parents were dusted over the stigma of the female parents; stigma remains receptive after anthesis for a period of 5 to 10 days and blooming continues up to 21 days. After pollination, the female parent spikes were bagged and labelled. The dusting of pollen was repeated three to four times every alternate day to ensure sufficient seed setting.

In the succeeding *kharif* 2019-20, the complete set of 56 entries was sown in a Randomized Complete Block Design (RCBD) with two replications. Each entry was planted in a single row of 6.0 meter with the spacing of 90 cm x 60 cm. All the recommended agronomic practices including 40:40:20 kg $N:P_2O_5:K_2O$ per ha were followed. Prophylactic spray of thiodicarb @ 1g/l and propiconazole @ 0.5 ml/l were taken up to manage capsule borer and gray mold disease respectively. Observations were recorded on five randomly selected plants for nine traits *viz*., days to maturity of primary spike (DMPS), number of nodes up to primary spike (NNPS), effective length of primary spike in cm (ELPS), number of capsules on primary spike (NCPS), number of effective spikes per plant (NESPP), 100 seed weight in g (HSW), volume weight in g (VW), seed yield per plant in g (SYPP) and oil content in % (OC). The observations on days to maturity were recorded plot basis. The data were subjected to analysis of variance (ANOVA) and predictability ratio of the lines and testers performance as per the L × T model given by Singh and Chaudhary (1977) using statistical package, Windostat Version 9.3 from Indostat services, Hyderabad (India).

The variance due to general combining ability (GCA) and specific combining ability (SCA) for nine traits was analyzed to find out the gene action among them. Sprague and Tatum (1942) defined GCA as the average performance of a parental line in a series of hybrid combinations and SCA as the performance of the parental lines in a specific hybrid combination. The parents showing high average combining ability in crosses are considered to have good GCA while if their potential to combine well is confined to a particular cross they are considered to have good SCA. From the statistical point of view, the GCA is the main effect and the SCA is an interaction effect. The GCA reflects additive and additive × additive interaction effect. The SCA reflects dominance, additive × dominance and dominance × dominance interaction effects (Fasahat *et al*., 2016).

Degree of dominance is defined as follows. The genetic value of the heterozygote = the mean of the genetic values of the corresponding two homozygotes + the degree of dominance X half the difference between the genetic values of the better homozygote and the worse homozygote. No dominance corresponds to a degree of 0, partial to a degree between 0 and 1, complete dominance to a degree of 1 and overdominance to a degree larger than 1. Positive as well as negative degrees may exist. The average degree of dominance is estimated as the square root of the average squared degree of dominance (Lagerval, 1961).

RESULTS AND DISCUSSION

The ANOVA results showed that the mean squares (MS) due to genotypes were significant for all the traits studied. The MS due to genotypes were further partitioned into parents, hybrids and parents vs. hybrids. The parents differed significantly for all the traits except volume weight (VW). The hybrids differed significantly for all the traits except Effective length of primary spike (ELPS) and VW, which indicated that considerable genetic variability was present among the parents and hybrids (Table 1). The ANOVA results further revealed that the MS due to parents vs. hybrids were significant for all the traits, indicating the possibility of heterotic effects (Table 1).

The ANOVA for combining ability revealed that MS due to the hybrids were significant for all the traits except VW. The MS due to the females were significant for all traits except number of nodes upto primary spike (NNPS), number of effective spikes per plant (NESPP) and seed yield per plant (SYPP) whereas the males were significant for ELPS. The MS due to L × T interaction were significant for all the traits except ELPS, hundred seed weight (HSW) and VW. This suggests that the variation for seed yield in hybrids may be strongly influenced by the L × T interaction effects. The magnitude of MS due to the lines was larger for most traits than the testers indicating that the lines were diverse than the testers (Table 2).

The MS due to GCA and GCA effects indicated the involvement of both additive and non-additive gene action in determining the yield traits. The MS due to L × T interactions were highly significant for seed yield and its components, which indicated the importance of SCA variance. Similar results were reported by Chaudhari *et al*. (2011), Ramesh *et al*. (2013), Rajani *et al*. (2015), Patel *et al*. (2015), Patted *et al*. (2016), Punewar *et al*. (2017) and Delvadiya *et al*. (2018).

Higher SCA variance than GCA variance for all the traits indicated the predominance of non-additive gene action. The ratio between GCA and SCA variances was highest for ELPS (0.12) and VW (0.12) followed by DMPS (0.09), NCPS (0.07), NNPS (0.07) HSW and OC (0.06). The ratio was less than one in all the traits, which indicates the predominance of non-additive gene action. The degree of dominance was more than one for days to maturity for primary spike (DMPS), NNPS, NESPP and SYPP which indicates over dominance whereas for the other traits the value ranged between 0 to 1 indicating partial dominance. Therefore, these traits could be improved through heterosis breeding (Table 3). The above findings are in agreement with the earlier reports of Ramesh *et al*. (2000), Kavani *et al*. (2001), Ramu *et al*. (2002),Thakker *et al*. (2005) and Tank *et al*. (2003). Dominant gene action for seed yield in castor was reported earlier by several researchers (Ramu *et al*., 2002; Lavanya and Chandramohan, 2003; Tank *et al.,* 2003; Solanki *et al.,* 2004; Thakker *et al.,* 2005; Venkataramana *et al.,* 2005; Solanki, 2006; Chaudhari *et al.,* 2011; Ramesh *et al.,* 2013; Rajani *et al.,* 2015; Patel *et al.,* 2015; Patted *et al.,* 2016; Panewar *et al.,* 2017; Delvadiya *et al.,* 2018).

Table 1 Analysis of variance (mean squares) for yield and its components

Source of Variation	Df	Days to maturity of primary spike	Number of nodes up to primary spike	Effective length of primary spike (cm)	Number of capsules on primary spike	Number of effective spikes per plant	100 seed weight (g)	Volume weight (g)	Seed yield per plant (g)	Oil content (%)
Replicates	1	14.35	0.53	7.97	17.61	0.27	1.86	14.42	80.25	1.39
Genotypes	52	109.51**	1.53**	84.54**	273.64**	5.11**	15.35**	51.64*	1124.94**	6.53**
Parents	12	129.26**	1.33**	146.90**	436.36**	4.96**	12.77*	44.73	1298.57**	11.05**
Parents (Line)	4	35.25**	0.12	54.22	93.60	9.46**	5.34	33.37	1263.68**	24.15**
Parents (Testers)	7	156.82**	2.01**	47.00	175.96**	1.31	18.47*	56.73	950.16**	4.35**
Parents (L vs T)	1	312.40**	1.38	1216.93**	3630.20**	12.54**	2.60	6.21	3876.98**	5.52*
Parents vs Hybrids	1	56.52**	8.03**	1089.40**	2561.40**	46.89**	90.68**	505.88**	3417.70**	127.69**
Hybrids	39	104.79**	1.42**	39.58	164.92**	4.09**	14.21**	42.12	1012.72**	2.03**
Line Effect	4	427.88**	2.49	132.03**	524.51**	9.63	55.40**	102.93*	2227.72	6.08*
Tester Effect	7	31.35	2.12	64.85*	115.30	0.96	15.55	48.73	735.29	1.69
Line * Tester Eff.	28	76.99**	1.09**	20.06	125.95**	4.08**	7.99	31.78	908.51**	1.54*
Error	52	4.06	0.40	39.12	54.65	1.14	6.16	28.24	178.97	0.89

Table 2 Analysis of variance and estimates of combining ability for yield and its components

Source of Variation	Df	Days to maturity of primary Spike	Number of nodes up to primary spike	Effective length of primary spike (cm)	Number of capsules on primary spike	Number of effective spikes per plant	100 seed weight (g)	100 volume Weight (g)	Seed yield per plant (g)	Oil content (%)
Replicates	1	19.01*	0.11	129.03 **	4.58	0.217	0.57	55.58	1.31	0.11
Crosses	39	104.79**	1.42**	39.58 **	164.99 **	4.09 **	14.21 **	42.12	1012.72 **	2.03 **
Line Effect	4	427.88**	2.49	132.03 **	524.51 **	9.64	55.40 **	102.93 *	2227.72	6.08 *
Tester Effect	7	31.36	2.12	64.85 *	115.30	0.96	15.56	48.73	735.29	1.69
Line *Tester Eff.	28	76.99**	1.10 **	20.06	125.95 **	4.08 **	7.80	31.78	908.51 **	1.54 *
Error	39	3.94	0.35	14.99	54.56	1.39	6.03	32.37	154.28	0.69

*, ** Significant at 5 % and 1 % levels of probability, respectively

Table 3 Estimates of GCA and SCA variances, degrees of dominance and % contribution of Lines, Testers and Lines x Testers to crosses in castor

Traits	GCA	SCA	GCA/ SCA Ratio	Degree of Dominance	Lines	Testers	Lines x Testers
Days to maturity of primary spike	21.39	215.57	0.09	1.03	41.87	5.37	52.75
Number of nodes up to primary spike	0.12	1.71	0.07	1.09	17.94	26.73	55.33
Effective length of primary spike(cm)	6.60	56.16	0.12	1.02	34.21	29.41	36.38
Number of capsules on primary spike	26.23	352.66	0.07	0.94	32.62	12.55	54.83
Number of effective spikes per plant	0.48	11.42	0.04	1.52	24.15	4.21	71.64
100 seed weight(g)	5.15	88.98	0.06	0.45	40.36	19.65	39.98
Volume weight(g)	2.77	22.37	0.12	0.49	25.06	20.76	54.17
Seed yield per plant (g)	111.39	2543.83	0.04	1.35	22.56	13.03	64.41
Oil content (%)	0.30	4.30	0.06	0.84	30.72	14.95	54.33

Per cent contribution of line, testers and line x testers to the crosses (Table 3) revealed that the lines contribute more to the performance of the crosses in case of DMPS, ELPS, NCPS, NESP, HSW, VW and oil content (OC) whereas of the testers contribute more to the performance of crosses only in case of NNPS indicating the significant contribution of the female parents in the hybrid performance. The contribution of lines and testers were found equally important for the development of the yield and its attributing characters. This showed that average general combiner could give high heterotic performance and could be effectively used in heterosis breeding programmes. Similar results were also reported by Pandey and Singh (2002), Yamanura *et al.* (2014), Patel *et al.* (2015), Patted *et al.* (2016), Panewar *et al.* (2017) and Delvadiya *et al.* (2018).

Trait-wise estimation of GCA effects of L × T is presented in Table 4. The good general combiners identified for various traits included JP-96, VP-1, DPC-9, RG-2661-1, RG-109 and RG-3160 for seed yield and its components, JP-96, VP-1, RG-43 and RG-1771 for DMPS, M-574, DPC-18, and RG-3160 for NNPS, VP-1 and RG-109 for ELPS, VP-1, DPC-9, RG-2661-1, RG-3160 and RG-392 for NCPS and NESPP, DPC-9 and RG-72 for HSW and VP-1 and RG-43 for VW. Heritability is a good indicator of the transmission of traits from parents to their offspring (Falconer.,1989). High heritability coupled with high GA were observed for the traits *viz.,* DMPS, NCPS, SYPP and ELPS indicating that genotypic variation for the characters could probably be attributed to high additive effect. Moderate GA with high heritability was observed in HSW and VW. Low GA was observed in NNPS, NESPP and OC suggesting that selection for these traits may not be effective. Predictability ratios was high in HSW, VW, OC and NCPS, moderate in DMPS, NNPS, NES/P and SYPP and low or negative in ELPS (Table 4).

Table 4 Estimates of general combining ability effects among of nine quantitative traits in Castor

Traits	Days to maturity of primary spike	Number of nodes up to primary spike	Effective length of primary spike (cm)	Number of capsules on primary spike	Number of effective spikes per plant	100 seed weight (g)	Volume weight (g)	Seed yield/plant (g)	Oil content (%)
LINES									
VP-1	-3.375 **	-0.467 **	4.397 **	4.351 *	0.708 *	-2.592 **	3.156 *	4.970	0.214
JP-96	-7.313 **	-0.142	1.099	-1.718	-0.198	1.120	1.531	12.638 **	0.495
M-574	2.938 **	0.435 **	-0.568	-2.593	-1.239 **	-1.042	-0.321	-18.417 **	-1.036
DPC-18	5.188 **	0.386 *	-2.464	-7.180 **	0.184	0.356	-0.806	4.466	-0.063
DPC-9	2.563 **	-0.212	-2.464	7.140 **	0.545 *	2.160 **	-3.560 *	-3.658	0.390
TESTERS									
RG-43	-3.588 **	-0.805 **	-1.462	-0.221	0.044	-1.696 *	2.790	-2.710	0.018
RG-1771	-1.788 **	-0.207	-1.831	-4.836 *	-0.389	-0.952	-3.374	-0.752	-0.499
RG-109	0.913	0.363	3.737	-2.868	0.267	1.212	2.201	6.654	-0.450
RG-2661-1	1.013	0.327	1.913	4.808 *	0.379	0.276	1.176	13.921 **	0.264
RG-392	0.413	-0.093	-0.898	2.387	0.322	0.910	-1.383	-10.207 *	0.029
RG-72	1.513 *	-0.347	-3.997	-1.670	-0.423	1.855 *	-2.022	1.379	0.609
RG-3160	0.313	0.641 **	2.336	3.898	-0.075	-0.737	1.430	3.869	0.394
RG-1608	1.213	0.118	0.204	-1.501	-0.122	-0.867	-0.818	-12.152 **	-0.368
CD 95% GCA(Line)	1.019	0.320	3.163	3.738	0.540	1.255	2.687	6.765	0.477
CD 95% GCA(Tester)	1.289	0.405	4.001	4.729	0.683	1.588	3.399	8.557	0.603
Heritability (NS) %	47.408	34.821	47.644	39.320	23.853	53.027	31.543	30.610	37.500
Genetic Advance 5 %	8.355	0.658	4.295	8.252	0.804	3.186	3.131	16.134	0.857
Predictability Ratio	0.488	0.457	-22.387	0.534	0.303	0.832	0.805	0.355	0.588

The best three crosses exhibited high SCA along with their *per se* performance, standard heterosis and GCA status of the parents. The data presented in Table 5 indicated that the cross combination, DPC-18 × RG-1771, was a good specific combiner for SYPP and ELPS. The cross combination, DPC-18 × RG-2661-1 was a good specific combiner for early maturity as it showed highly significant negative SCA effect. The early maturing hybrid could be advantageous for rainfed situations because it could escape the terminal drought situation. The crosses, VP-1 × RG-2661-1, DPC-9 × RG-43 and DPC-18 × RG-392 for NNPS, VP-1 × RG-43, DPC-18 × RG-3160 and JP-96 × RG-109 for NCPS, DPC-9 × RG-109, DPC-18 × RG-1608 and M-574 × RG-1771 for HSW, JP-96 × RG-1771, DPC-18 × RG-72 and M-574 × RG-2661-1 were good specific combiners for OC. Similar results of significant SCA effects for yield contributing traits were reported by Solanki and Joshi (2000), Thakker *et al.* (2005), Kanwal *et al.* (2006), Golakia *et al.* (2008), Bard *et al.* (2009), Chandresh (2009), Monapara *et al.* (2010), Sodavadiya *et al.* (2010), Chaudhari *et al.* (2011), Ramesh *et al.* (2013), Rajani *et al.* (2015), Patel *et al.* (2015), Patted *et al.* (2016), Panewar *et al.* (2017) and Delvadiya *et al.* (2018).

The highest seed yield/plant was recorded by the hybrid, VP-1× RG-109 (105.04g) followed by DPC-18×RG-1771 (98.26 g) and DPC-18 × RG-2661-1 (97.97g). These three crosses showing high mean and significant positive SCA effects for seed yield involved the parents with high × high and high × low GCA effects (Table 6). Similar results were reported by Chaudhari *et al.* (2011), Ramesh *et al.* (2013), Rajani *et al.* (2015), Patel *et al.* (2015), Patted *et al.* (2016), Panewar *et al.* (2017) and Delvadiya *et al.* (2018). The better performance of the hybrids involving high × low or low × low general combiners indicated dominance × dominance (epitasis) type of gene action. The crosses showing high SCA effects involving one good general combiner indicated additive × dominance type gene interaction, which exhibited high heterotic performance for yield and yield related traits. The results suggested that the crosses having high mean performance and positive SCA effects for seed yield and related traits had necessarily involved both or at least one parent as good combiner, which could be commercially exploited for hybrid development in castor.

Table 5 Comparison of three best crosses on the basis of specific combining ability effects for different traits

Traits	Crosses	SCA effect	GCA effect and Status			Standard heterosis	*Per se*	Significant SCA effect for other traits
			P1	P2	Status			
Days to maturity of primary Spike	DPC-9 X RG-1608	-10.96**	2.56**	1.21	H×L	-0.57	87.50	-
	DPC-18 X RG-2661-1	-10.39**	5.19**	1.01	H×L	2.84	90.50	DFF
	DPC-9 X RG-3160	-9.06**	2.56**	0.31	H×L	0.57	88.50	-
Number of nodes up to primary spike	VP-1 X RG-2661-1	1.16*	-0.48**	0.33	L×H	11.39*	14.66	-
	DPC-9 X RG-43	1.14*	-0.21	-0.81**	L×L	4.60	13.77	-
	DPC-18 X RG-392	0.72	0.39*	-0.98	H×L	11.39*	14.66	NESPP
Effective length of primary spike (cm)	DPC-9 X RG-43	4.97	-2.46	-1.46	L×L	115.96**	31.67	NN
	VP-1 X RG-72	4.81	4.39**	-3.99	H×L	144.36**	35.83	-
	DPC-18 X RG-1771	4.17	-2.46	-1.83	L×L	107.98**	30.50	SY
Number of capsules on primary spike	VP-1 X RG-43	10.82*	4.35*	-0.22	H×L	218.43**	56.25	-
	DPC-18 X RG-3160	10.31	-7.18**	3.89	L×H	173.59**	48.33	SY
	JP-96 X RG-109	9.12	-1.72	-2.87	L×L	159.47**	45.83	-
Number of effective spikes per plant	DPC-9 X RG-2661-1	2.76**	0.55*	0.38	H×H	308.08**	8.84	SY
	DPC-9 X RG-109	2.31**	0.55*	0.27	H×H	282.45**	8.28	HSW, DFF
	VP-1 X RG-3160	2.11	0.71*	-0.08	H×L	264.90	7.90	-
100 Seed weight (g)	DPC-9 X RG-109	3.61*	2.16**	1.21	H×H	35.35**	39.44	DFF, NES/P
	DPC-18 X RG-1608	2.46	0.36	-0.87	H×L	18.07*	34.41	-
	M-574 X RG-1771	2.10	-1.04	-0.95	L×L	11.75	32.57	DFF, DM
Volume weight (g)	DPC-18 X RG-72	5.52	-0.81	-2.02	L×L	16.60	63.99	DM
	M-574 X RG-72	4.35	-0.32	-2.02	L×L	15.34	63.30	-
	JP-96 X RG-392	4.36	1.53	-1.38	H×L	19.90*	65.80	DM,SY
Seed yield per plant(g)	M-574 X RG-1608	41.17**	-18.42**	-12.15**	L×L	143.65**	71.08	-
	DPC-18 X RG-1771	34.06**	4.47	-0.75	H×L	236.80**	98.26	-
	VP-1 X RG-109	32.94**	4.97	6.65	H×H	260.05**	105.04	-
Oil content (%)	JP-96 X RG-1771	1.76*	0.49	-0.50	H×L	3.15	47.70	-
	DPC-18 X RG-72	1.75	-0.06	0.61	L×H	4.32*	48.25	DMPS
	M-574 X RG-2661-1	1.42*	-1.03	0.26	L×H	0.75	46.59	-

Table 6 Three crosses based on *per se* performance for yield and yield traits in castor

Traits	Crosses	*Per se*	SCA effect	GCA status	Standard heterosis
	DPC-18 X G-3160	98.50	-1.688	H × L	11.93 **
Days to maturity of primary spike	DPC-9 X RG-43	98.00	4.338 **	H × L	11.36 **
	VP-1 X RG-72	97.00	4.175 **	H × L	10.23 **
	M-574 X RG-3160	15.00	0.275	H × H	13.94 **
Number of nodes up to primary spike	M-574 X RG-2661-1	14.72	0.304	H × H	11.77 *
	VP-1 X RG-2661-1	14.66	1.156 *	L × H	11.39 *
	VP-1 X RG-3160	40.83	3.472	H × H	178.45 **
Effective length of primary spike (cm)	VP-1 X RG-1608	39.17	3.939	H × L	167.10 **
	JP-96 X RG-109	38.83	3.369	H × H	164.81 **
	DPC-9 X RG-3160	58.33	5.995	H × H	230.23 **
Number of capsules on primary spike	DPC-9 X RG-392	57.81	6.986	H × H	227.29 **
	VP-1 X RG-2661-1	56.72	6.254	H × H	221.06 **
	DPC-9 X RG-2661-1	8.84	2.756 **	H × H	308.08 **
Number of effective spikes per plant	DPC-9 X RG-109	8.28	2.313 **	H × H	282.45 **
	VP-1 X RG-3160	7.90	2.112 **	H × L	264.90 **
	DPC-9 X RG-109	39.44	3.608 *	H × H	35.35 **
100-seed weight (g)	DPC-18 X RG-392	36.78	3.054	H × H	26.22 **
	DPC-9 X RG-2661-1	36.59	1.689	H × L	25.55 **
	VP-1 X RG-3160	68.07	2.200	H × H	24.04 *
Volume weight (g)	JP-96 X RG-3160	67.78	3.530	H × H	23.51 *
	JP-96 X RG-43	66.27	0.665	H × H	20.76 *
	VP-1X RG-109	105.04	32.935 **	H × H	260.05 **
Seed yield per plant (g)	DPC-18 X RG-1771	98.26	34.060 **	H × L	236.80 **
	DPC-18 X RG-2661-1	97.97	19.097	H × H	235.80 **
	DPC-18 X RG-72	48.25	1.758	L × H	4.32 *
Oil content (%)	JP-96 X RG-1771	47.70	1.763 *	H × L	3.15
	DPC-9 X RG-392	47.60	1.240	H × L	2.93

In this study, the parents JP-96, VP-1, DPC-9, RG-2661-1, RG-109 and RG-3160 were identified as good general combiners for seed yield and its components. The hybrid, DPC-18 × RG-2661-1 was identified as good specific combiner for early flowering and maturity, which has the advantage in the rainfed situations to escape the terminal moisture stress.

The hybrid combinations: VP-1 × RG-109 (105.04 g/plant), DPC-18 × RG-1771 (98.26g/plant) and DPC-18 × RG-2661-1 (97.97 g/plant) recorded higher seed yield. These three crosses showing high mean and significantly positive SCA effects for seed yield involved high × high and high × low GCA effects of parents. Hence, these cross combinations are promising in breeding programme for improvement of yield in castor.

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Relationship of node number with days to flowering and yield traits in castor (*Ricinus communis* L.) hybrids under rainfed and irrigated conditions

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ABSTRACT

A set of 150 hybrids were evaluated in augmented design with three checks under rainfed and irrigated conditions at research farm of ICAR-Indian Institute of Oilseeds Research, Telangana and Anand Agricultural University, Anand, Gujarat to understand the environmental effect on node number and its influence on yield attributing traits. Results indicated that the number of nodes to the base of primary spike (NN) influenced not only days to 50% flowering (DFF) and yield traits but also plant canopy particularly under rainfed conditions. Under both rainfed and irrigated conditions, the genotypes with high node number, in general, recorded increased plant height, days to 50% flowering (DFF), primary spike length, and seed yield/plant. Under rainfed conditions, most of the early hybrids with NN <12 and DFF≤ 44 DAS recorded less seed yield, whereas, the yield potential was high in hybrids having NN 12 to 15 and DFF 45 to 50 DAS. However, no such pattern was noticed under irrigated conditions. Test weight and oil content were not influenced by node number or days for flowering.

Keywords: Castor, Days to 50% flowering, G x E interaction, Node number, Seed yield

Castor is an industrially important oilseed crop suitable for both rainfed and irrigated cultivation in tropical and sub-tropical climatic conditions. In India, it is cultivated in an area of 9.7 lakh hectare with a production of 16.6 lakh tonnes and productivity of 1,720 kg/ha (Anonymous, 2018). India is the largest producer of castor in the world and accounts for 69% of the castor area and 85% of the production (2017-18). In India, major castor area is in Gujarat (5.9 lakh ha; 72%) followed by Rajasthan (1.3 lakh ha; 15.9%), Telangana and Andhra Pradesh (0.58 lakh ha; 7 %) during the year 2017-18. During 2018-19, approximately 87% and 13% castor area was under irrigated and rainfed cultivation, respectively (Annual Report-2019-20). The world's first hybrid, GCH-3, was released in 1968 from Oilseeds Research Station, Junagadh, Gujarat, India. Since then 22 hybrids have been released through active collaboration between Indian Council of Agricultural Research-Indian Institute of Oilseeds Research and State Agricultural Universities. Since 1990s, productivity in castor has substantially increased from about 320 kg/ha to 1700 kg/ha mainly due to cultivation of hybrids having resistance/tolerance to both biotic and abiotic stresses. Currently, the prominent hybrids in cultivation in India are GCH-4, GCH-7, GCH-8, GCH-9, DCH-177, DCH-519, PCH-111, YRCH-1 and ICH-66.

Castor was originally a perennial and long duration crop which flowers in about 90 days after sowing (DAS). However, in high yielding varieties and hybrids flowering starts between 45-65 DAS. Nature of flowering in castor is indeterminate where both main stem and branches terminate with a raceme (spike). Number of nodes to the primary raceme (NN) and internode length on the stem vary widely across castor genotypes. The NN ranges from 5 to 39 in Indian castor germplasm collection (data unpublished). Zimmerman (1958) reported that NN ranged from 6 to 45 in a segregating population and suggested that genotypes beyond this range may not flower. Parental lines having 5 to 25 nodes are presently being used in castor improvement programmes.

As of now, there is no standard classification of parents and hybrids as early, medium and late flowering types based on NN, days to 50% flowering (DFF) and maturity of primary spike in castor. However, reasonably, under rainfed conditions, the castor hybrids with mean NN 6-8 and DFF 30-40 days as very early and NN 9-12 and DFF 41-45 days as early flowering; NN 13-16 and mean DFF 46-55 DAS as medium flowering and NN 17-21 and mean DFF>55 DAS are considered as late flowering types. Whereas under irrigated conditions, castor hybrids with NN≤15 and mean DFF≤50 are considered as early, NN16-20 and mean DFF51-60 DAS as medium flowering, and NN>20 and mean DFF>60 DAS are considered as late flowering types (AICRP-castor technical compendium-2020-21). This classification helps in better understanding of the performance of hybrids having different NN and flowering durations. The NN and intermodal length influence the plant height, DFF, seed yield traits and nature of canopy. There are conflicting reports on the relationships among seed yield, NN and DFF in castor. Dhedhi *et al*. (2010), Tewari and Mishra (2013) and Patel and Nakarani (2016) reported negative correlation between seed yield/plant with NN and DFF.

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Whereas, Kanti *et al.* (2015) reported that plant height and NN had significant positive associations with DFF and seed yield. Nagarajan *et al.* (2019) reported positive correlation between seed yield and NN, plant height, test weight and oil content whereas association of NN with DFF and days to maturity was reported negative.

Castor growers are facing challenges posed by shortage of labourers, increased cost of cultivation, changed cropping patterns, erratic rainfall, aberrant temperatures and increased incidences of diseases like grey mold, wilt and sucking pests (leafhopper, whitefly, thrips and mirid bugs). Varieties or hybrids with more than 12 NN grow very tall with larger canopy under high rainfall/moisture conditions, which severely interferes with crop management and harvesting. Hence, the farmers prefer dwarf, early and high yielding varieties and hybrids with less canopy that is amenable for agronomic and plant protection measures. Though, genetic resources for developing very early hybrids, with NN <8 and DFF < 40 DAS, are available, they are low yielding (<218 g/plant) and may not be suitable for sustainable cultivation under rainfed conditions. However, genetic resources are available for developing moderately high seed yielding early hybrids (>220 g/plant, NN 8-11, DFF 40-47 DAS) with a short stature and less canopy, which may be suitable for rainfed conditions. Under irrigated conditions of Gujarat and Rajasthan, the present popular hybrids have NN of 19-20, DFF of 60 DAS and seed yield of 348 g/plant. In this context, there is a need to study the relationship of NN with DFF and yield traits in castor hybrids under different agro-climatic situations, which would eventually help to develop breeding strategies. The present study was aimed at understanding the relationship of NN with crop duration, stature and seed yield in a set of diverse castor hybrids under rainfed and irrigated conditions at two locations.

MATERIALS AND METHODS

The study material consisted of 150 hybrids derived from 15 female (pistillate) and 62 male (monoecious) parents. The hybrids derived from diverse parents represented the available range of NN (5 to 25) in castor improvement programmes of India. These hybrids along with three checks, DCH-177, DCH-519 and GCH-7 were evaluated in a augmented randomized block design (ARBD) at two locations viz., Hyderabad [Research farm of ICAR-Indian Institute of Oilseeds Research (ICAR-IIOR) Telangana (17.25 N & 78.32 E)], and Anand [Research farm of Anand Agricultural University (AAU), Gujarat (22.53 °N and 72.97 °E)], which represent rainfed and irrigated conditions, respectively. Hybrids were derived by hand pollination between parents having different NN and DFF.

R-15-1299, DPC-23, DPC-15, DPC-9, IPC-40 were the early female parents with NN≤12 and DFF≤45 DAS. The medium to late flowering female parents were: DPC-16, M-574, SKP-84, DPC-22, IPC 31, DPC-25, M 619, IPC 30, Rb-1459 and JP-77-1which represented the NN between >12 to 25 and DFF>45 DAS. Male parents (62) represented the NN in the range of 10 to 22 and DFF in the range of 40-65 DAS. All the parental lines were selected based on their performance under irrigated conditions at ICAR-IIOR, Hyderabad.

At the Narkhoda Research Farm of ICAR-IIOR, ICAR-IIOR, there were regular rain spells supplying adequate moisture till 4th August, 2016 followed by a dry spell till 27th August, 2016 (23 days during initiation of primary spike). Heavy rainfall was recorded (400 mm) in the month of September, 2016 and rainfall continued till 25th October, 2016 followed by a complete dry spell during the remaining duration of trial. At AAU, Anand, 222.6 mm rainfall was recorded in September and October, 2016. Rainfall pattern, temperature and relative humidity during the crop duration at ICAR-IIOR Narkhoda research farm and AAU farm are provided in graphs 1 and 2, respectively.

At ICAR-IIOR, sowing was taken up on 27th June, 2016 with a spacing of 90 x 60 cm in red soils following monsoon rains. The trial was conducted completely under rainfed conditions from sowing to last harvesting. At AAU, sowing was taken up on 4th September, 2016 with a spacing of 120 x 60 cm in sandy loam soil and the trial was conducted under irrigated conditions and a total of six irrigations were provided. In both the locations, entries were sown in two rows of 6 m length. Data on seven characters, *viz.,* number of nodes to primary spike (NN), days to 50% flowering (DFF), plant height recorded from collar region to the base of primary spike (cm) (PHT), primary spike length (cm) (PSL), final seed yield/plant (g) (FSYP), 100-seed weight (g) (TW), and oil content in percentage (OC) estimated by Nuclear Magnetic Resonance (NMR) method were recorded. The data on seed yield were recorded from five plants in each entry at 90, 120 and 150 days after sowing (DAS) at ICAR-IIOR and 150, 180 and 210 DAS at AAU. The data were subjected to analysis of variance (ANOVA) using the software Windostat Version 9.2 (Indostat services, Hyderabad). Performance of hybrids was assessed based on trait means (adjusted) derived from ANOVA. Duncan's Multiple Range Test of means and grouping and Pearson's correlation coefficients were obtained by analysing the trait data using SAS version 9.1.

RESULTS AND DISCUSSION

Analysis of variance: Analysis of variance of augmented design indicated that there were significant differences among the genotypes for all the traits under both rainfed (Table 1) and irrigated (Table 2) conditions indicating presence of adequate variability among the traits studied.

Genotypic response for node numbers under rainfed conditions: The number of nodes among 150 hybrids ranged from 6-19, where 75% of the hybrids were having 10-15 node numbers. There were significant differences in expression of days to 50% flowering, plant height, primary spike length and seed yield whereas differences were non-significant for 100 seed weight and oil content due to variation in the node numbers (Table 3). Days to 50% flowering ranged from 34 to 61 days with the mean of 45.2 days. The response of hybrids with 6, 7 and 8 node numbers were similar for all the characters studied except for days to 50% flowering. Hybrids with node number 9, 10, 11 and 12 had similar expression for the characters studied. Hybrids with higher node number 13, 14 and 15 expressed the traits in a similar way. Hybrids with node number 16, 17 and 18 expressed the traits similarly, while hybrids with 19 node numbers representing only 2 hybrids exhibited longer time to 50% flowering and flowering duration. Significant variation was observed for days to 50% flowering, plant height, length of primary spike and seed yield among the hybrids of different groups (classes)based on node numbers, which can be classified into 1.Very low (6-8), 2. Low (9-12), 3. Medium (13-16) and 4. High (>17).

Performance of promising hybrids under rainfed condition (Table 4) indicated that the very early hybrids, in general, were less yielding, though harvesting of their primary spikes started from 75-85 DAS (Table 4). In general, the hybrids flowering at ≤ 40 DAS, had shorter spike length and early maturity of primary spike compared to early and medium flowering hybrids. Seed yield of very early flowering hybrids was high only up to 120 DAS, may be due to apparent low drought tolerance during the dry spells (monsoon and post monsoon) encountered during the crop growth period. Higher FYSP of more than 300 g/plant was recorded only in hybrids with NN ≥12 and flowering ≥45 DAS as they had longer spike, though lesser number of spikes and their seed yield potential extended upto 180 DAS with tolerance to moisture stress during the mid and post-monsoon period. Primary spike was ready for harvesting by 90-110 DAS in early and medium flowering hybrids. There were no significant differences in TW and OC among the hybrids irrespective of their NN and DFF and it ranged from 21 to 40 grams and 42% to 54% respectively.

Phenotypic correlations (Table 5) under rainfed conditions were high and significant between NN and other traits (r=>0.79); positive and non-significant with FSYP (0.42), TW (0.08) and negative and non-significant with OC (-0.06). However, PHT (r=0.79), DFF (r=0.79) and PSL (r=0.72) had significant and positive correlations with FSYP and with each other (Table 5). This indicated that early hybrids with higher intermodal length may positively influence the PHT, DFF, PSL and consequently FSYP also. These correlations were significant only at p=0.05 probably be due to high G x E interactions of hybrids with the environment.

Genotypic response for node numbers in irrigated conditions: Under irrigated condition, increase in node number was observed in all the hybrids, ranging from 13-25, where 75 % of the hybrids were having 17-22 node numbers (Table 6).There were significant variation for days to 50% flowering, plant height, primary spike length and oil content while there were no significant differences for seed yield and test weight due to variation in the node numbers (Table 6). Days to 50% flowering ranged from 37 to 62 days with a mean of 57 days. The hybrids with 13, 14 and >16 node numbers differed for days to 50% flowering and plant height. DFF increased with increase in NN and there was significant variation, which resulted in three distinct classes ranging from 37-62 days after sowing. Similarly, variation in plant height due to node numbers was observed and there were 10 distinct classes for plant height ranging from 65-180 cm. Primary spike length differed significantly due to node number ranging from 39-92 cm and longer spikes were observed in hybrids with higher node numbers. Node number failed to group hybrids in to discrete groups for seed yield and test weight. However, oil content was significantly higher in hybrids with higher node number.

Performance of promising hybrids under irrigated condition is presented in Table 7. In general, harvesting of primary spike was possible only after 113 DAS under irrigated conditions. The hybrids with lower NN had lower values for DFF, PHT and PSL but the difference in FSYP/plant was minimum in all the hybrids irrespective of their NN and DFF. Both the early and medium/late flowering hybrids had better FSYP, TW and OC and it mainly depended on the nature of parental combinations rather than on NN and DFF. FSYP ranged from 170 to 450 grams per plant in hybrids with NN ≤16 while it ranges from 143 to 540 grams in hybrids with NN from 17 to 20.

Phenotypic correlations under irrigated condition are presented in table 8. There were no significant correlation between different traits except between NN and PHT (0.66), PHT and PSL (0.53), DFF and PS (0.51). Interestingly, node number had no correlations with DFF, PSL and other seed yield traits.

Our experimental results showed that the NN influenced the days to 50% flowering and other agro-morphological traits and the extent of influence depended on the environment and parental combinations. As the node number increased, there was a general tendency for increased DFF, PHT, PSL FSYP, though genotypic differences did exist in hybrids with the same NN both within and between rainfed and irrigated conditions. However, the increase in FSYP, though genotype specific, was observed only up to 15 and 20 NN under rainfed and irrigated conditions respectively. The hybrids having NN higher than this optimum may have longer PSL but their yielding ability substantially decreased due to lesser branching and consequent lesser number of productive spikes. Though FSYP was generally higher in medium flowering hybrids, certain hybrids in both early and medium flowering category had higher TW and OC indicating that these two traits were largely dependent on specific parental combinations rather than on NN and DFF.

Table 1 ANOVA Summary (Mean Sum of Squares) under rainfed condition at ICAR-IIOR

	df	NN	PHT	DFF	PSL	FSYP	TW	OC
Block	14	1.3	562*	10.2**	21	1729***	7.8***	11.5*
Treatment	152	9.2*	496 *	36*	94*	3008*	14.5*	3.7**
Hybrids	149	10.4*	546*	46*	108*	3711*	15.1*	3.2***
Checks	2	76.2*	3031 *	267*	298*	2848***	55.8*	35.3*
Checks vs. Varieties	1	8.2**	196 ***	6.0	60	845	196*	38.2*
Error	28	0.65	43	3.5	23.6	714	3.6	1.6
CD @95%								
Control treatment means	1	0.60	5	1.4	3.6	20	1.5	0.94
Test treatments in the same block	1	2.34	19	5.4	14.1	77.4	5.5	3.7
Test treatments not in the same block	1	2.70	22	6.2	16	89.4	6.4	4.2
Test treatment and a control treatment	1	1.97	16	4.5	11.8	65	4.6	3.1
CV (%)		6.3	8.3	4.3	11.5	18	6.1	2.6

*, **, *** Significance at 5%, 1%, and 0.1%, respectively, NN- Node number, PHT-Plant height (cm), DFF- Days to 50% flowering, PSL- Primary spike length (cm), FYSP- Final seed yield per plant (g), TW-Test weight (g), OC (%)

Table 2 ANOVA Summary (Mean Sum of Squares) under Irrigated Condition at Anand

	df	NN	PHT	DFF	PSL	FSYP	TW	OC
Block	14	1.4	699 ***	10	105	2855	2.4	2.5***
Treatments	152	3.6*	794 **	25*	166	6411*	15.2*	3*
Hybrids	149	5.0*	1302 *	28*	236**	6798*	16.7*	3.4*
Checks	2	1.7	571	1.1	107	8169***	83*	7.6**
Checks vs. Varieties	1	6.8***	136	4	92	31915*	44.5*	8.2**
Error	28	1.2	304	18	93	1698	2.7	0.92
CD @95%								
Control treatment means	1	0.8	13.1	3.2	7	30.8	1.2	0.72
Test treatments in the same block	1	3.2	50.5	12.3	28	119	4.7	2.8
Test treatments not in the same block	1	3.7	58.4	14.2	32.1	138	5.5	3.2
Test treatment and a control treatment	1	2.7	42.7	10.4	23.6	101	3.9	2.5
CV (%)		5.8	17	8.20	12	13.5	5	1.90

*, **, ***Significance at 5%, 1%, and 0.1% level, respectively, NN- Node number, PHT-Plant height (cm), DFF- Days to 50% flowering, PSL- Primary spike length (cm), FYSP- Final seed yield per plant (g), TW-Test weight (g), OC (%)

Peat (1928) highlighted the change in node number with changed planting date. Zimmerman (1958) also studied the effect of planting date on number of nodes and reported differential response of hybrids to changed planting date, where some varieties/hybrids were more affected than the others and the mean node number changed from 8 to 16 in some varieties. The results of the present study also substantiated the findings of these studies as extent of NN variation depended not only on the environment but also on the hybrids.

In both the situations, NN not only influenced DFF but also FSYP (Table 3 and 6). Generally the influence of NN on DFF and seed yield traits was more conspicuous and significant under rainfed situation than in irrigated condition indicating that they were highly influenced by both the environment and parental combinations. In both the situations, ratio of DFF/NN (Table 4 and 7) decreased with increased NN indicating that the number of days taken for flowering decreased per unit increase in NN. There were conspicuous differences in the ratio of DFF/NN of hybrids in the two locations. It ranged from 2.9 (NN 16-18) to 6.6 (NN 5) under the rainfed condition, while it was 2.6 (NN 24), 2.9 (NN 13) to 4 (NN 17) under irrigated condition. Difference in the ratio of DFF/NN was more distinct and was of higher magnitude under the rainfed condition (2.9 to 6.6) than that was under the irrigated condition (2.5 to 3.4 in all hybrids).

Table 3 Duncan's Multiple Range Test means and grouping for 14 classes of node numbers under rainfed condition

Node No.	Number of hybrids	DFF	PHT	PSL	FYSP	TW	OC
6	10	34G	34F	28E	132CDE	29.40AB	47.73A
7	8	37FG	38F	28E	129CDE	29.45AB	47.18A
8	6	38F	48F	28E	123CDE	28.66AB	46.85A
9	8	39F	77CDE	37CD	108E	31.80AB	49.24A
10	16	42E	71E	34DE	115DE	29.33AB	47.90A
11	15	43E	71DE	34DE	132CDE	29.68AB	46.70A
12	20	44E	82CDE	37CD	158BCDE	28.16B	46.61A
13	11	47D	77CDE	43C	174ABCD	28.74AB	47.48A
14	23	50CD	87CD	43C	156BCDE	29.38AB	46.51A
15	13	50CD	88C	52B	210AB	31.77AB	47.61A
16	9	51BC	113AB	55AB	229A	33.10AB	49.03A
17	7	53B	107B	55AB	183ABC	30.44AB	47.17A
18	5	54B	123A	59A	175ABCD	31.40AB	48.65A
19	2	61A	127A	55AB	110DE	33.70A	49.18A

DFF- Days for 50% flowering, PHT-Plant height (cm), PSL-Primary spike length (cm), Test weight (g), Oil content (%)

Under rainfed conditions of southern India, poor performance of very early and majority of early hybrids may be due to their inability to withstand moisture stress, possibly due to their lower root length and mass, lesser number and size of leaves in comparison with hybrids having NN ≥ 12. Most of the early flowering hybrids also had lower ability to recover from moisture stress and put forth new racemes. But these early hybrids, though low yielding, maintained shorter plant height/canopy despite continuous rains, leading to easy crop management and harvesting operations. Some hybrids with NN from 12 to 15 seemed to be more suitable for cultivation under rainfed conditions due to their better regeneration and raceme/spike producing ability even after the moisture stress was relieved as well as during the post monsoon period. However, though these hybrids with ≥12 NN produced higher yields under rainfed condition, they grew taller due to continuous rains during September and October months of the south-west monsoon, causing difficulty in crop management and harvesting. The farmers experience these difficulties due to higher canopy and height of hybrids with ≥12 NN under more rainy days and therefore they require high yielding hybrids having shorter canopy/plant height even under the situations of continuous rainy days. In this context, there is a need to develop drought tolerant and high yielding hybrids with NN <12, with a short stature and canopy. Along with NN and DFF, test weight and drought tolerance have major influence on the yielding ability of hybrids under rainfed conditions. Hybrids from a particular parental combination had stable and higher test weight under moisture stress also under rainfed conditions irrespective of their NN and DFF (Table 4). But under irrigated conditions of Anand, Gujarat, most of the hybrids had better and higher test weight and oil content compared to those in rainfed conditions. This study indicated the possibility of developing high yielding early hybrids with shorter canopy for cultivation in the states of Gujarat, Rajasthan and Haryana.

The correlations indicated that PHT, DFF and PSL have higher influence on FSYP, rather than NN, TW and OC *per se* under rainfed conditions. The correlation study corroborated with some of the findings of Kanti *et al.* (2015) that NN had positive association with PHT and DFF, under rainfed conditions.TW was mainly dependent on parental combinations rather on NN and DFF. TW had a strong and positive correlation only with PSL and OC. This could be due to better opportunity for seed filling in longer primary spikes (due to longer duration for the maturity of spike) under rainfed situations, thereby leading to better TW and OC. However, there was no correlation of FSYP with TW and OC. Notwithstanding this, higher TW is an important criterion for higher seed yield under rainfed conditions as it was observed that some hybrids had the tendency for lower TW, particularly under moisture stress conditions. These correlations indicated that the medium flowering hybrids, having relatively higher PHT, DFF, longer PSL (consequent better TW) are better seed yielders than early flowering hybrids under rained conditions. Correlation between seed yield and other traits have been reported by various authors in castor hybrids, though majority of the studies were carried out under irrigated conditions with limited number of hybrids. There are contradictory reports on the correlation of seed yield with number of nodes to primary spike and days to 50% flowering. Adeyanju *et al.* (2010) studied agronomic traits in 28 selected castor hybrids under irrigated conditions and reported positive correlation between oil yield and days to 50% flowering, days to maturity, spike length and plant height. Tewari and Mishra (2013) studied 30 hybrids under irrigated conditions and reported positive correlation between oil yield and spike length, number of capsules, number of spikes, 100 seed weight and oil content but negative correlation with number of nodes to primary spike, days to 50% flowering, days to maturity, and plant height. Dhedhi *et al.* (2010) and Patel and Nakarani (2016) evaluated 29 hybrids and 43 hybrids under irrigated conditions respectively and have reported negative correlation of seed yield per plant with number of nodes to primary spike and days to 50% flowering. Kanti *et al.* (2015) reported that the plant height and number of nodes up to the primary spike had significant positive associations with days to 50% flowering, days to maturity, 100-seed weight and seed yield/plant in 33 germplasm accessions under rainfed conditions. Nagarajan *et al.* (2019) studied 68 hybrids under irrigated conditions and reported positive correlation between seed yield and number of nodes to primary spike, plant height, length of primary spike, test weight and oil content but negative correlation with days to 50% flowering and days to maturity.

Table 4 Promising hybrids for each NN category and their FSYP under rainfed condition

Hybrid	NN	DFF	DFF/NN	PHT	PSL	FSYP	TW	OC
CEH 454	5	33	6.6	29	31	101	29	48
CEH 456	6	35	5.8	32	24	160	32	49
CEH 416	7	41	5.9	32	31	218	32	46
CEH 417	8	43	5.4	46	28	232	36	51
CEH 448	9	37	4.1	89	42	173	33	50
CEH 435	10	42	4.2	64	37	252	34	49
CEH 420	11	45	4.1	56	28	224	28	46
CEH 422	12	47	3.9	44	43	315	35	46
CEH 432	13	49	3.8	88	66	276	31	51
CEH 434	14	48	3.4	87	54	246	30	52
CEH 427	15	53	3.5	78	57	333	33	46
CEH 441	16	46	2.9	112	49	415	30	49
CEH 443	17	51	3.0	118	57	256	30	49
CEH 438	18	53	2.9	116	61	263	30	46
CEH 380	19	54	2.8	121	54	115	33	48

NN- Node number, DFF- Days for 50% flowering, DFF/NN- Ratio, PHT-Plant height (cm), PSL-Primary spike length (cm), Test weight (g), Oil content (%).

Table 5 Phenotypic correlations among the traits in hybrids evaluated under rainfed conditions

Trait	NN	PHT	DFF	PSL	FSYP	TW
PHT	0.81*					
DFF	0.91*	0.85 *				
PSL	0.79*	0.79 *	0.84 *			
FSYP	0.42	0.79 *	0.79 *	0.72 *		
TW	0.080	0.33	0.28	0.41 **	0.37	
OC	-0.06	0.17	- 0.01	0.04	0.18	0.42 **

*, ** Significance at 5% and 1%, respectively, NN- Node number, PHT-Plant height, DFF- Days to 50% flowering, PSL- Primary spike length, FYSP- Final seed yield per plant, TW-Test weight

Table 6 Duncan's Multiple Range Test means and grouping for 12 classes of node numbers under irrigated condition

Node No.	Number of hybrids	DFF	PHT	PSL	FYSP	TW (g)	OC
13	1	37C	65GF	39C	242A	31.05A	47.60B
14	6	47B	52G	56BC	250A	32.84A	49.10AB
16	7	54A	84GEF	74AB	249A	30.48A	49.00AB
17	15	56A	97EF	78A	299A	33.81A	48.50AB
18	22	56A	101ED	81A	294A	32.53A	48.94AB
19	25	55A	111CED	76AB	310A	32.12A	49.34AB
20	43	58A	115CEBD	85A	299A	32.29A	49.31AB
21	12	58A	110CED	78A	278A	33.26A	49.27AB
22	11	60A	135CBD	83A	335A	34.37A	50.97A
23	5	61A	146B	75AB	237A	31.61A	50.96A
24	4	62A	180A	92A	357A	32.51A	51.00A
25	2	62A	140CB	74AB	346A	30.31A	49.51AB

DFF- Days for 50% flowering, PHT-Plant height (cm), PSL-Primary spike length (cm), Test weigh (g), Oil content (%)

Table 7 Promising hybrids for each NN category and their FSYP under irrigated condition

Hybrid	NN	DFF (days)	DFF/NN	PHT (cm)	PSL (cm)	FSYP (g)	TW (g)	OC (%)
CEH 452	13	38	2.9	34	45	247	33	50
CEH 309	14	48	3.4	76	67	387	36	49
CEH 371	16	52	3.3	73	68	450	29	49
CEH 400	17	68	4.0	114	81	505	44	51
CEH 396	18	59	3.3	107	89	442	31	49
CEH 537	19	55	2.9	117	82	553	30	47
CEH 397	20	63	3.2	139	98	426	36	50
CEH 446	21	60	2.9	154	99	390	31	47
CEH 401	22	68	3.1	142	77	434	37	53
CEH 439	23	63	2.7	190	70	291	37	51
CEH 438	24	62	2.6	203	81	409	31	49
CEH 377	25	64	2.6	177	83	322	32	52

Table 8 Phenotypic Correlations among the traits in hybrids evaluated in Irrigated conditions

	NN	PHT	DFF	PSL	FSYP	TW
PHT	0.66*					
DFF	0.46	0.09				
PSL	0.41	0.53*	0.51*			
FSYP	0.10	0.29	0.15	0.27		
TW	0.03	0.19	0.01	0.11	0.15	
OIL	0.22	0.29	0.16	0.16	0.14	0.34

* Significance at 5%, NN- Node number, PHT-Plant height, DFF- Days to 50% flowering, PSL-Primary spike length, FYSP- Final seed yield per plant, TW-Test weight

These results in the present and other studies established that the correlations between NN with DFF and seed yield traits in castor hybrids were moderate but highly influenced by the environment and does not follow a specific pattern as they differ according to the growing conditions and hybrids. Notwithstanding this, NN in combination with DFF, PSL and TW serves as indirect selection criteria for high yielding hybrids under rainfed conditions than in irrigated conditions. However NN *per se* has a limited role for use as an indirect selection criterion for seed yield both under rainfed and irrigated conditions. This indirect selection criterion for higher seed yield can be applicable only in the context of castor hybrids having node number (NN) from 6 to 16 under rainfed conditions.

The results of this study indicated that the performance of castor hybrids was highly influenced by the environment. Distinct selection and evaluation strategies are required to be adopted in castor improvement programmes separately for rainfed and irrigated conditions. From the present study, it is evident that it is possible to develop high yielding very early and early hybrids having short plant stature for their sustainable cultivation with NN <12, DFF <47 DAS and seed yield of 220 to 252 g/plant under rainfed cultivation in peninsular India and 14-16 NN, DFF of 48 DAS and seed yield of 387 to 450 g/plant under irrigated conditions of Gujarat and Rajasthan. It was also observed that the low yielding early hybrids under rainfed conditions yielded better under irrigated conditions, which calls for robust field trials across diverse locations for a better insight on the nature of GxE interactions affecting the castor performance under different agro-ecological situations.

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Genetic analysis for yield and its attributes in safflower (*Carthamus tinctorius* L.)

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ABSTRACT

The present investigation was carried out to study genetic variability, character association and genetic divergence for yield and its attributing traits among 70 genotypes of safflower at Agricultural Research Station, Tandur. The genotypic coefficients of variation (GCV) were less compared to the phenotypic coefficients of variation (PCV) for all the characters. High GCV was observed for seed yield/plot followed by test weight and high PCV values were observed for oil content, test weight, seed yield/plot and number of effective capitula/plant. High heritability coupled with high genetic advance was observed for seed yield/plot, number of seeds/capitulum, number of effective capitula/plant and days to maturity. Seed yield/plot was significantly and positively correlated with days to 50% flowering, days to maturity, number of seeds/capitulum and test weight. Path coefficient analysis indicated that days to maturity exhibited maximum direct effect followed by test weight and number of seeds/capitulum on seed yield. The genotypes were grouped into 11 different clusters based on Mahalanobis D^2 statistics. Clusters VIII and IX exhibited maximum inter cluster distance. Seed yield/plot contributed most towards genetic divergence. Highest mean values were recorded for seed yield/plot in cluster IX, number of effective capitula/plant in Cluster X, number of seeds/ capitulum and test weight in Cluster XI.

Keywords: Character association, GCV, Genetic divergence, PCV, Safflower, Variability

Safflower is one of the important and oldest oilseed crops cultivated across various agroecologies. In India, it covers an area of 46,000 ha with a production of 25,000 t and productivity of 537 kg/ha (Indiastat, 2018-19). It is mainly cultivated in Maharashtra, Karnataka, and to a limited extent in Telangana, Andhra Pradesh, Madhya Pradesh, Orissa, Bihar and West Bengal. It is mainly cultivated for seed which is a source of oil rich in polyunsaturated fatty acid (linoleic acid, 78%) and for the orange-red dye (carthamin) extracted from its petals. In addition to oil it is known to have many medicinal properties i.e. beneficial in treating several chronic diseases, and is widely used in chinese herbal preparations. It is drought tolerant because of its strong and deep penetrating tap root system and cultivated in rabi season under limited soil moisture conditions in Vertisols. It remains succulent during early stages of growth and assumes xerophytic nature at later stages reducing moisture losses from the plant.

Genetic variability is of greatest interest to the plant breeder as it plays a vital role in framing successful breeding programme. Study of variability, heritability and genetic advance in the germplasm will help to ascertain the real potential of the genotypes. Correlation coefficient analyses helps to understand the relationships between yield and yield contributing traits. Path analysis is used to determine the amount of direct and indirect effects of various yield contributing traits on seed yield. For selection to be effective and for identification of superior genotypes, there is a need for genetic divergence in the population. Mahalonobis D^2 statistic is widely used for analysis of genetic diversity in safflower. The objective of the present investigation was to study the variability, character association and genetic divergence for yield and its attributing traits to identify the most appropriate selection criteria and suitable parents for yield improvement in safflower.

MATERIALS AND METHODS

Sixty eight safflower genotypes received from ICAR-Indian Institute of Oilseeds Research (IIOR), Hyderabad under AICRP on Safflower scheme along with two checks namely A-1 and PBNS-12 were evaluated in Augmented Block Design during *rabi* 2018 at Agricultural Research Station, Tandur. The entries were sown in 5m long one row plot with a spacing of 45 cm between the rows and 20 cm between the plants. The crop was raised following all the recommended package of practices to ensure a good crop. Data of the seven characters *viz.,* days to 50% flowering, days to maturity, number of effective capitula/plant, number of seeds/capitulum, test weight (g), seed yield/plot (g) and oil content (%) was recorded on five random plants except for days to 50% flowering and days to maturity where data are recorded on plot basis. Statistical analysis was carried out using WINDOSTAT software package Version 8.5. Analysis of variance was computed using Augmented Block Design as per standard statistical

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procedure given by Panse and Sukhatme (1978). Heritability (h^2) in the broad sense was calculated according to the formula given by Allard (1960). Phenotypic and Genotypic coefficients of variation (PCV and GCV) were computed according to Burton (1952). Mahalonobis D^2 statistic (Rao, 1952) was used to analyze the genetic divergence. Phenotypic and genotypic coefficients of correlation were computed according to Al-Jibouri *et al*. (1958).

RESULTS AND DISCUSSION

Analysis of variance involving a set of 70 genotypes of safflower for seven quantitative characters revealed highly significant mean sum of squares for all the characters indicating greater diversity among the genotypes. The results pertaining to genetic parameters *viz.,* phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), broad sense heritability (h^2bs) and genetic advance as percent of mean (GAM) for the seven characters are furnished in Table 1. The PCV generally was higher than the GCV for all the traits indicating the significant effect of environment. Similar results were reported by Choulwar *et al.* (2005) and Mohamed and Elmogtaba (2018). The highest magnitude of PCV was observed for oil content (66.39%) followed by test weight (57.20%), seed yield /plot, number of effective capitula/plant, number of seeds/capitula and days to 50% flowering. Highest GCV was observed for seed yield/plot (49.65%) followed by test weight (30.53%), number of effective capitula/plant, number of seeds/capitula and oil content. Similar reports of high GCV and PCV for number of effective capitula/plant and seed yield/plot were given by Pushpavalli and Kumar (2017) and Minnie et al. (2018). Heritability estimates were high for seed yield/plot (89.3 %) followed by number of seeds/capitulum (85.9%) and number of effective capitula/plant (72.9%) and days to maturity (69.9%). The results are in consonance with the reports given by Pushpavalli and Kumar (2017) and Mohamed and Elmogtaba (2018). High heritability coupled with high genetic advance was recorded for seed yield/plot and days to maturity as reported earlier by Pushpavalli and Kumar (2017) and Minnie *et al.* (2018). The characters exhibiting high heritability and high genetic advance indicate the role of additive gene action in controlling these traits and thus offer greater opportunities for improvement through selection.

Mahalonobis D^2 values classified 70 genotypes into 11 distinct clusters with variable number of germplasm in each group revealing the existence of considerable genetic diversity in the accessions. In hybridization programs selection of genetically diverse parents is important to generate a wide array of recombinants and hence the knowledge of genetic diversity among the accessions is necessary. Cluster II and Cluster IV comprised of 12 genotypes each followed by cluster III (10), Cluster I and Cluster VI with 7 genotypes each, cluster V, VII, VII and IX with five genotypes each, while clusters X and XI were solitary (Table 4). The checks A-1 and PBNS-12 were grouped in cluster IX and cluster II respectively. The maximum inter cluster distance was observed between cluster VIII and IX (1139.0) followed by cluster IX and X (994.5), while minimum genetic distance was observed between cluster III and cluster VII (91.8) (Table 2). Hence, genotypes from cluster VIII, IX and X can be used as parents in breeding programmes to broaden the genetic base. Cluster XI recorded highest mean values for number of seeds /capitula (30.7) and test weight (6.1). Cluster X recorded highest number of effective capitula/plant (34.8). Highest seed yield/plot was recorded in Cluster IX (1294.8) followed by Cluster XI (1132.0 g) and genotypes in cluster VI had highest oil content of 31.8% (Table 3). Hence, genotypes in cluster XI can be utilized in breeding programmes to improve seed number/capitulum and test weight. Cluster VI and cluster IX genotypes can be utilized to enhance seed yield and oil content. Genotypes in cluster III have comparatively shorter duration while those in cluster IX have high seed yields. As there is considerable genetic diversity between these two clusters (625.5), crossing can be affected between the genotypes of these clusters for developing early duration drought escaping varieties under *rabi* situations.

The percentage variation contributed by each of the seven traits to the total genetic divergence was studied (Table 5). The information related to genetic diversity and *per se* performance of genotypes can be reliably used in the selection of genetically diverse and agronomically superior genotypes for use as parents in the hybridization programme. The characters contributing the most to genetic divergence are considered for the purpose of effective selection. In the present study, maximum contribution towards genetic divergence was by seed yield/plot (98.2%) followed by number of effective capitula/plant (0.6%) and days to 50% flowering (0.6%). Oil content and number of seeds/capitulum contributed the least (0.2) towards genetic divergence. Similar results were reported in studies by Shivani and Sreelakshmi (2013), Shivani and Sreelakshmi (2014) and Pushpavalli *et al*. (2016).

Phenotypic correlations estimated among the seven traits indicated inherent association between the traits which might have occurred due to the pleiotropy or linkage or both (Table 6). Seed yield/plot exhibited positive correlation with test weight (r=0.5381), days to maturity (r=0.3603) and number of seeds/capitulum (r=0.3080). Positive correlation of test weight with seed yield/plant was also reported by Bidgoli *et al*. (2006), Mozaffari and Asadi (2006), Karimi *et al.* (2014), Bahmankar *et al.* (2014) and Joseph Raju *et al.* (2019). Seed yield/plot was not correlated with number of effective capitula/plant (0.2135) and oil content (0.1373). However, Bahmankar *et al.* (2014), Golkar *et al.* (2011), Kurhade and Charjan (2016) and Joseph Raju *et al.* (2019) reported a strong association between number of effective capitula/plant and seed yield /plant. Days to 50% flowering was positively correlated with days to maturity (r=0.9952) as reported by Rafiei (2002), Abulhasani (2003) and Pushpavalli and Kumar (2017).

Table 1 Estimation of genetic parameters for yield and its related traits in safflower genotypes

Traits	GCV (%)	PCV (%)	Heritability (h^2 bs) (%)	Genetic advance (5%)	Genetic advance as % of mean (5%)
Days to 50% flowering	18.24	26.36	8.8	9.57	11.17
Days to maturity	17.74	17.82	69.9	45.30	36.37
Number of effective capitula/plant	29.05	34.03	72.9	13.52	51.09
Number of seeds/capitulum	26.65	28.76	85.9	12.09	50.89
Test weight (g)	30.53	57.20	28.5	1.68	33.58
Seed yield/plot (g)	49.65	49.65	89.3	69.50	102.28
Oil content (%)	20.75	66.39	9.8	3.89	13.36

Table 2 Average intra (bold) and inter cluster D^2 values based on yield and its related traits in safflower

Cluster	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI	Cluster VII	Cluster VIII	Cluster IX	Cluster X	Cluster XI
Cluster I	**46.05**	185.32	356.21	636.889	94.32	492.29	273.79	869.33	276.94	724.49	110.99
Cluster II		**58.88**	183.41	460.27	100.10	315.98	102.49	692.13	452.80	547.10	287.39
Cluster III			**62.22**	288.95	268.38	146.59	91.76	519.40	625.47	374.26	460.54
Cluster IV				**62.51**	548.84	151.60	365.67	241.68	906.63	99.24	742.34
Cluster V					**22.56**	404.06	185.01	781.34	361.71	636.22	194.84
Cluster VI						**32.14**	220.50	380.51	762.47	234.46	597.67
Cluster VII							**17.46**	597.87	544.01	452.40	378.44
Cluster VIII								**78.96**	1138.96	152.22	974.98
Cluster IX									**91.05**	994.51	173.05
Cluster X										-	830.10
Cluster XI											-

Table 3 Cluster mean values (Tocher Method) for yield and its related traits in safflower

	Days to 50% flowering	Days to maturity	Number of effective capitula/plant	Number of seeds/capitulum	Test weight (g)	Seed yield/plot (g)*	Oil content (%)
Cluster I	87.43	127.43	23.66	30.57	4.96	1025.71	28.90
Cluster II	86.50	126.50	30.13	24.15	5.54	847.50	28.79
Cluster III	83.80	123.80	29.94	20.14	5.34	673.50	30.23
Cluster IV	91.17	131.17	25.15	24.70	4.84	391.0	31.44
Cluster V	90.80	130.80	29.36	24.68	5.78	938.00	29.15
Cluster VI	86.29	126.29	22.63	23.91	4.92	534.86	31.77
Cluster VII	88.60	128.60	24.60	20.76	5.66	754.00	29.16
Cluster VIII	92.80	132.80	28.48	26.80	3.67	158.40	31.59
Cluster IX	90.80	130.80	27.68	25.80	5.71	1294.80	28.25
Cluster X	94.00	134.0	34.80	29.20	4.29	302.00	28.73
Cluster XI	85.00	125.0	33.50	30.70	6.06	1132.00	27.18

*Plot size: Single row of 7m length

Table 4 Clustering pattern among 70 genotypes of safflower based on yield and its related traits by Tocher method

Cluster	No. of genotypes	Entries
I	7	GMU 6891, GMU 884, GMU 7569, GMU 955, GMU 753, GMU 2486, GMU 7273
II	12	GMU 1894, GMU 1397, GMU 667, GMU 6926, GMU 4893, GMU 1360, GMU 6852, GMU 1183, GMU 1811, PBNS-12, GMU 5142, GMU 2380
III	10	GMU 7456, GMU 4665, GMU 1301, GMU 5136, GMU 1731, GMU 2775, GMU 2830, GMU 7581, GMU 5149, GMU 972
IV	12	GMU 1175, GMU 7572, GMU 7573, GMU 7448, GMU 6886, GMU 4814, GMU 7594, GMU 4965, GMU 5133, GMU 5135, GMU 6834, GMU 2687
V	5	GMU 2684, GMU 1628, GMU 1067, GMU 974, GMU 3266
VI	7	GMU 9593, GMU 7569, GMU 3944, GMU 7363, GMU 609, GMU 5097, GMU 2928
VII	5	GMU 2644, GMU 7591, GMU 880, GMU 5134, GMU 4914
VIII	5	GMU 7331, GMU 7599, GMU 7568, GMU 7618, GMU 7579
IX	5	GMU 7399, GMU 590, GMU 2424, A-1, GMU 6915
X	1	GMU 7436
XI	1	GMU 589

Table 5 Percent contribution of yield and its related traits towards divergence in safflower

Traits	Times ranked first	Contribution (%)
Days to 50% flowering	13	0.54
Days to maturity	8	0.33
Number of effective capitula / plant	14	0.58
Number of seeds / capitulum	4	0.17
Test weight (g)	0	0
Seed yield/plot (g)	2371	98.18
Oil content (%)	4	0.17

Table 6 Estimates of Phenotypic (r_p) correlation coefficients among yield and its related traits in safflower

Traits	Days to 50% flowering	Days to maturity	Number of effective capitula/plant	Number of seeds/ capitulum	Test weight (g)	Oil content (%)	Seed yield/plot (g)
Days to 50% flowering		0.9952***	0.5488***	0.6354***	0.5129***	0.8100***	0.2835*
Days to maturity			0.5690***	0.6464***	0.5347***	0.8264***	0.3603***
Number of effective capitula/plant				0.3254**	0.3128**	0.4744***	0.2135
Number of seeds/Capitulum					0.2418*	0.4872***	0.3080**
Test weight (g)						0.3838**	0.5381***
Oil content (%)							0.1373

*Significance at 5% level, ** Significance at 1% level, *** Significance at 0.5% level

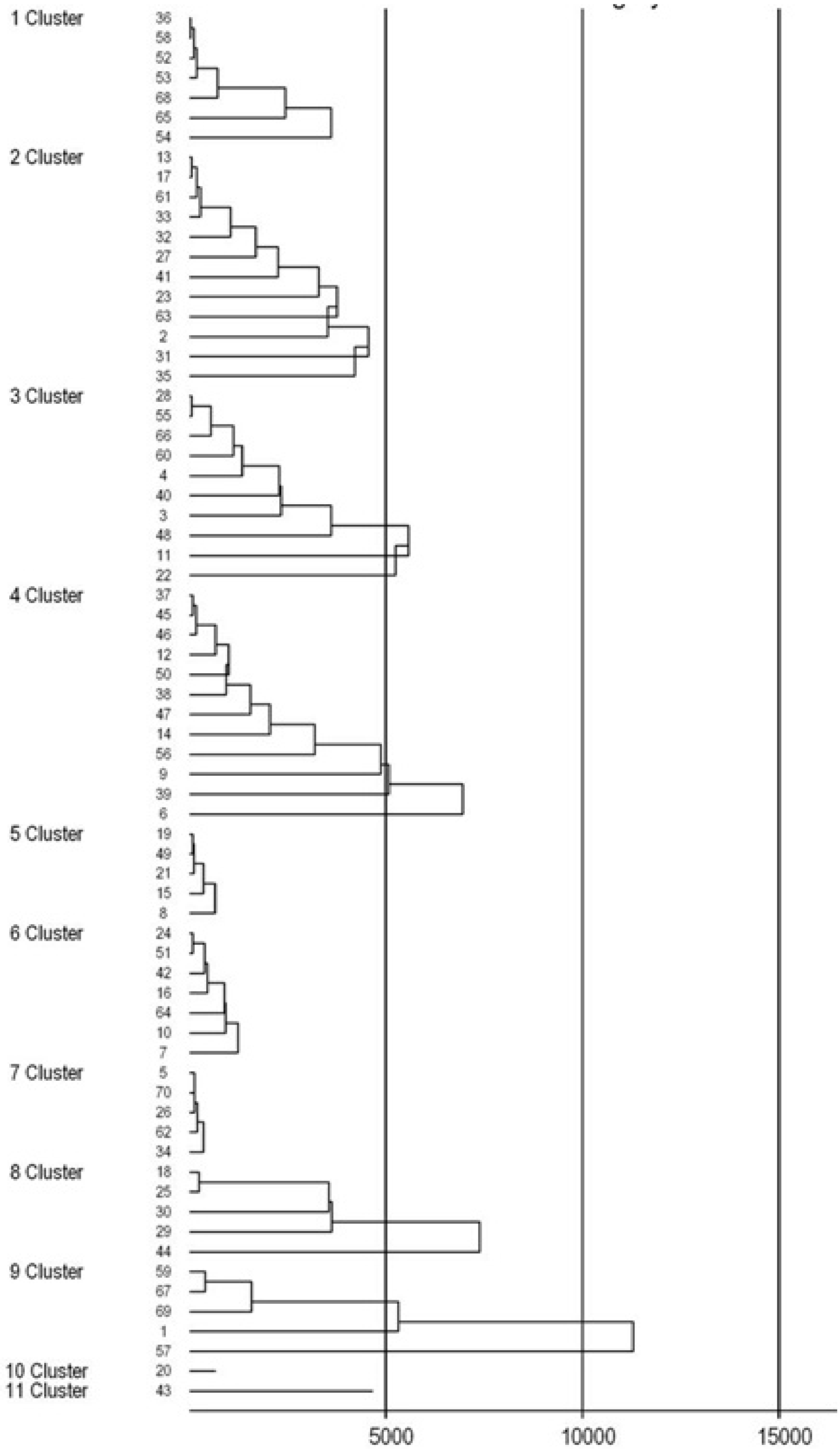

Fig. 1. Clustering in 70 genotypes of safflower based on yield and its related traits

Table 7 Estimates of phenotypic path coefficients among yield and its related traits in safflower

Traits	Days to 50% flowering	Days to maturity	Number of effective capitula/plant	Number of seeds/ capitulum	Test weight (g)	Oil content (%)	Seed yield per plot (g)
Days to 50% flowering	-1.3237***	-1.3174***	-0.7265***	-0.8410***	-0.6789***	-1.0730***	0.2835*
Days to maturity	1.4140***	1.4208***	0.8084***	0.9184***	0.7598***	1.1742***	0.3063**
Number of effective capitula/plant	0.0189	0.0196	0.0344	0.0112	0.0108	0.0163	0.2135
Number of seeds/capitulum	0.1520	0.1546	0.0778	0.2392*	0.0578	0.1165	0.3080**
Test weight (g)	0.2561*	0.2670*	0.1562	0.1208	0.4993***	0.1916	0.5381***
Oil content (%)	-0.2338	-0.2384*	-0.1368	-0.1405	-0.1107	-0.2885*	0.1373

* Significance at 5% level, ** Significance at 1% level, *** Significance at 0.5% level; R Square= 0.3700; Residual Effect= 0.7937

In the present investigation, path coefficient analysis was performed to estimate the direct and indirect contribution of various plant characters to seed yield/plot. Compartmentalization of correlation coefficients into direct and indirect effects differentiated the true nature of association observed among various characters. Days to maturity (1.4208) exhibited maximum direct effect followed by test weight (0.4993) and number of seeds/capitulum (0.2392) (Table 7). Similar results were reported by Malleshappa (2000), Pushpavalli *et al.* (2016), Pushpavalli and Kumar (2017), Mohamed and Elmogtaba (2018) and Joseph Raju *et al.* (2019). Days to 50% flowering and oil content exhibited negative direct effect on seed yield/plot. The three traits namely test weight, days to maturity and number of seeds/capitulum showed positive and significant correlations as well as positive direct effects on seed yield/plot. Hence selection may reliably be done based on these characters for improving seed yield.

The present investigation indicated high estimates of PCV and GCV for seed yield/plot, oil content, number of effective capitula/plant, number of seeds/capitulum and test weight which provides scope for genetic improvement through selection. Further, high heritability coupled with high genetic advance was observed for seed yield/plot and days to maturity indicating the role of additive gene action in controlling these traits. Hence pedigree method of breeding would be rewarding to improve the traits under study. On the basis of genetic divergence, it may be concluded that good recombinants would be possible from crosses between the genotypes of clusters VIII and IX followed by cluster IX and X in varietal improvement of safflower. The trait specific genotypes identified will be useful in the selection of parents for crop improvement. Seed yield/plot contributed to maximum genetic diversity followed by number of effective capitula/plant. Character association studies connoted that the characters namely test weight, days to maturity and number of seeds/capitulum were positively and significantly correlated with seed yield/plot. These traits can be used as selection criteria for seed yield improvement.

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Mutagenic effectiveness and efficiency of ethyl methane sulphonate (EMS) mutagen in linseed (*Linum usitatissimum* L.)

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ABSTRACT

Induced mutation study was carried out to study the mutagenic effectiveness and efficiency of the mutagen ethyl methane sulphonate (EMS) in two genotypes of linseed, Him Alsi-2 and Kangra Local. On the basis of survival percentage in M_1 generation under lab conditions the LD_{50} dose for both genotypes was estimated. Only three doses (one higher and one lower dose to LD_{50}) were selected for raising M_2 generation. Effects of these concentrations were studied on various morphological characteristics. Mutagen EMS was effective and efficient in producing chlorophyll and viable macromutations in M_2 generation. Three types of chlorophyll mutants i.e. albina, xantha and radina were observed. Different types of alterations in seed color, seed texture, flower shape and plant type were observed. The macromutations although are not very useful for plant breeding but help in determining the effective mutagen doses and have also known to play an important role in evolution. EMS concentrations showing maximum effectiveness and efficiency in both varieties were different indicating varietal sensitivity towards EMS.

Keywords: EMS, Linseed, Mutagenic efficiency, Mutagenic effectiveness, Mutation

Linseed (*Linum usitatissimum* L.) is one of the major oilseed and fibre crops that belongs to family Linaceae. It is the only agriculturally important species in the family Linaceae, which consists of 13 genera and 300 species (Heywood, 1978). Linum is the largest genera with 180-200 species including cultivated flax (*Linum usitatissimum*) (Gill, 1987). Linseed is unique among oilseeds as its oil is one of the richest vegetarian sources of linolenic (omega-3) and linoleic (omega-6) polyunsaturated fatty acid (PUFA) which offer potential health benefits since they are not synthesized in the organism and must be ingested through food. Its seeds contain about 33 to 45 % of oil, which is used in human and animal diets and for various industrial uses. Linseed oil helps in decreasing cholesterol level (Singh and Marker, 2006), preventing cancer especially breast, prostate and other hormone sensitive cancers when included in the diet chain.

For the genetic improvement of linseed, conventional breeding methods have been the basic tools for releasing new cultivars with durable resistance to diseases, agronomic fitness and greater yield stability (Green *et al.*, 2008). However, the narrow genetic base used for the development of linseed cultivars (Fu *et al.*, 2002; Cloutier *et al.*, 2009), the scarce availability of related species to incorporate new variation, the lack of hybrid production systems (Green *et al.*, 2008), and the limited genomic tools for molecular breeding (Cloutier *et al.,* 2011) have hampered yield and quality improvements, limiting linseed competitiveness. Also, through the process of continuous selection for superior traits genetic diversity is lost through fixation, thereby increasing dependency of breeders on smaller sets of superior genotypes that has created successive bottlenecks. Therefore, in addition to conventional breeding, programmes such as mutation breeding can be adopted to overcome such bottlenecks. To widen the genetic base, the use of mutagens has been proved to be beneficial. Mutations are sudden and heritable changes in the genetic sequence and they are the main cause of diversity among organisms. Physical and chemical mutagens have been used to accelerate mutation rate (Muller 1927) and induce useful phenotypic variations in plants (Vasline *et al.,* 2005). Shah *et al.* (2008) reported that mutagens may cause genetic changes in an organism, break the linkages and produce many new promising traits for the improvement of crop plants. EMS has the potential of altering loci of particular interest without inducing a great number of closely linked mutations. However, the choice of mutagen and its different doses is one of the important steps in mutation breeding programme.

Mutagenic effectiveness and efficiency are two different properties of a mutagen. Mutagenic effectiveness means the rate of mutation as related to dose whereas, mutagenic efficiency refers to the mutation rate in relation to damage. Although, both are two different properties but the usefulness of any mutagen in plant breeding programme depends on both of them. A highly effective mutagen may not necessarily show high efficiency and *vice versa.* Various factors like biological, environmental and chemical ones modify the effectiveness and efficiency of different mutagens and the mutation rate (Blixt, 1970; Fujimoto and Yamagata, 1982). The selection of effective and efficient mutagen is very essential to recover high frequency and spectrum of macro-mutations along with the mutagenic effectiveness and efficiency of different doses of EMS. Therefore, the present investigation was undertaken to study the frequency and spectrum of macromutations along with the mutagenic effectiveness and efficiency of different doses of EMS on different plant attributes in linseed.

MATERIALS AND METHODS

The experimental material consisted of the seeds of well adapted variety of linseed "Him Alsi-2" and local landrace "Kangra Local". As per literature cited, the different doses of chemical mutagen EMS were selected. Treatments were given individually. In each treatment 300 seeds of each genotype Him Alsi-2 and Kangra Local were used which were exposed to 8 different doses of EMS *viz.,* 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 per cent. Seeds were pre-soaked in distilled water for 6 hours and then treated with freshly prepared EMS solutions for 8 hours followed by continuous washing under running tap water for 2 hours to terminate the residual effect of mutagen chemical. The volume of mutagen solution used was three times that of seeds so that EMS effect can be equally distributed. The control sample consisted of equal number of seeds soaked in distilled water alone under identical condition. 100 treated seeds from each treatment were grown aseptically on moist filter papers in Petri dishes and were evaluated for germination percentage on the basis of which LD_{50} doses for both varieties were estimated with the help of probit analysis.

After the completion of the treatment, treated seeds were immediately sown in eight different plots at a spacing of 30 cm × 10 cm as M_1 generation in *rabi* 2016-17. Seeds were harvested on individual plant basis from M_1 plants. Seeds from only 3 doses (one higher and one lower to LD_{50}) were sown as plant progenies in *rabi* 2017-18 as M_2 generation. All the recommended cultural measures were carried out during the growth period of the crop. In M_2 generation, the progenies were screened at different stages of growth (as listed in Table 1) several times for morphological mutations namely chlorophyll mutations, plant type, stem type, flower shape, seed colour, seed texture and sterility throughout the crop duration. Mutagenic effectiveness and efficiency for chlorophyll mutations, viable macromutations and total macromutations (chlorophyll + viable macromutations) was estimated.

Mutation frequency was calculated as percentage of mutated M_2 progenies for both chlorophyll and morphological mutations in each treatment.

$$\text{Mutation frequency on } M_2 \text{ plant basis } (M_f) = \frac{\text{No. of mutant plants}}{\text{Total number of } M_2 \text{ plants}} \times 100$$

Mutagenic effectiveness and efficiency (%):

$$\text{Mutagenic effectiveness} = \frac{M_f}{\text{Conc. * time}}$$

$$\text{Mutagenic efficiency} = \frac{Mf}{\% \text{ BI}}$$

Where,

Mf = mutation frequency (plant basis)

Conc. = concentration of EMS in per cent

% BI = per cent biological damage

$$\text{Per cent biological injury} = \frac{\text{Plants germinated - Plants survived at the time of maturity}}{\text{Total No. of } M_2 \text{ seeds sown in each treatment}} \times 100$$

Chlorophyll mutations: Chlorophyll mutations are the most conspicuous and easily detectable, as they have been extensively used to find out the sensitivity of crop plants to mutagens and to elucidate effectiveness and efficiency of mutagens (Gaul, 1960). They have also been noted to depict the damage caused to the treated material. The frequency of chlorophyll mutations was calculated as the percentage of chlorophyll mutants isolated in the whole population of a particular treatment.

RESULTS AND DISCUSSION

The effectiveness of the mutagen is better judged by studying the progenies in M_2 generation. M_2 generation was raised in *rabi* 2017-18 in plant progeny rows. The dosage of EMS for raising M_2 was fixed based on the LD_{50} values calculated for both genotypes. The LD_{50} of two linseed varieties Him Alsi-2 and Kangra Local was found at 0.70 and 0.60 per cent of EMS doses respectively. A slight variation in LD_{50} values between different varieties of same species is a common phenomenon in mutation breeding as resistance offered by the biological material depends on maturity, size, hardness and moisture content etc., at the time of treatment. Such variations in LD_{50} were observed by Karthika and Lakshmi (2006) in soybean, Jain and Khandelwal (2008) in mung bean, Selvam *et al.* (2010) in urd bean, Yadav *et al.* (2016) in rapeseed-mustard, and Veni *et al.* (2017) in blackgram. Data on single plant basis were recorded for different morphological traits and observations were also recorded for chlorophyll and viable macromutations. Some of the effects of mutations can be beneficial. However, useless mutations out number those having significant and beneficial effects. The macromutations are usually undesirable due to accompanying genetic instability (Tah, 2006) but they (distinct qualitative genetic variations) are easily identified and therefore can be efficiently selected for varietal development programs, or otherwise exploited through cross breeding (Wani, 2011). As far as chlorophyll mutations are concerned, although not useful for plant breeding purpose as the plants do not survive long, they may be helpful to select suitable mutagen at appropriate concentration so as to use them in mutagenesis programme (Makeen *et al.,* 2013).

Chlorophyll mutations: Based on the intensity of pigmentation at seedling stage, three types of chlorophyll mutations *viz.,* albina, xantha and radina were recorded (Fig. 1). The frequency based on M_2 plant basis was observed minimum at the middle dose of treatment in both genotypes. When compairing the two genotypes, Him Alsi-2 showed more frequency rate than Kangra Local (Table 2).

For both varieties effectiveness showed a random change without following a proper trend. 0.60 per cent EMS concentration was the most effective dose for Him Alsi-2 whereas, 0.50 per cent EMS concentration was most effective for genotype Kangra Local (Table 3). In terms of mutagenic efficiency, 0.80 per cent EMS for Him Alsi-2 and 0.50 per cent EMS for Kangra Local were the most efficient doses (Table 3).

The two genotypes of linseed differed in their response to mutagen which is in line with the studies of Goyal (2019) in urdbean, Pradhan (2019) in sesame. The varietal differences in incidence of chlorophyll mutations is due to the differences in the number of genes controlling the chlorophyll development in different varieties (Bhatia and Swaminathan, 1963). The frequency of chlorophyll mutants in general was low in this crop and it may be because the oilseed crops are resistant to induction of chlorophyll mutations (Rajan, 1969; Rangaswamy, 1973). Due to the lethal nature of the chlorophyll mutants, they do not possess much economic importance, however they could be helpful in recognizing the threshold dose of a mutagen that would be likely to increase the genetic variability and number of economically useful mutants in subsequent generations (Goyal *et al.,* 2019).

Viable macromutations: These mutants were classified for deviation from the normal looking plants. In both the linseed genotypes Him Alsi-2 and Kangra Local spreading and erect type mutants were obtained in contrast to semi-erect type (control). Star-shaped flowers were observed in different concentration of EMS in Him Alsi-2, while disk-shaped flowers were observed in control (Fig. 2). However, for Kangra Local no mutants for flower shape were observed. Single stem mutants were found in different treatments in both the genotypes in contrary to the control having branched stem type. Three different types of seed color mutants *viz.,* fawn, light brown and dark brown were found in Him Alsi-2 and only two (light brown and dark brown) were observed in Kangra Local in contrast to brown colour seeds of the control (Fig. 3). Rough surface and sterile mutants were also observed in contrast to smooth and shiny seed surface of the control. Change in the seed colour and texture are a result of changes in the cellular structure and metabolism of the plants e.g., dilation of thylakoid membranes, alteration in photosynthesis, modulation of the antioxidative system and accumulation of phenolic compounds (Gnanamurthy and Dhanavel, 2014).

Fig. 1. Different chlorophyll mutants observed in M_2 generation of linseed

Mutagenic effectiveness and efficiency: Maximum frequency for viable macromutation was observed at 0.70 per cent for both the genotypes, Him Alsi-2 and Kangra Local (Table 3). In terms of mutagenic effectiveness (Table 4), for variety Him Alsi-2 there was random change in mutagenic effectiveness without following a linear relationship between mutagenic effectiveness and different EMS concentrations with 0.70 per cent as the most effective dose. In genotype Kangra Local, there was gradual increase in effectiveness with increase in the concentration of EMS. Hence, 0.70 per cent was the most effective dose.The mutagenic effectiveness based on per cent lethality was observed maximum at 0.70 per cent in variety Him Alsi-2 and at 0.60 per cent in Kangra Local (Table 4). There was random change in mutagenic efficiency without following proper trend in both genotypes.

Total macromutations: The maximum mutagenic effectiveness was observed in treatment of highest concentration in both genotypes indicating that higher concentrations were more effective in producing macromutations (Table 5). It was also observed that the response of two genotypes in terms of spectrum and frequency and mutagenic effectiveness and efficiency for the mutagen was varying. The presence of differences in the mutagenic effectiveness of identical mutagen concentration in both the genotypes indicates the presence of genetic divergence among them as observed in lentil by Laskar and Khan (2017). Varietal response towards different mutagen doses was also observed by Khursheed *et al.* (2015; 2017) in Hordeum vulgare and faba bean respectively.

EMS was found effective and efficient in producing chlorophyll and viable macromutations in both genotypes. However, the spectrum and frequency of macromutations varied in two genotypes. The EMS concentrations showing maximum effectiveness and efficiency in both genotypes were different indicating varying varietal sensitivity towards EMS. Further, the dose found effective was not necessarily found efficient for producing mutations in both genotypes. The most effective dose for producing chlorophyll mutations between both genotypes was 0.60 per cent with 0.50 per cent as the most efficient. For viable macromutations, most effective concentration recorded was 0.70 per cent while 0.60 per cent was the most efficient. For total macromutations 0.70 per cent was the most effective while 0.60 per cent was the most efficient dose. Also, the study of the morphological mutant characters can be utilized for identification and characterization of linseed genotypes.

Table 1 Different morpho types along with their stage of observation

Morpho type	Stage of observation recording
Chlorophyll mutations	one week after germination (died after one week)
Albina	initial 15 days
Xantha	initial 25-30 days
Radina	
Plant type	initial 30 days
Flower Shape	flowering stage
Stem type	from germination up to flowering
Seed Colour	at maturity
Seed texture	after threshing

Table 2 Spectrum and frequency of chlorophyll mutation induced by EMS in M_2 generation of Him Alsi-2 and Kangra Local

Treatments (%)	Albino	Xantha	Radina	Total	Mutation frequency (%)
Him Alsi- 2					
0.60	2(1.000)	1(0.500)	1(0.500)	4	2.000
0.70	-	-	1(0.667)	1	0.667
0.80	3(1.973)	1(0.657)	-	4	2.632
Kangra Local					
0.50	2(0.625)	1(0.312)	-	3	0.938
0.60	1(0.526)	-	-	1	0.526
0.70	-	1(0.826)	-	1	0.826

Table 3 Mutagenic effectiveness and efficiency of EMS for chlorophyll mutants in M_2 generation

Treatments (%)	Mutation Frequency (%)	Per cent lethality (%)	Mutagenic Effectiveness (%)	Mutagenic Efficiency (%)
Him Alsi-2				
0.60	2.000	37.78	0.417	0.053
0.70	0.667	41.46	0.119	0.016
0.80	2.632	39.00	0.411	0.067
Kangra Local				
0.50	0.526	6.369	0.234	0.147
0.60	0.826	7.595	0.110	0.069
0.70	4.615	16.809	0.148	0.049

Table 4. Spectrum and frequency of viable macromutations induced by EMS in M_2 generation of Him Alsi-2 and Kangra

Treatments (%)	Plant type		Flower shape	Stem type		Seed color		Seed texture	Sterile	Total	Mutation frequency (%)
	Spreading	Erect	Star- shaped	Single	Fawn	Light brown	Dark brown	Rough			
Him Alsi-2											
0.60	1(0.500)	-	-	-	-	1(0.500)	1(0.500)	1(0.500)	1(0.500)	5	2.500
0.70	2(1.33)	1(0.666)	1(0.666)	2(1.333)	-	-	1(0.666)	-	-	7	4.667
0.80	-	2(1.315)	2(1.315)	-	2(1.315)	-		-	-	6	3.947
Control	Semi-erect		Disk-shaped	Branched		Brown		Shiny	-	-	-
Kangra Local											
0.50	-	-	-	1(0.312)	-	1(0.312)	2(0.625)	-	2(0.625)	6	1.875
0.60	1(0.526)	2(1.052)	-	1(0.526)	-	1(0.526)	2(1.052)	-	-	7	3.684
0.70	1(0.826)	1(0.826)	-	-	-	-	2(1.652)	1(0.826)	1(0.826)	6	4.959
Control	Semi-erect		-	Branched		Brown		Shiny	-	-	-

Table 5 Mutagenic effectiveness and efficiency of EMS for viable macromutants in M_2 generation

Treatments(%)	Mutation frequency (%)	Per cent lethality (%)	Mutagenic effectiveness (%)	Mutagenic efficiency (%)
Him Alsi -2				
0.60	2.500	37.78	0.521	0.066
0.70	4.667	41.46	0.833	0.113
0.80	3.947	39.00	0.617	0.101
Kangra Local				
0.50	1.875	6.369	0.469	0.294
0.60	3.684	7.595	0.768	0.485
0.70	4.959	16.809	0.885	0.295

Table 6 Mutagenic effectiveness and efficiency of EMS for total macromutations

Treatments (%)	Mutation frequency (%)	Per cent lethality (%)	Mutagenic effectiveness (%)	Mutagenic efficiency (%)
Him Alsi-2				
0.60	4.50	37.78	0.938	0.119
0.70	5.33	41.46	0.952	0.129
0.80	6.58	39.00	1.028	0.169
Kangra Local				
0.50	2.813	6.369	0.703	0.442
0.60	4.211	7.595	0.877	0.554
0.70	5.785	16.809	1.033	0.344

Star-shaped

Disk- shaped (Control)

Fig. 2. Mutants for flower shape observed during M_2 generation

Fig. 3. Mutants for seed colour observed during M_2 generation

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Evaluation of irrigation levels and plant geometry for drip irrigation in groundnut (*Arachis hypogaea* L.)

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ABSTRACT

Field experiments were conducted for two consecutive years during *kharif* 2013 and 2014 to evaluate the irrigation levels and plant geometry for drip irrigation in groundnut. The experiment was laid out in split plot design with different irrigation levels in main plots *viz*., I1 - 100% of daily evaporation rate (Td) by drip every alternate day, I2 - 80% of daily evaporation rate (Td) by drip every alternate day, I3 - 60% of daily evaporation rate (Td) by drip every alternate day, I4 - Border strip irrigation at 1.0 IW/CPE ratio irrigation water depth (5cm). In sub plots four plant geometry levels were imposed *viz*., G1 - Conventional sowing (row to row : 30 cm) with one lateral to each row, G2 - One lateral between two rows, G3 - Paired - rows (15/30 cm apart) with one median lateral to each pair, G4 - One lateral between two pairs. All the treatments were replicated three times. Among the different irrigation levels, irrigating the groundnut at 100% average daily evaporation rate (Td) by drip at alternate days had significant effect on groundnut growth and yield parameters and registered higher pod yield of 2250 kg/ha. Among the different plant geometry one lateral between two pairs significantly influenced the growth and yield parameters and recorded higher pod yield of 2205 kg/ha.

Keywords: Drip irrigation, Groundnut, Irrigation levels, Plant geometry

Groundnut (*Arachis hypogaea* L.) is the 13th most important food crop and 4th most important oilseed crop of the world. In India 82 per cent of the total production of groundnut is concentrated in five states. Gujarat is the leading producer of groundnut contributing 34.8 per cent of total production followed by Rajasthan (15.5%), Tamil Nadu (13%) Andhra Pradesh (11.8%) and Karnataka (7.1%) (Kamala Bai *et al.,* 2019). Availability of water for human consumption, agriculture and environmental requirements is rapidly becoming scarcer. Water is the main constraint in the development of agriculture in many states in India. Therefore, it is necessary to adopt efficient irrigation methods that are economically viable, technically feasible and socially acceptable. Drip irrigation is widely recognized as one of the most efficient methods of watering crops. Generally viewed as a technology for large commercial farmers, drip irrigation is now showing great promise for raising land productivity, water efficiency and incomes of poor, small farmers. Well-maintained drip systems can achieve application efficiency as high as 95 per cent. Losses to evaporation, deep percolation and surface run-off are negligible.

In India, research in various institutions has consistently shown that drip irrigation cuts water use by 30-60 per cent and raises crop yield by 5-50 per cent, compared with traditional surface irrigation methods. Despite being the most efficient method of irrigation, the drip system in still not popular because of high capital costs, and is not available for a plot less than 0.4 hectare.

Scientific agriculture should aim to achieve the twin objectives of higher productivity and better use efficiency. As the scope of increasing area under irrigation is limited, the efficient use of water is crucially dependent on advanced irrigation management technique.

In groundnut, maintenance of optimum soil moisture at critical growth stages is the key factor for achieving higher yields (Patil *et al.,* 2009). New approaches to increase water use efficiency are possible through identification of right sources of irrigation management strategies for higher growth and yield attributes of groundnut. But research on drip irrigation levels and suitable plant geometry for groundnut is lacking. Hence, keeping these facts in view present investigation was carried out to evaluate irrigation levels and plant geometry for drip irrigation in groundnut.

MATERIALS AND METHODS

Description of study area: Field experiments were conducted over two consecutive years during *kharif* seasons of 2013 and 2014 at Regional Research Station, Tamil Nadu Agricultural University, Vridhachalam (110 30°N, 790 26°E, and 42.67 m altitude) to evaluate irrigation levels and plant geometry for drip irrigation in groundnut. The total rainfall received during the cropping period was 308 mm and 415 mm during 2013 and 2014 respectively. The soil of experimental field was sandy loam low in available N, moderate in available P, high in available K, with a pH of 6.5 and organic carbon of 0.20%.

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Experiment materials and arrangement of experiment: The experiment was laid out in split plot design with different irrigation levels in main plot, I1 - 100% of daily evaporation rate (Td) by drip alternate day, I2 - 80% of daily evaporation rate (Td) by drip alternate day, I3 - 60% of daily evaporation rate (Td) by drip alternate day, I4 - Border strip irrigation at 1.0 IW/CPE ratio irrigation water depth (5cm) Different plant geometry levels as subplot treatments were imposed *viz.,* G1 - Conventional Sowing (row to row : 30 cm) with one lateral to each row, G2 - One lateral between two rows, G3 - Paired - rows (15/30 cm apart) with one median lateral to each pair, G4 - One lateral between two pairs. All the treatments were replicated thrice. Uniform fertilizer schedule of 25:50:75 kg NPK/ha was applied. In each lateral the drippers were arranged at 45 cm distance between each dripper. Drip irrigation was scheduled based on daily pan evaporation (PE) as suggested by Loganathan and Krishnamoorthy (1977) and the volume of irrigation water was calculated by using following formula:

$$\text{Volume of irrigation (V)} = CPE \times Kp \times Kc \times \text{Area (m}^2\text{)} \times Wp - ER$$

Where,

CPE - Cumulative pan evaporation (mm);
Kp - Pan factor (0.8);
Kc - Crop coefficient; Wp - Wetted percentage (80%) for drip
ER - Effective rainfall

The surface irrigation was given at 1.0 IW/CPE ratio with 5 cm depth of water. The groundnut variety VRI 2 of 105 days duration was used for the study. During the crop season, inter culture operations *viz.,* weeding and earthing up were done at 45 DAS in all treatments uniformly. The amount of irrigation water applied was based on the cumulative pan evaporation. The growth and yield parameters were recorded and analyzed statistically.

Data on growth and yield attributes were observed at the time of harvest. For this purpose five plants were peg-marked in each treatment in all the three replications. The groundnut crop was harvested at 105 days. Pod yield of groundnut were measured as total yield per plot and transformed to kg/ha.

Field water use efficiency (WUE) was computed using the equation of Saeed and El-Nadi (1997)

$$WUE = Y/W \text{ (kg/ha/mm)}$$

Where,
Y = Economic yield (kg/ha)
W = Total water used (mm)

Statistical analysis: Data were statistically analyzed following the procedure given by Gomez and Gomez (2010). A two-way ANOVA was used to determine significant difference among different drip irrigation levels and plant geometry. Wherever the results were significant, critical differences were worked out at five per cent level and non significant results were noted as N.S.

Economics: The cost of cultivation excluding cost of irrigation (Cc) included cost of various inputs *viz*., cost towards land preparation, seeds, seed treatment, fertilizer, sowing, weeding, inter culturing , harvesting, stripping, cleaning and packing etc. The fixed cost (C_t) included the cost of pumping/delivery and irrigation system. It was assumed that the 7.5 HP pumping system can serve 6 ha area (4ha/season, 2 season/year) for 15 years

$$C_t = C_c + C_i \text{ in which, } C_i = C_v + C_t$$

where,

C_t = Total Cost of cultivation (Rs./season/ha)
C_c = cost of cultivation excluding cost of irrigation (Rs./ha/season)
C_i = cost of irrigation (Rs./ha/season)
C_v = variable cost of irrigation water applications (Rs./ha/season)

RESULTS AND DISCUSSION

Growth parameters: The growth attributes *viz.,* plant height (cm), final plant stand (No./ha) dry matter production (DMP) at harvest (g/plant) indeed was found to be significantly influenced (Table 1) by different plant geometry and irrigation levels. At harvest, conventional sowing with one lateral between each row (G1) recorded higher plant height (42.7 cm), final plant stand (2,37,000/ha) and dry matter production (24.6 g/plant). Among the different levels of irrigation, irrigation of 100 % average daily evaporation rate by drip every alternate day (I1) recorded higher plant height (43.4 cm), final plant stand (2,48,000/ha) and dry matter production (25.0 g/plant). Retarded plant height (35.0 cm), poor plant stand (224/ha) and low dry matter production (21.6 g/plant) was recorded at a plant geometry with one lateral between two pairs (G4). Similarly, Wane *et al.* (2009) reported higher plant height and DMP under drip irrigation to groundnut compared to conventional method of surface irrigation The maintenance of continuously high soil water potential, thus minimizing wide fluctuations in soil water content during the irrigation cycle, is an important and advantageous feature of drip irrigation which influenced the plant growth rate (Ranjitha *et al.,* 2018). Further, increased availability of soil moisture under drip irrigation at rhizosphere region might have led to effective absorption and utilization of available nutrients and better proliferation of roots resulting in quick crop growth. The use of drip system offers a great degree of control over water which helps to meet the water requirement of crops which in turn also helps to have a control over the plant growth (Soni and Raja, 2017).

Yield parameters: Perceptible difference in number of pods/plant and shelling percentage was observed among the various treatments of plant geometry and irrigation levels of groundnut (Table 1). One lateral between two rows of groundnut recorded higher number of pods/plant (34.2 pods/plant) and higher shelling percentage (75.7%). Among different irrigation levels, 100% average daily evaporation rate by drip at alternate day (I1) recorded maximum number of pods/plant (33.4 pods/plant). The number of pods/plant is an important yield attribute that finally contributes to the pod yield/ha. Irrigation under drip treatment might have created favorable moisture conditions for the crop growth consequently increased the values of the yield attributes than border strip irrigation as reported by Patel *et al.* (2009) and Suresh *et al.* (2013). However, significant difference was not observed in test weight and shelling percentage of groundnut. Interaction effect between different plant geometry and irrigation levels was not noticed on the yield parameters of groundnut.

Yield (kg/ha): Different plant geometry and irrigation levels had significant influence on pod yield of groundnut (Table 2). Higher pod yield (2205 kg/ha) was recorded under plant geometry with one lateral between two rows of groundnut (G2). Among different irrigation levels, 100% average daily evaporation rate (Td) by drip at alternate day (I1) recorded higher pod yield (2250 kg/ha). Similarly, Vjayalakshmi *et al.* (2011) reported that irrigating groundnut at 100% daily evaporation rate by drip resulted in maximum pod yield. Significant interaction effect of different plant geometry and irrigation levels was noticed on pod yield of groundnut. Drip irrigation system act as vehicle for carrying and delivering water to the root zone in précise manner thus maintaining the crop growth favourably paving way for higher pod yield in groundnut (Bhaskaran and Subrahmanyam, 2012). The plant geometry with one lateral between two rows of groundnut (G2) with 100% average daily evaporation rate (Td) by drip at alternate day (I1) recorded higher pod yield (2640 kg/ha). Similar findings were reported by Khonok *et al.* (2015).

Table 1 Effect of plant geometry and irrigation levels on growth parameters of groundnut (Pooled data of two years)

Treatments	Plant height (cm) at harvest	DMP (g/plant) at harvest	Final Plant stand (000 Nos./ha)	No. of Pods/plant	100 kernel weight (g)	Shelling percentage
Irrigation levels						
I 1	43.4	25.0	248	33.4	43.8	75.4
I 2	40.3	24.0	235	29.6	43.1	74.3
I 3	37.5	22.8	226	26.3	42.3	72.3
I4	34.5	21.7	224	23.2	41.8	71.6
S.Em (±)	0.47	0.29	26.4	0.31	0.50	0.69
CD=P(0.05)	1.67	1.06	96	1.12	NS	2.23
Plant Geometry						
G1	42.7	24.6	237	29.7	43.2	73.7
G2	40.0	24.3	244	34.2	44.0	75.7
G3	38.0	22.7	229	26.2	42.3	72.7
G4	35.0	21.6	224	22.3	41.5	71.5
S.Em (±)	0.71	0.44	42.4	0.53	0.78	1.20
CD=P(0.05)	2.17	1.32	127	1.58	NS	NS

Irrigation levels

I1 - 100% of average daily evaporation rate by drip at alternate day

I2 - 80% of average daily evaporation rate by drip at alternate day

I3 - 60% of average daily evaporation rate by drip at alternate day

I4 - Border Strip irrigation at 1.0 IW/CPE ratio irrigation water depth (5cm)

Plant geometry

G1 - Conventional sowing (row to row: 30cm) with one lateral to each row

G2 - One lateral between two rows

G3 - Paired rows (15/30 cm apart) with one median lateral to each pair

G4 - One lateral between two pairs

Table 2 Effect of plant geometry and irrigation levels on groundnut pod yield (kg/ha) (Pooled data of two years)

Treatments	Pod yield (kg/ha)				
	G1	G2	G3	G4	Mean
I 1	2442	2640	2021	1897	2250
I 2	2165	2325	1954	1853	2074
I 3	2035	2024	1888	1805	1938
I4	1766	1833	1848	1809	1814
	2102	2205	1928	1841	
	S.Em	CD=P(0.05)			
Main Plot (M)	22.36	80.4			
Sub-plot (S)	37.36	111.7			
S x M	74.72	228.3			
M x S	68.47	209.2			

I1 to I4 and G1to G4 were irrigation levels and plant geometry as described in Table 1

Table 3 Effect of plant geometry and irrigation levels on economics of groundnut

Treatments	Cost of cultivation (₹/ha)	Gross income (₹/ha)	Net income (₹/ha)	B:C ratio
Irrigation regimes				
I1	49000	107591	58591	2.19
I2	47000	99736	52736	2.12
I3	43500	93799	50299	2.15
I4	46500	84712	38212	1.82
Plant geometry				
G1	46500	100467	53967	2.16
G2	45500	105901	60401	2.32
G3	44000	93297	49297	2.12
G4	49000	107591	58591	2.19

I1 to I4 and G1to G4 were irrigation levels and plant geometry as described in Table 1
Cost of seed and pod were taken at ₹, - ₹70/ha and ₹ 47/ha, respectively

Table 4 Effect of plant geometry and irrigation levels on water requirement and water use efficiency of groundnut (Pooled data of two years)

Treatments	Quantity of water applied (mm)	Water saving over control (%)	Water use efficiency (kg/ha/mm)
Irrigation regimes			
I1	417	49.76	5.37
I2	335	59.64	6.19
I3	273	67.11	7.09
I4	830	-	2.19
Plant geometry			
G1	582	-	3.62
G2	392	32.65	5.63
G3	463	20.45	4.15
G4	352	39.52	5.24

I1 to I4 and G1to G4 were irrigation levels and plant geometry as described in Table 1

Economics: The economics of groundnut (Table 3) under different plant geometry and irrigation levels showed considerable variations. Gross income (₹1,07,591/ha), net income (₹58,591/ha) and B:C ratio (2.19) were higher by irrigating 100% average daily evaporation rate (Td) by drip at alternate day (I1). Low gross income (₹84,712/ha), net income (₹38,212/ha) and B:C ratio (1.82) was realized under border strip irrigation method (I1). Mathukia *et al.* (2014) reported higher returns in drip irrigation with low returns in conventional irrigation methods. Among the different plant geometry levels, one lateral to two rows of groundnut (G2) has recorded maximum gross income (₹1,05,901,/ha), net income (₹60,401/ha) and B:C ratio (2.32).

Water requirement (mm) and water use efficiency (kg/hamm): The water requirement and water use efficiency (Table 4) varied among different plant geometry and irrigation levels to groundnut. The water use efficiency explains effective utilization of water by crop in terms of water saving as well as yield augmentation. Irrigation with 60% average daily evaporation rate (Td) by drip every alternate day (I3) consumed less water (273 mm) and recorded higher water use efficiency (7.09 kg/hamm), whereas, border strip irrigation at 1.0 IW/CPE ratio irrigation water depth (5cm) consumed more water (830 mm) and recorded low water use efficiency (2.19 kg /hamm). Similar results of low water requirement with high water use efficiency under drip irrigation and high water requirement with low water use efficiency was observed by Soni *et al.* (2016).

Under different plant geometry levels, one lateral between two pairs of groundnut rows (G4) consumed less water (352 mm). Only a portion of the soil surface around the crop was wetted, which resulted in reduced water requirement (Soni *et al.,* 2019). However, water use efficiency was highest (5.63 kg /hamm) with plant geometry of one lateral to two rows of groundnut (G2).

The results revealed that irrigating the groundnut at 100% average daily evaporation rate (Td) by drip every alternate day had significant effect on groundnut growth and yield parameters and registered higher pod yield (2250 kg/ha). Maintaining one lateral between two rows significantly influenced the growth and yield parameters and recorded a higher pod yield (2205 kg/ha) of groundnut. Irrigating the groundnut crop at 100% average daily evaporation rate (Td) by drip every alternate day with one lateral between two rows produced significantly higher pod yield (2640 kg/ha).

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Agro-economic evaluation of oilseed crops in rice fallow situation in Alfisols

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ABSTRACT

A field study was conducted with an objective of identifying suitable and profitable oilseed crop(s) for rice fallow situation in Alfisols. Four crops *viz.,* castor, groundnut, sunflower and sesame were evaluated for two years (*rabi*/summer 2014-15 and 2015-16).The castor equivalent yield was significantly higher with groundnut (3978 and 3864 kg/ha) and was followed by sesame crop (3460 and 3306 kg/ha). The pooled analysis revealed that groundnut and castor recorded significantly higher production efficiency, but, significantly higher WUE was registered with groundnut and sesame. Higher gross returns (₹ 73,687/ha) were accrued with groundnut, whereas, higher net returns (₹ 33,441/ha) and B:C ratio (2.56) were accrued when sesame was grown in rice fallows. Hence, sesame has been identified as the most profitable crops in rice fallows under South Indian conditions in Alfisols.

Keywords: Castor, Groundnut, Production efficiency, Rice fallows, Sesame, Sunflower, WUE

In India, the rice based cropping systems are the major food production systems with rice as the first crop. A substantial part of it remains fallow during subsequent post monsoon season (*rabi*/summer) due to various reasons such as lack of extended irrigation facilities, cultivation of long duration varieties of rice, early withdrawal of monsoon rains leading to soil moisture stress at planting time of winter crops, waterlogging and excess moisture during November/December, lack of appropriate varieties of winter crops for late planting and stray cattle menace, etc. (Ali, 2014; Singh *et al.,* 2017). Of the total rice-fallow areas spread over South Asia, 88.3% area is present in India (11.65 M ha) alone (Gumma *et al.,* 2016). Normally, the available water storage ability of the soil in rice fallows ranges between 150 to 200 mm (Das *et al.,* 2017). Soils in rice fallow lands are fully saturated during the rice growing season, hence, the residual moisture is left in the soils at the time of harvest (Bourai *et al.,* 2002). Research findings reveal that these unutilized areas can be put into use for sequence cropping by utilizing the inherent soil moisture during *rabi*/summer seasons (Das *et al.,* 2014) so as to make rice fallows a profitable enterprise (Maclean *et al.,* 2002) in India, Nepal and Bangladesh (Musa *et al.,* 1998).These rice fallow systems are prevalent in many north and north eastern states (Yadav *et al.,* 2015), in southern states especially Andhra Pradesh, Tamil Nadu, Karnataka and to some extent in Telangana. They have diversified edapho-climatic conditions and are suitable for growing a wide range of crops during post rainy season with efficient utilization of residual soil moisture (Harris *et al.,* 1999, Ali and Kumar, 2009; Ashoka *et al.,* 2017) preferably short duration crops(Kumar *et al.,* 2018; Kumar *et al.,* 2019). Efficient utilization of rice fallow systems can accelerate the growth of Indian Agriculture. However, very little efforts have been made to efficiently utilize these rice fallow areas. Nevertheless, the selection of demand-driven, profitable and low water requiring short duration crops is critical.

India has already achieved self-sufficiency in food grain production. Though country made a significant improvement in the total oilseeds production i.e., from 5.26 MT (1949-50) to 32.3 MT (2018-19) (Economic Survey, 2019-20) due to yellow revolution and favourable policy changes (Thapa *et al*., 2019). The country is presently importing 60% of its domestic requirements of edible oils worth of >₹77,000 crores per annum (Ramesh *et al*., 2019) due to growing population and change in food habits. Hence, it is pertinent to encourage oilseed crops in rice fallows to achieve horizontal and vertical revolution. Furthermore, a scheme *viz*., targeting rice fallow areas (TRFA) is being operationalized by the Ministry of Agriculture and Farmers' Welfare, Government of India with an objective of growing short-duration pulses and oilseeds in rice fallows to improve the production of oilseed production.

Though, many researchers say that residual moisture is sufficient to grow crops in rice fallows, supplemental irrigation is required especially on light textured soils under South Indian tropical conditions. Thus, selection of crops for rice fallows depends on extent of residual soil moisture and availability of irrigation water.

We selected four oilseed crops for study in rice fallows. Sunflower due to its short growing duration (80-90 days), day-neutral nature and low water requirement fits well in multiple cropping systems. Groundnut is another short duration (110-120 days) prime leguminous oilseed crop in South India. Sesame is a short duration (80 days) and low water requiring crop with high oil content and production

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efficiency. They are suitable for rice fallow situations especially in tail-end areas where there is a restriction for second crop due to limitation of irrigation water (Reddy *et al*., 2002). Castor, though a long duration crop, but, has high oil content (50%), it is preferred in southern part of the country in view of its repellency for wild boars. Keeping in view the above facts, the present study was conducted to understand the agro-economic feasibility of growing oilseed crops with a few or additional irrigations in rice fallows.

MATERIALS AND METHODS

A field experiment was conducted for two consecutive years during summer 2014-15 and 2015-16 at Regional Agricultural Research Station, Palem (Professor Jayashankar Telangana State Agricultural University), Telangana. Agro-climatologically, it comes under the Southern Telangana Zone (STZ). Four crops *viz.,* castor, groundnut, sunflower and sesame with five replications were tested in a randomized block design (RBD). The experimental site was sandy loam soil with a pH of 5.8, organic carbon of 0.38%, available N of 232 kg/ha, phosphorus of 24.7 kg/ha and potash of 478 kg/ha.

The experiment was taken up in rice fallows after the harvest of *kharif* rice (BPT 5204) which was sown during end of June and harvested during December.The leftover stubbles were incorporated by passing the rotavator followed by tilling the land with the cultivator twice, to bring the field to a fine tilth so as to facilitate sowing all the four crops under test. A gross plot size of 5.4m x 6.0m and a net plot size of 3.6m x 4.8m was maintained. PCH-111, a high yielding, Fusarium wilt resistant and double bloom castor hybrid; K-6, a high yielding bunchy type and popular variety of groundnut in Telangana; GK-2002, a high yielding hybrid of sunflower with high tolerance to bud necrosis virus and Alternaria, medium tall growing with droopy flat medium heads and maturity of 90 days,compact seed filling, high oil percentage (40-45%); Swetha til, a high yielding white seeded and stem rot tolerant variety of sesame were used in the experiment.

The recommended agronomic operations and plant protection measures were adopted as per PJTSAU recommendations for growing healthy crops. Groundnut was harvested on 05-06-2015 and 13-05-2016, sunflower was harvested on 16-05-2015 and 12-04-2016, sesame was harvested on 03-05-2015 and 04-04-2016. In the case of castor, 75% dried spikes were harvested three times i.e., during May, June and July in both the years of experimentation. The details of weather parameters during the crop growth period are provided in Fig. 1a,b and c

The castor equivalent yield (CEY), production efficiency (PE) and water use efficiency (WUE) were computed by the following formulae:

CEY = $(Y_c{*}P_c/P_{castor})+(Y_{castor})$
PE = Y/D
WUE = Y/W (Fuentes *et al*., 2003)

Where
Y_c: Economic yield of groundnut/sunflower/sesame (kg/ha)
P_c: Price of groundnut/sunflower/sesame (Rs/kg)
Y_{castor}: Economic yield of castor (kg/ha)
P_{castor}: Price of castor (Rs/kg)
Y: Economic yield (kg/ha) of a crop (castor/groundnut/sunflower/sesame)
D: Duration of crop (castor: 150 days, groundnut: 110 days in 2014-15 and 120 days in 2015-16, sesame: 80 days, sunflower: 90 days)
W: Water used (mm) (effective rainfall+water applied)

The applied irrigation water was measured by using a water meter installed at the site of experimentation. The total water used (W) was computed by summing up the effective rainfall (ER) and water applied (Wa) and the related data are furnished in Fig. 2 a and b.

The experimental data were analyzed statistically using Fisher's analysis of variance technique. Standard error of means (SEm ±) and least significant difference (LSD) at 5 % probability (p=0.05) were worked out to understand and interpret the differences among the treatment means (Panse and Sukhatme, 1985).

RESULTS AND DISCUSSION

Castor equivalent yield, production efficiency and water use efficiency: The yield of groundnut (1413 and 1534 kg/ha), sunflower (798 and 857 kg/ha) and sesame (656 and 715 kg/ha) was slightly higher during 2015-16 as compared to that of 2014-15 (Table 1). This was due to excess soil moisture following high summer rainfall which in turn suppressed crop growth and yield in first year. Excess soil moisture content can cause anaerobic environment for seed germination or establishment, subsequent growth and development (Hassanzadeh *et al.,* 2009). On the contrary, reverse was true in case of castor as seed yield was higher during 2014-15 (1959 kg/ha) than 2015-16 (1672 kg/ha) which was due to higher rainfall received during first year (108.8 mm) associated with relatively lower temperature and high relative humidity than second year (53.8 mm) (Fig 1a to c) during March to May thus availability of sufficient moisture and nutients for this long duration crop. Earlier, Sesha Saila Sree *et al.* (2008) reported that higher seed yield of summer castor was associated with adequate moisture availability.

The CEY, PE and WUE among four selected crops were found to be statistically significant. Equivalent yield indicates productivity of a system. Significantly higher CEY was observed with groundnut (3978 and 3864 kg/ha) and was followed by sesame crop (3460 and 3306 kg/ha) during 2014-15 and 2015-16, respectively (Table 1).The higher castor equivalent yield of sesame was due to higher market price. On pooled basis, CEY of groundnut was 16%, 55%

and 116% higher than that of sesame, sunflower and castor crops, respectively. Previously, Kumar *et al.* (2019) reported suitability of short duration pulses (chickpea, lentil and lathyrus) and oilseeds (safflower, linseed and mustard) under rice-fallow situation, with supplemented life saving irrigation, in north-east India.

Castor crop recorded significantly higher production efficiency during first year, while, groundnut had higher efficiency in the second year of experimentation. However, these two crops were at par and significantly superior to sunflower and sesame, either on individual year or pooled data basis. Further, groundnut (3.23 kg/ha/mm) and sesame (3.00 kg/ha/mm) recorded significantly higher WUE than that of castor (2.68 kg/ha/mm) and sunflower (2.16 kg/ha/mm) (Table 1).

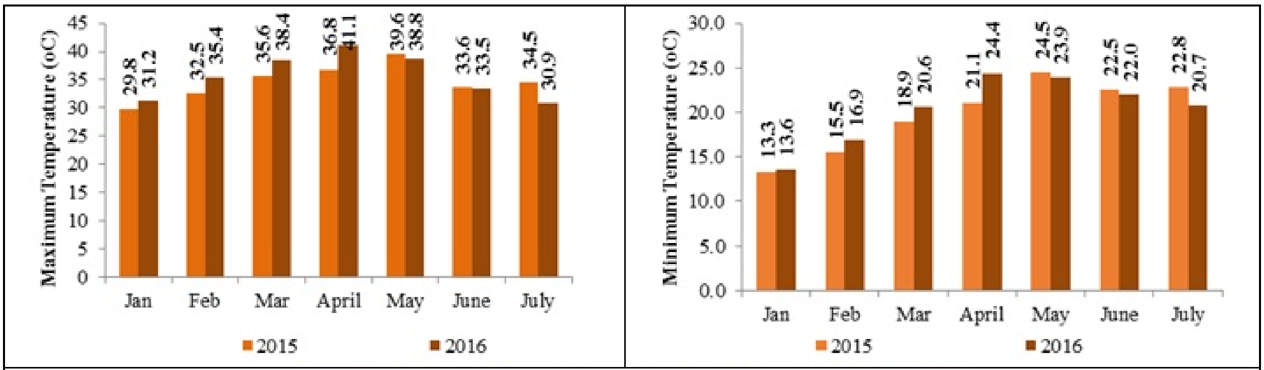

Fig. 1a. Maximum and minimum temperature during 2015 and 2016

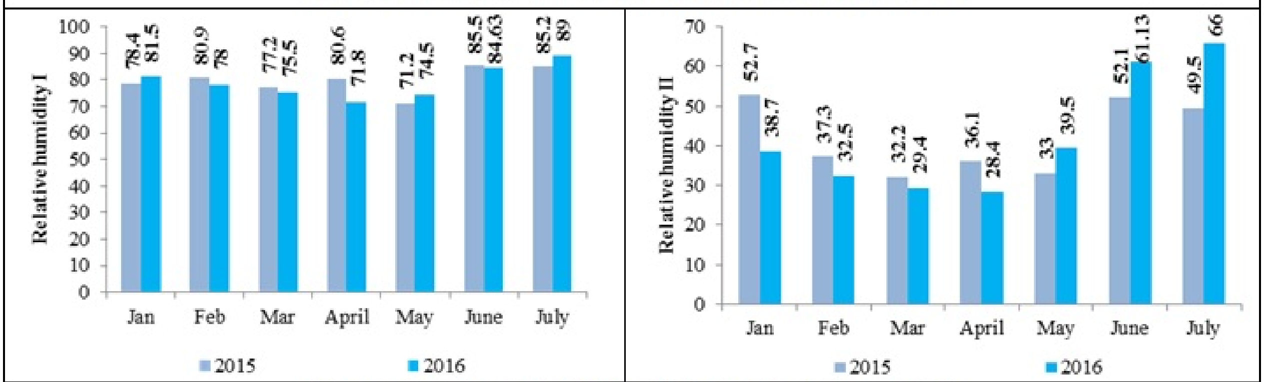

Fig.1b. Relative humidity (RH-I and RH-II) during 2015 and 2016

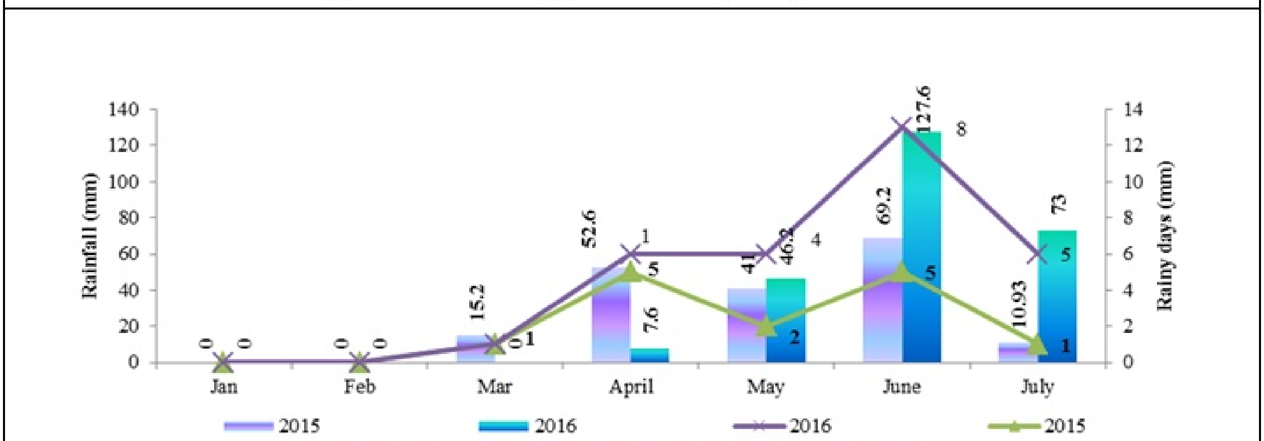

Fig.1c. Rainfall and no. of rainy days duri ng 2015 and 2016

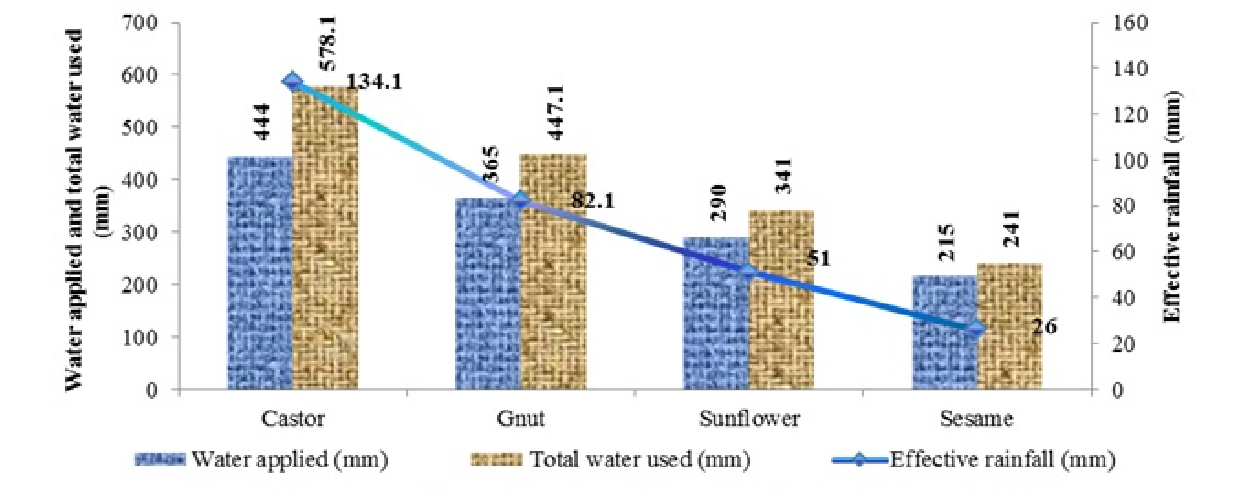

Fig. 2a. Effective rainfall received, water applied and total water used during 2014-15

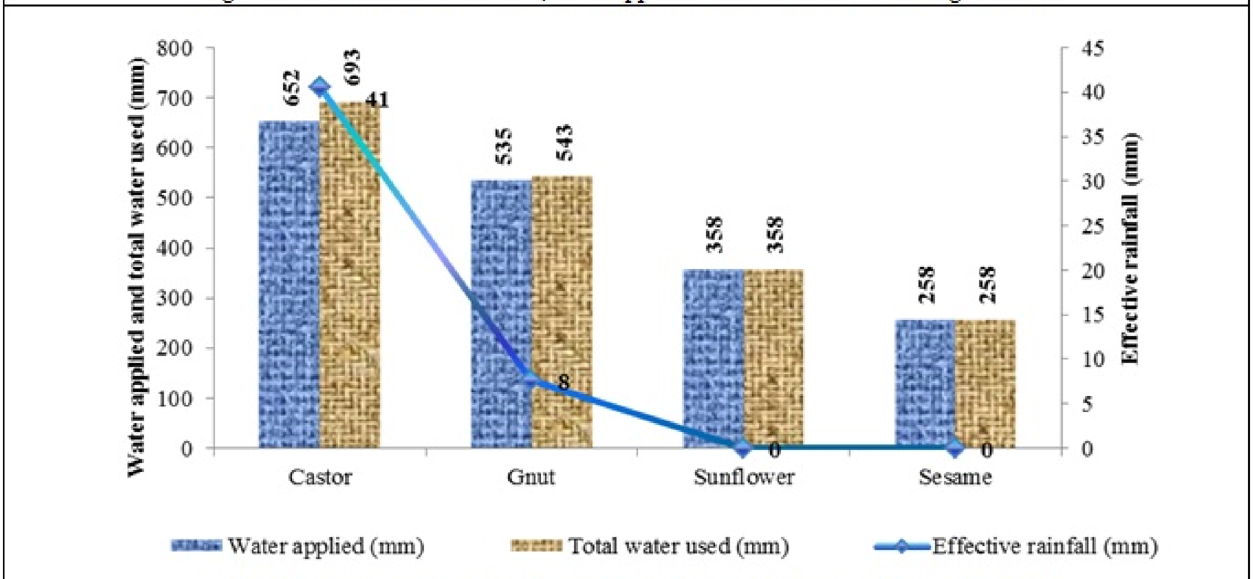

Fig. 2b. Effective rainfall received, water applied and total water used during 2015-16

Table 1 Performance of certain crops in rice fallows (2014-15 and 2015-16)

Treatments	Seed/pod yield (kg/ha)			CEY (kg/ha)			Production efficiency ((kg/ha/day)			WUE (kg/ha/mm)			Gross returns (₹/ha)			Net returns (₹/ha) (B:C ratio)		
	I year	II year	Pooled	I year	II year	Pooled	I year	II year	Pooled	I year	II year	Pooled	I year	II year	Pooled	I year	II year	Pooled
Castor	1959	1672	1816	1959	1672	1816	13.1	11.1	12.1	3.39	2.51	2.68	68578	58527	63553	31453 (1.85)	21402 (1.58)	26428 (1.72)
Groundnut	1413	1534	1474	3978	3864	3921	12.8	12.8	12.8	3.16	3.05	3.23	70653	76720	73687	21878 (1.45)	27945 (1.57)	24912 (1.51)
Sunflower	798	857	828	2643	2407	2525	8.9	9.5	9.2	2.34	1.96	2.16	23939	25723	24831	-5436 (0.81)	-3652 (0.88)	-4544 (0.85)
Sesame	656	715	686	3460	3306	3383	8.2	8.9	8.6	2.72	2.89	3.00	52514	57168	54841	31114 (2.45)	35768 (2.67)	33441 (2.56)
SEm±				62	55	57	0.51	0.39	0.36	0.13	0.09	0.09						
CD (0.05)				195	172	177	1.57	1.20	1.11	0.41	0.28	0.28						

I yr: 2014-15 IIyr: 2015-16; Market price : castor: ₹ 35/kg seed; Groundnut: ₹ 50/kg pod; Sunflower: ₹ 30/kg seed; Sesame: ₹ 80/kg seed

Economic analysis: Though the gross returns were in the order of groundnut>castor>sesame>sunflower, the net returns and B:C ratio were in the order of sesame>castor>groundnut>sunflower. The net returns were less in case of groundnut due to higher cost of cultivation (₹48,775/ha) than other crops (Table 1). Further, sunflower cultivation was not profitable due to less CEY and poor performance of the crop following lodging by heavy winds and poor seed filling due to terminal heat stress due to higher solar radiation (Fig 1e). Earlier, Ramesh *et al*. (2019) while reviewing the research confirmed that sesame fits well for rice fallow situation with less external water application, but, low or high moisture stress affects the standing crop. Further, rice-fallows can be transformed for profitable cultivation of location specific pulses/oilseed crops through adoption of best management practices (Kumar *et al.,* 2019). Furthermore, Behera *et al.* (2014) recommended pulse crop like greengram coupled with conservation agriculture practices for realising higher system productivity and profitability in rice-fallow areas in Odisha. Singh *et al*. (2017) recommended urdbean in rice fallows in Odisha and South India.

From our experiment it could be concluded that sesame could be recommended for cultivation in rice fallows due to its short duration, less water requirement, realization of higher net returns and B:C ratio. It is suitable in the areas where irrigation water is very limited (150-200 mm). Groundnut could be suitable in the areas where irrigation water availability is medium (300-400 mm). Castor could be recommended in the areas where wild boar is a problem and there is assured availability of irrigation water (500 mm). In case of sunflower, short statured, non-lodging and high yielding hybrids tolerant to terminal heat stress suitable for rice fallows are required. Furthermore, we opine that there is a dire need to breed extra early short duration varieties with thermal insensitiveness in view of less moisture/water availability. Adoption of best management practices like integrated nutrient, weed, pest and disease management practices and need based supplemental irrigation will boost up the yield of crops in rice fallows.

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Assessment of selected soil chemical properties at different depths and altitudes for groundnut (*Arachis hypogaea* L.) production in Hakim Gara shrub land of Harari Region of eastern Ethiopia

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ABSTRACT

Ethiopia has a huge potential for growing and exporting various low land oilseed crops like niger (noug), linseed, mustard, sesame, groundnut and safflower. Currently the present achievements are very low because of least share of land and input to these crops resulting in low production and productivity. The present study was conducted to assess the suitability of soil chemical properties at different depths and altitudes for production of low land oil seed crop groundnut (*Arachis hypogaea* L.) which is the major crop in Hakim Gara shrub land of Harari Region of eastern Ethiopia. Soil samples were collected along with altitudinal gradients of the land features between 2001 and 2113 meters above sea level at 0-20 cm and 20-40 cm depths. There were decreasing trend recorded in soil organic matter, soil organic carbon, cation exchange capacity and total nitrogen *i.e.* 5.52 to 12.24, 3.20 to 7.10 %, 35.2 to 50.6 cmol(+)/kg and 0.1 to 0.8 %, respectively. However, slight increase in pH was recorded with increase in soil depth except for soil of upper altitude. Percent total nitrogen, cation exchange capacity and altitude were positively correlated with soil organic carbon. While pH and depth were negatively correlated with soil organic carbon. Thus, soil chemical properties are the most important management interventions that are to be addressed to increase the groundnut production capacity in Hakim Gara shrub land. Therefore, stakeholders should focus on management activities that improve soil chemical properties to boost groundnut production capacity of the soil in this region of Ethiopia.

Keywords: Altitude, Ethiopia, Groundnut, Hakim Gara, Soil chemical properties, Soil depth

In Ethiopia, agricultural production is very low because of various factors *i.e.* natural hazards, inappropriate use of land and poor agricultural practices which have greatly reduced the productivity of soils by declining soil fertility (Mulugeta, 2004). People are dependent mostly on conserved good soils and least shared of land (Brady and Weil, 2002). Declining soil fertility has continued to be a major constraint of oilseed production in many parts of the tropical region. Soil testing is the measurement of the physical and chemical properties of soils. The results of soil chemical testing are most important in determining the relative ability of a particular soil to supply plant nutrients during a particular crop growing season, predict the probability of obtaining a profitable response to fertilizer application, determine the need to adjust soil pH, diagnose problems such as excessive salinity or alkalinity, provide a basis for fertilizer recommendations for a given crop production and evaluate the fertility status of soil as the basis for planning a nutrient management program.

Oilseed crops including niger (noug), linseed, mustard, sesame, groundnut and safflower are grown for paramount economic and nutritive importance in Ethiopia. These crops provide income at the household level and foreign currency to the country (Biru and Daraje, 2018). Pulse and oilseed crops are important in crop rotation to replenish soil fertility through biological nitrogen fixation in endosymbiotic association with nodule bacteria known as Rhizobium. These crops serve as break crops to a number of pests and provide sustainability to the whole farming system in Ethiopia. They are also good sources of food and feed to improve the nutritive status of the poor population who cannot afford animal products. While Ethiopia has a huge potential for growing and exporting various pulse and oilseed crops, but currently the achievements are very low because of the least share of land and input to these crops resulting in low production and productivity (Berhanu, 2009). According to CSA (2009), of the total 12,230,803 ha of land cultivated to grains in Ethiopia, the pulse and oilseed crops occupy 14.1 % and 7.6%, respectively. To keep the farming system healthy and sustainable, these crops should occupy at least 50% of the crop land as against 21.7 per cent.

To solve the problem of oil seed production, a systematic approach of scientific methods is very much required to assess the fertility status of soils through their physical, chemical and biological properties. This is a pre-requisite for designing appropriate management strategies and thereby solving many challenges that the Ethiopians are facing in the whole sector of oilseed crop production and in their efforts towards the natural resource management for sustainable development (Wakene, 2001). Only a few studies have been conducted on low land oilseed crop production in general and that of the Hakim Gara shrub land soil in particular.

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Therefore, the objective of this study was to assess the suitability of selected soil chemical properties at different altitudes and depths for low land oil seed groundnut (*Arachis hypogaea* L.) production which is major oilseed crop in Hakim Gara shrub land of Harari Region of eastern Ethiopia.

MATERIALS AND METHODS

Description of study area: HakimGara is located in Hakim District of Harari National Regional State, in the Eastern midlands of Ethiopia. The land features of the study area are relatively mountainous with good shrub land vegetation coverage. Based on the topographic features and vegetation conditions of Hakim Gara Shrub land of Hakim district is believed to represent the shrub highland areas of Harari region. Hakim Gara is found at about 1.5 km in the south eastern direction from Harar city which is the administrative city of Eastern Harerghe Zone. Harar city is about 526 km far from Addis Ababa in the north east direction of Ethiopia (Fig. 1).

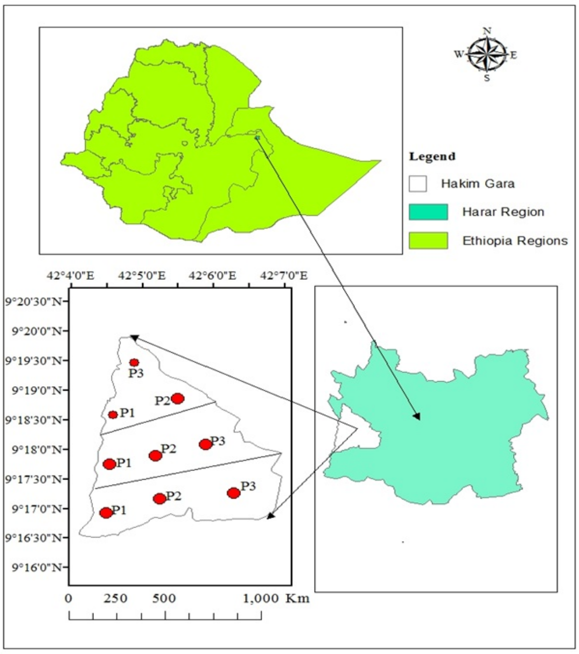

Fig. 1 Location map of the study area and soil sampling pits

Description of altitude: The altitude of Hakim Gara shrub land ranges from 2001 to 2113 meters above sea level (masl). All sampls were collected by dividing the shrub land into three altitudinal gradients namely upper, middle and lower altitude between the range from (2001 to 2033, 2033 to 2064 and 2064 to 2113 MSL, respectively). The mean annual rainfall of the area ranges from 636.7 to 917.9 mm and the mean monthly maximum and minimum temperature range from 22.6 to 28.4°C and 5.1 to 16°C, respectively. The total area of the shrub land is around 50 hectare. The dominant tree species are *Juniperus procera*, *Lantana camara* (in Barkarkate), *Canisa edulis* (Agamsa), *Olea europe, Acacia albida, Acacia synic* (Wangayo) and others are found in scattered manner. The shrub is mostly used for browsing, fire wood and also as sources of construction wood by the local people. According to the Soil Survey (2001) conducted in the region, the major soil types of the area are Arenosols, Leptosols, Luvisols, Cambisols, Nitisols, Regosols and Rendzinas. In undulating plains the dominant soil types are Nitisols, Regosols and Luvisols. While on ridges and ridge tops occupy almost half of the regions by Leptosols, Regosols and Rendzinas. The dominant soil type of the above altitude in the study area was loamy and loamy sand except few of them that have silt loam.

Soil sampling sites selection: Soil sampling sites were selected based on altitudinal gradients of the landscape and vegetation types *i.e.* tree, shrubs and herbs. The shrub land was divided into three sampling sites namely upper, middle and lower altitudinal gradients. Three soil sampling sites were selected from each altitudinal gradient. Every sampling site was geo referenced using GPS (Global Position System).

Soil sampling and preparation: Three soil profiles were opened at each slope gradient. Disturbed soil samples were collected from each profile at the depth of 0-20 cm and 20-40cm. A total of 18 soil samples were collected. The disturbed samples were air dried and crushed to pass through 2 mm sieve for determination of soil cation exchange capacity and pH. Sub samples from each disturbed soil sample were ground to the size of 0.5 mm for the determination of soil organic carbon, organic matter and nitrogen contents. All the samples were made ready for the analysis of soil chemical properties.

Analysis of soil chemical properties: The pH of soil was measured potentiometrically using a pH meter with glass electrode in the supernatant suspension of 1:2.5 (soil : water) ratio. The Kjeldahl method was followed for total nitrogen determination as described by Jackson (1958). Cation exchange capacity (CEC) of the soil was determined by the method outlined by Sahu and Mishra, 1994 by measuring the total amount of a given cation needed to replace all the cation from a soil exchange site and it was expressed in centimoles per 100 gram soil (cmol/100g soil}. While analyzing the data it was converted into cmol/kg. The organic carbon content of all samples was determined by the procedure described by Walkley and Black (1934). Organic matter content of soils is determined by converting the analytically determined organic carbon percentage to percent organic matter through arithmetic conversion (Westman *et al.*, 2006).

Statistical analysis: Statistical Package for the Social Sciences (SPSS) version 20 was used to analyze soil data by descriptive procedures and a Pearson correlation matrix.

RESULTS AND DISCUSSION

Soil reaction: Soil reaction (pH) in the study area showed increasing trends with soil depth in P1 and P3 at lower altitudes and P2 at middle altitudes. There were slight changes in the pH of soils of other sample pits with soil depth at the respective altitudes (Table 2). Soil pH values at surface layer (0-20 cm) ranged from 7.12 to 7.26. According to the rating of Benton (2003) for pH ranges, the soil reaction for surface soil at all altitudes was neutral. The pH values for subsurface (20-40 cm) soil ranged from 7.13 to 7.35, which varied from neutral to slightly alkaline reaction. The pH measured in surface/sub-surface soil varied between neutral to slightly alkaline reaction for all the soil samples in all altitudes which is most suitable for groundnut production. Therefore, the soils of the study area need not have lime to alleviate the acidity or alkalinity problem to increase the productivity of groundnut crop. Similarly, Gani *et al*. (1992) observed that soil acidity amelioration is helpful to increase groundnut production in case the pH of the soil was not suitable. Tegenu *et al*. (2008) also reported that the pH range of most productive soils varies between 5.5 and 7.5. Slattery *et al.* (1999) observed that the soil organisms grow best at neutral pH. Kumar *et al.* (2014), have observed variation in soil moisture stress and soil salinity factors to be affecting groundnut productivity. Soil pH was slightly negatively correlated with soil organic carbon ($P<0.01$). From the soil reaction point of view, soil of the study area is productive since the pH value is neutral and close to neutral that favoured conducive environment for most soil organisms.

Soil organic carbon: The recorded percent organic carbon contents of the soils decreased with soil depth in all sample pits at all altitudinal gradients (Table 2). Slight decrease in percent organic carbon contents was recorded with depth in all sampling points of lower altitude and P2 of middle altitude while a drastic change in percent organic carbon content with soil depth was recorded for soils of all sampling points of upper altitude and P1 and P3 of middle altitude. Percent organic carbon content for surface soil 0-20 cm depth in the study area ranged from 4.43 to 7.10, while its content varied from 4.03 to 5.31% for subsurface soil (20-40 cm) at the respective altitudes. According to the rating of Walkley and Black (1934), soil organic carbon content of soil of the study area was in the medium range which is good for groundnut production. Percent organic carbon was higher in the surface layer (0-20 cm) than its content in subsurface (20-40 cm). Higher soil organic carbon content in the surface soil might be due to higher clay content and rapid organic matter input which is suitable for groundnut production in the area. Similar trend was reported by Mehraj (2009) that the level of soil organic carbon was higher in the surface layer, dropping with an increase in soil depth. The reduction of soil organic carbon along depth could be linked to higher accumulation of plant debris and clay on surface soil than sub surface soil (Table 2).

With respect to altitude, there were slight differences in the percent soil organic carbon content. The results showed the increase in organic carbon from lower to middle altitude and decrease from middle to upper altitude. High soil organic carbon content at mid altitude may be due to gentle slope of the land, good management system and fertility status of the soil as compared to lower and upper altitude and also dense vegetation coverage than other altitudes. All three altitudes are suitable for groundnut crop production in the study area. When we compared among them the middle altitudes were more suitable or productive than the rest due to higher organic carbon and organic matter content. The similar findings were also reported by Ranjan *et al.* (2014). Production potential of oilseed crop is principally affected by soil-site parameters by climate, topography, fertility and management practices.

Data in Table 2 show that total nitrogen, cation exchange capacity and altitude were positively correlated with soil organic carbon. Cation exchange capacity (Table 2) were positively and significantly correlated with soil organic carbon ($P<0.01$). The recorded data in the Table 1 showed that as these parameters increased, the soil organic carbon also increased while pH and depth were negatively and significantly correlated with soil organic carbon ($P<0.01$). Similar findings have been reported by Azlan *et al.* (2012) wherein the correlation analysis indicated that soil organic matter and total nitrogen were positively correlated with total organic carbon while depth was negatively correlated with soil organic carbon.

Total nitrogen: A decreasing trend in total nitrogen (TN) was observed with soil depth in all sample pits at respective altitudes (Table 1). This decrease in total nitrogen content could be due to decrease in soil organic carbon content with depth. Relatively, higher nitrogen content in the surface (0-20 cm) is the result of accumulation of plant debris on the soil surface. Similar finding was reported by Yu and Jia (2014) that total nitrogen and soil organic carbon storage increased significantly with plantation age, but there were different changes as with soil depth. The mean was highest but most variable in the surface soil layer and dropped significantly in the subsurface soil layer. Total nitrogen concentrations peaked at (0-20 cm).

With respect to altitude, there were slight differences in the percent total nitrogen content of the soil. The results showed slight increase from lower to middle altitude and decrease from middle to upper altitude. High total nitrogen at mid altitude may be due to dense vegetation coverage and litter input than others. The decrease in total nitrogen content between altitudes might be due to low vegetation cover and less accumulation of litter due to human intervention in the area. Total nitrogen was positively and significantly (P<0.01) correlated with soil organic carbon (Table 2). Percent total nitrogen content of (0-20) cm depth in the study area was in the range of 0.13 to 0.8 which varied between low and high soil total nitrogen content according to the rating of Kjeldahl (1992). Further, for 20-40cm depth, percent total nitrogen of the study area was in the range of 0.1 to 0.5 which varied between low and medium content as per the classification.

Cation exchange capacity: As indicated in Table 1, a decreasing trend of soil cation exchange capacity was observed with increasing soil depths in all sample pits at lower, middle and upper altitude of the Hakim Gara shrub land. Cation exchange capacity was highest in the surface layer (0-20 cm) and lowest in subsurface depth (20-40 cm). The value of cation exchange capacity increase from lower to middle altitude and decreased from middle to upper altitude in the study area. This may be due to availability of relatively high organic matter and clay content in the middle altitude than other altitudes which have sand soil with low organic matter. The higher value of cation exchange capacity at the surface in the study area might be due to high decomposition of litters due to favorable environment and high organic matter input which responsible to increase the value of cation exchange capacity. Similar finding was reported by Foth (1990) and Brady and Weil (2002) who found that soils with large amounts of clay and organic matter has higher cation exchange capacity than sandy soils with low organic matter. In surface horizons of forest soils, higher organic matter and clay contents significantly contribute to the cation exchange capacity.

Cation exchange capacity of the soil for (0-20cm) depth in the study area ranged from 38.4 to 50.6 [cmol(+)/kg]. According to the rating of Hazelton and Murphy (2007) cation exchange capacity of soil of the study area was very high except P1 and P2 of lower and middle altitude which was high (Table 1). Similarly, cation exchange capacity of subsurface soil (20-40cm) depth ranged from 36.2 to 43.6 [cmol(+)/kg], which was very high except for soil of P1 at lower and P2 at both middle and upper altitudes. The recorded values of cation exchange capacity (Table 2) were positively and significantly correlated with soil organic carbon contents (P<0.01).

Soil micro organisms: There was high amount and diversity of microorganisms in the study area. This may be due to favorable environmental condition and soil pH of the study area. The amount and diversity of microorganisms of the soils indicated decreased with soil depth in all sample points at all altitudinal gradients of the study area. This coincides with results from a long-term study on litter degradation, soil microbial functional diversity (quality and quantity) which showed decrease with soil depth (Tian *et al*., 2015). Soil pH values of the study area ranged from 7.12 to 7.26 and 7.13 to 7.35 for surface and subsurface layers respectively which corresponded to neutral to slightly alkaline reaction. According to the rating of Benton (2003) for pH ranges, the soil reaction for surface soil at all altitudes was neutral. Tegenu *et al.* (2008) reported that the pH range of most productive soils was between 5.5 and 7.5. Slattery *et al.* (1999) observed that the soil organisms grew best at neutral pH.

Table 1 Selected soil chemical properties at the respective altitudes and depths

Altitude	Pit No	Depth (cm)	pH	OC (%)	OM(%)	TN (%)	CEC (cmol(+)/kg
Lower (2001-2033 masl)	P1	0-20	7.22	4.43	7.64	0.13	38.6
		20-40	7.32	4.03	6.95	0.01	36.2
	P2	0-20	7.20	5.85	10.08	0.17	46.4
		20-40	7.28	5.15	8.87	0.15	43.6
	P3	0-20	7.24	4.76	8.21	0.24	42.8
		20-40	7.30	4.52	7.79	0.21	41.0
Middle (2033-2064 masl)	P1	0-20	7.22	6.86	11.83	0.19	47.4
		20-40	7.25	4.21	7.25	0.16	41.6
	P2	0-20	7.26	4.79	8.25	0.18	38.4
		20-40	7.35	4.37	7.53	0.60	36.2
	P3	0-20	7.14	7.10	12.24	0.80	50.6
		20-40	7.27	4.94	8.52	0.30	42.6
Upper (2064-2113 mssl)	P1	0-20	7.12	5.52	9.52	0.18	42.6
		20-40	7.22	3.20	5.52	0.16	40.6
	P2	0-20	7.17	5.46	9.41	0.25	44.8
		20-40	7.14	3.32	5.72	0.23	35.2
	P3	0-20	7.15	6.47	11.15	0.52	47.2
		20-40	7.13	5.31	9.15	0.50	42.5

OC=Organic Carbon, OM=Organic Matter,TN=Total Nitrogen, CEC=Cation Exchange Capacity

Table 2 Pearson correlations (2-tailed) for dependent and independent variables

	Soil Chemical Properties					
	Altitude	Depth	pH	OC	TN	CEC
Altitude	1					
Depth	--	1				
pH	-.639	.447	1			
OC	.035	-.642**	-.396	1		
TN	.354	.134	-.367	.431	1	
CEC	.071	-.533	-.459	.873**	.445	1

OC = Organic Carbon, TN = Total Nitrogen, CEC =Cation Exchange Capacity
**Correlation is significant at the 0.01 level (2- tailed).
* Correlation is significant at the 0.05level (2- tailed).

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Physiological trait diversity for drought tolerance in Indian mustard (*Brassica juncea*) and genotypes mapping

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ABSTRACT

A set of 18 genotypes of *Brassica juncea* L. including four released cultivars (checks) were screened for various physiological traits under normal and deficit moisture in cemented blocks with three replications. Maximum SCMR (SPAD chlorophyll reading) with minimum per cent reduction under moisture stress was recorded in DRMRCI 72, 80 and 89 genotypes at 45 and 60 DAS compared to check cultivars. Higher moisture stress index (MSI), relative water content (RWC), lesser excised leaf water loss and transpiration rate were observed in DRMRCI 80, DRMRCI 89 and DRMRCI 90 genotypes under moisture stress condition. The DRMRCI 66, 72 and 89 genotypes recorded higher siliquae wall weight, siliquae number on main shoot, seed yield and YSI (yield stability index) under moisture stress compared to check cultivars. Under stress condition, seed yield showed significant and positive correlation with YSI (r=0.68), number of siliquae on main shoot (r=0.72) and RWC (r=0.46). Similarly, YSI showed significant and positive correlation with SCMR (r=0.49 at 45 and r=0.61 at 60 DAS), MSI (r=0.60), RWC (0.78), siliquae wall weight (r=0.77) and number of siliquae on main shoot (r=0.58). Based on SCMR, MSI, RWC, siliqua wall weight and number, genotypes DRMRCI 72, 80, 89 and 90 were identified as drought tolerant and may be used for breeding of drought tolerant varieties of Indian mustard.

Keywords: Drought tolerance, Genotypes, Indian mustard, Physiological traits, Seed yield, Trait diversity

Global food security is being challenged by emerging biotic and abiotic stresses under present climates world-wide (Lesk *et al.,* 2016). The major impact of climate change is noticed on rainfall frequency and its distribution which cause droughts (Lobell *et al.,* 2011) and affecting crop productivity. Plants subjected to moisture stress either due to less supply or more loss of water through transpiration (Anjum *et al.,* 2011) and substantially declines crop yield through negative effects on plant growth, physiology and reproduction (Yordanov *et al.,* 2000; Barnabas *et al.,* 2008; Praba *et al.,* 2009). Plant's capacity to withstand drought varies with its physiological, morphological and genetic variability (Duan *et al.,* 2007) and also species to species and environmental factors (Demirevska *et al.,* 2009). Reduced absorption and use of light and decreased harvest index are the major yield reducing factors under limited soil moisture supply (Earl and Davis, 2003). Drought also influence the plant nutrition due to slow microbes mediated mineralization processes (Schimel *et al.,* 2007) and availability through mass flow or diffusion (Barber, 1995) that leads to hampered plant growth, and ultimately productivity. Abiotic stress tolerance is a complex phenomenon that depends on interactive effect of different biochemical pathways that are activated/modulated in response to stress. Genetic improvement coupled with improved cultural practices is considered important in managing the abiotic stresses. In recent years, much emphasis has also been given on the development of high yielding varieties for limited soil moisture conditions through conventional or modern breeding approaches.

India, despite being the largest cultivator of oilseeds in the world, imports about 50% of domestic edible oil requirements with 11.2% share in total world import (Jat *et al.,* 2019). Indian mustard [*Brassica juncea* (L.) Czern & Coss] is the most important oilseed crop of Indian edible oil basket. However, facing challenges of abiotic stresses specially moisture stress at most of the cultivating sites where it is grown as rainfed or utera crop. Indian mustard is cultivated from tropical to subtropical and cold regions in wide array of rainfall (500-4200μmm), annual temperature (6-27°C), low water requirement (240-400μmm) and pH (4.3-8.3). Keeping in view of its wider climatic adaptability, identification of important agro-physiological traits which may contribute to drought tolerance and realizing higher yields may help plant breeders to develop new genotypes/varieties for rainfed conditions (Longenberger *et al.,* 2006; Valentovic *et al.,* 2006; Rao *et al.,* 2012; Rana and Chaudhary, 2013). Present study was undertaken to identify the drought tolerant physiological indices *vis-a-vis* genotypes of Indian mustard for moisture stress conditions which may be used in the abiotic stress breeding programme.

MATERIALS AND METHODS

Experimental details and layout: The experiment was conducted at research farm, ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur located at 77°3' E

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longitude, 27°15' N latitude and at an altitude of 178.37 meters above mean sea level under semi-arid conditions. The mean weekly maximum and minimum temperatures during the mustard growing season fluctuated between 20.8 to 40.9°C and 7.0 to 25.1°C, respectively (Fig. 1). Mean daily evaporation from 'USWB class A' pan evaporimeter ranged from 1.0 to 9.7 mm per day. Average relative humidity fluctuated between 20.4 to 57.8 percent at noon and sunshine hours from 5.9 in January to 10.3 in April. Rainfall is received in the months of October (5.3 mm) January (37.4 mm) and March (13.1 mm) during the crop season.

Experiment was laid out in cemented block of 6 × 3 m size (Fig. 2). Soil in the blocks was pulverized and mixed with farm yard manure and recommended dose of fertilizer. The seeds of 18 genotypes including 4 released cultivars were procured from ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur, Rajasthan and sown on October 17, 2016 in lines at a spacing of 30 x 20 cm in factorial randomized block design and replicated thrice.

Moisture stress was created by withholding the irrigations as per soil moisture tension. Tensiometer was calibrated with the moisture content at 100% field capacity (FC) (normal moisture) and at 50% field capacity (deficit moisture) through destructive soil sampling at various intervals. Then, tensiometer installed in the plots and irrigation was applied at the specified tensions (calibrated readings at 100% and 50% FC) created due to moisture loss in the soil (Fig. 3). Plant growth, physiological and yield observations were recorded from 5 randomly selected plants from each genotype and replication and averaged based on samples size of 15 (5 × 3). The genotypes were harvested on March 08, 2017 from each row and replication and then dried, threshed and cleaned. Siliqua wall weight was measures from 50 randomly selected siliquae of each genotype. Seeds were separated and the empty siliqua weight was measured. Siliquae number and seed yield were counted on main shoot of 5 randomly selected plants from each genotype and replication.

Physiological traits

Leaf chlorophyll content (SCMR): Leaf chlorophyll content was measured using SPAD chlorophyll meter reading (SCMR) at 45 and 60 DAS. SCMR data were recorded on top, middle and bottom leaves from five randomly selected plants of each genotype and averaged over the replications.

Excised leaf water loss (ELWL): Excised leaf water loss (ELWL) was measured on physiologically active leaves at 90 DAS. Leaves were weighed at three stages; immediately after sampling (fresh weight), after drying in an incubator at 28°C, 50% RH for 6 hours; after oven drying for 24 hours at 70°C and calculated the ELWL (Clarke, 1987) as per the formula given below.

ELWL= (Fresh weight - weight after 6 hrs. drying)/(Fresh weight - weight after 24 hrs. drying) × 100

Membrane stability index (MSI): Membrane stability index (MSI) measured on leaf strips (0.2 g) of uniform size as per standard protocol (Premachandra *et al.,* 1990; Sairam, 1994) from five randomly selected plants of each genotype and replication. Leaf strips were placed in test tubes containing 10 ml of double distilled water in two sets. Test tubes in one set were kept at 40°C in a water bath for 30 minutes and electrical conductivity was measured (C_1) using a conductivity bridge. Test tubes in the other set were incubated at 100°C in boiling water bath for 15 minutes and electrical conductivity was measured as above (C_2). The MSI was calculated using the following formula.

$$MSI = 1 - C_1 / C_2 \times 100$$

Where; C_1 = EC at 40 °C temperature for 30 minutes,
C_2 = EC at 100 °C temperature for 15 minutes

***Yield stability index (YSI)**:* Yield stability index was calculated based on seed yield under moisture stress condition compared to normal moisture from five randomly selected plants of each genotype and replication (Lewis, 1954).

YSI = (seed yield under stress /seed yield under normal condition) × 100

Relative water content (RWC): Relative water content is the appropriate measure of plant water status in terms of the physiological consequence of cellular water deficit. RWC was measured at 90 DAS on a clear sky day between 11.00 am to 12.00 pm from five randomly selected plants from each treatment. The fifth well exposed leaf of normal physiological status was used for sampling and RWC was calculated with fresh and dry weight (Barrs and Weatherley, 1962) as per the formula given below.

$$RWC\ (\%) = (FW - DW) / (TW - DW) \times 100$$

Where; FW = Fresh weight of leaf, DW = Dry weight of leaf,
TW = Turgid weight of leaf

Leaf transpiration rate: Leaf transpiration rate was measured using portable photosynthesis system (Model LI-6400, LICOR, inc. Lincoln, Nebraska USA) during 1000-1300 hours under clear sunshine conditions at 45 and 60 DAS. Measurements were taken from the fully expanded leaves on two-third above plant part randomly from 5 plants of each genotype and replication and averaged over the samples size of 15 (5×3).

Statistical analysis: To test the significance of variance in the data obtained for various characters, the analysis of variance for factorial randomized block design was adopted (Fisher, 1950). Significance of difference among the treatment effects was tested through 'F' test and least significant difference (LSD) was calculated wherever the results were found significant.

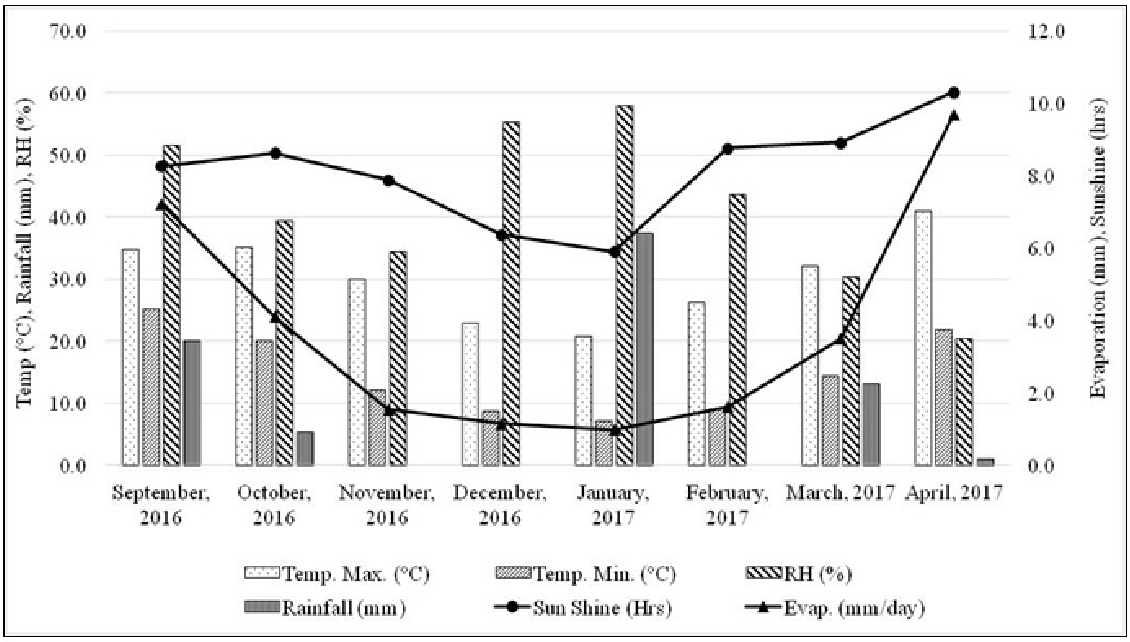

Fig. 1. Weather parameters during the crop season (2016-17)

Fig. 2. Experimental layout in cemented block with water percolation provision

Fig. 3. Tensiometer installed in the plots to measure moisture tension during the crop season

RESULTS AND DISCUSSION

Leaf chlorophyll content (SCMR): The genotypes showed significant variation in SCMR with the moisture condition and the stages of the crop (Table 1). At 45 DAS, significantly higher SCMR was recorded in DRMRCI 72, DRMRCI 89, DRMRCI 90 and DRMRCI 94 genotypes over the check cultivars (NRCDR 02, NRCHB 101, RH 749 and DRMRIJ 31) both under normal and deficit moisture conditions. The minimum per cent reduction in SCMR due to deficit moisture was recorded in DRMRCI 66 (2.8%), DRMRCI 67 (3.3%), DRMRCI 89 (2.4%) and DRMRCI 92 (2.6%) which was markedly lower than the check cultivars (>4.9%) (Fig. 4). At later growth stage of 60 DAS, the DRMRCI 71 genotype recorded markedly higher SCMR over the check cultivars under normal moisture condition, however, DRMRCI 80 and DRMRCI 89 recorded higher SCMR over check cultivars under deficit moisture condition.

Excised leaf water loss (ELWL): The per cent loss of leaf water under stress condition was estimated through ELWL index at 90 DAS (Table 2). The lower ELWL value indicates less leaf water loss under stress condition and more drought tolerance. The genotypes DRMRCI 72 (20%), DRMRCI 80 (19%) and DRMRCI 89 (18%) recorded significantly lower ELWL against the check cultivars (>23%) under normal moisture condition. Whereas, under deficit moisture condition DRMRCI 72 (21%), DRMRCI 80 (22%) and DRMRCI 94 (20%) recorded markedly lower ELWL compared to the check cultivars (>25%).

Membrane stability index (MSI): The membrane stability index showed cell membrane stability and disruption percentage at higher temperature conditions at 90 DAS (Table 2). The genotypes DRMRCI 72 (54%), DRMRCI 80 (56%), DRMRCI 89 (55%), DRMRCI 90 (58%) and DRMRCI 92 (50%) recorded significantly higher MSI over check cultivars (<47%) under normal moisture condition. Under deficit moisture, DRMRCI 72 (56%), DRMRCI 80 (58%), DRMRCI 89 (60%) and DRMRCI 90 (65%) recorded markedly higher MSI over the check cultivars (<51%).

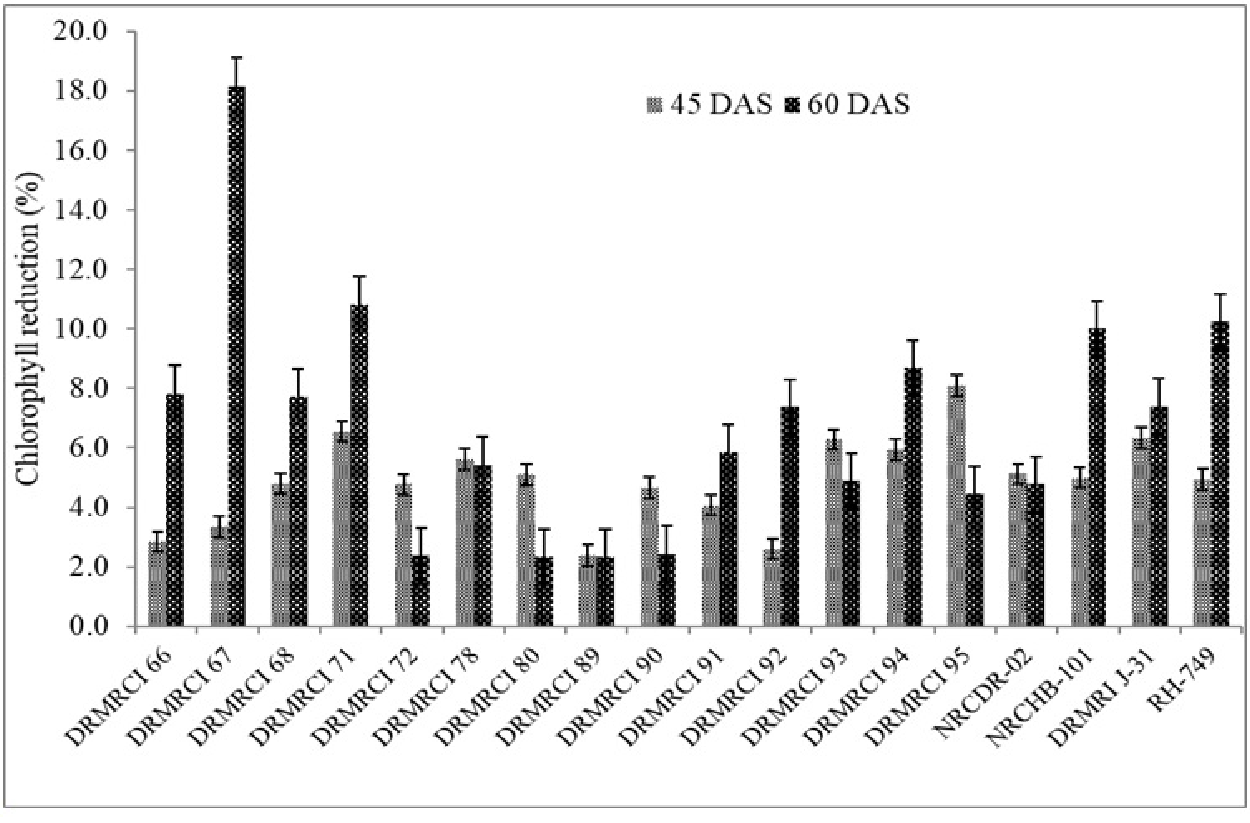

Fig. 4. Leaf chlorophyll reduction (%) due to moisture stress at 45 and 60 days after sowing

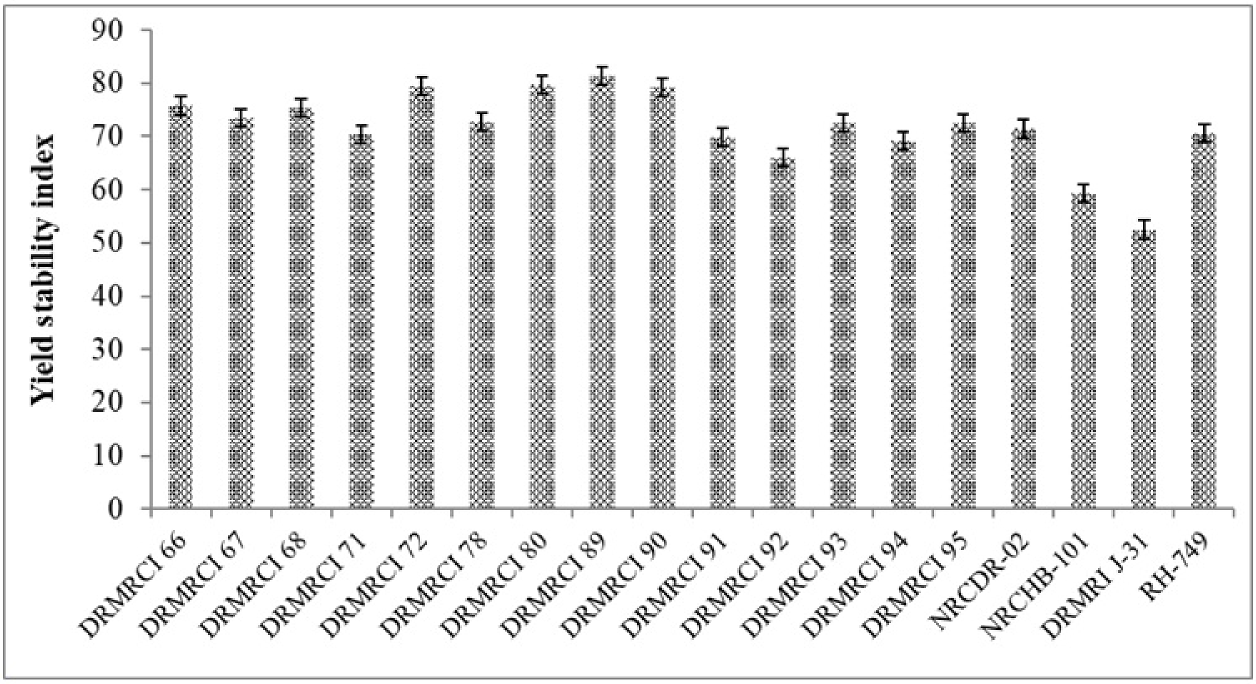

Fig. 5. Seed yield stability index of Indian mustard under moisture stress condition

Table 1 SCMR under contrasting moisture conditions at 45 and 60 days after sowing

Genotypes	45 DAS		60 DAS	
	100% FC	50% FC	100% FC	50% FC
DRMRCI 66	40	39	43	39
DRMRCI 67	38	37	43	35
DRMRCI 68	40	38	41	38
DRMRCI 71	41	38	44	39
DRMRCI 72	42	40	42	41
DRMRCI 78	40	38	38	36
DRMRCI 80	41	39	43	42
DRMRCI 89	42	41	42	41
DRMRCI 90	43	41	41	40
DRMRCI 91	40	38	39	37
DRMRCI 92	40	39	41	38
DRMRCI 93	43	40	42	40
DRMRCI 94	44	41	42	38
DRMRCI 95	41	38	42	40
Checks				
NRCDR 02	39	37	42	40
NRCHB 101	40	38	40	36
DRMRI J 31	39	37	40	37
RH 749	40	39	40	36
S.Em (±)	1.1		1.2	
LSD (P=0.05)	3.0		4.0	

SCMR: SPAD chlorophyll meter reading; DAS: Days after sowing; FC: Field capacity; LSD: Least significant difference; SEm: Standard error of mean

Table 2 Physiological traits under contrasting moisture conditions at 90 days after sowing

Genotypes	ELWL (%)		MSI (%)		RWC (%)		Transpiration rate (mmol $m^{-2}s^{-1}$)	
	100% FC	50% FC	100% FC	50% FC	100% FC	50% FC	100% FC	50% FC
DRMRCI 66	25	33	43	45	81	65	22	15
DRMRCI 67	24	25	41	43	78	71	21	17
DRMRCI 68	24	30	38	44	77	69	28	20
DRMRCI 71	27	27	48	50	82	71	24	16
DRMRCI 72	20	21	54	56	85	76	21	17
DRMRCI 78	29	33	46	54	79	72	21	14
DRMRCI 80	19	22	56	58	87	80	19	16
DRMRCI 89	18	23	55	60	91	84	19	13
DRMRCI 90	21	23	58	65	89	80	17	14
DRMRCI 91	26	28	47	51	84	73	25	16
DRMRCI 92	25	27	50	41	82	68	27	24
DRMRCI 93	24	28	49	54	81	76	23	16
DRMRCI 94	24	25	48	49	84	70	24	21
DRMRCI 95	24	26	40	43	83	74	22	17
Checks								
NRCDR 02	23	25	47	51	81	75	22	18
NRCHB 101	26	26	40	42	82	63	24	18
DRMRI J 31	28	37	44	46	85	63	22	17
RH 749	30	32	45	48	83	72	23	17
S.Em (±)	1.2		1.5		2.8		1.1	
LSD (P=0.05)	2.5		4.8		8.3		3.1	

ELWL: Excised leaf water loss; MSI: Membrane stability index; RWC: Relative water content; FC: Field capacity;
LSD: least significant difference; SEm.±: standard error of mean

Table 3 Seed wall weight, siliquae number on main shoot and seed yield of Indian mustard under contrasting moisture conditions at harvest

Genotypes	Siliquae wall weight/50 siliquae		Siliquae number on main shoot		Seed yield/5 plants (g)	
	100% FC	50% FC	100% FC	50% FC	100% FC	50% FC
DRMRCI 66	3.5	2.9	52	42	66	50
DRMRCI 67	3.7	3.4	51	38	68	50
DRMRCI 68	3.9	3.4	48	37	57	43
DRMRCI 71	3.7	3.3	50	38	58	41
DRMRCI 72	3.7	3.5	52	43	68	54
DRMRCI 78	3.8	3.4	50	39	55	40
DRMRCI 80	3.9	3.5	48	40	64	51
DRMRCI 89	3.6	3.4	49	42	59	48
DRMRCI 90	4.0	3.7	45	38	53	42
DRMRCI 91	4.1	3.5	44	34	63	44
DRMRCI 92	3.1	2.4	44	33	56	37
DRMRCI 93	3.7	3.1	50	38	57	41
DRMRCI 94	3.5	2.8	45	33	64	44
DRMRCI 95	4.1	3.4	40	31	62	45
Checks						
NRCDR 02	3.5	2.8	47	35	63	45
NRCHB 101	3.5	2.7	44	30	59	35
DRMRI J 31	3.6	2.4	52	35	67	35
RH 749	3.7	2.8	58	41	78	41
S.Em. (±)	0.1		1		3.7	
LSD (P=0.05)	0.3		3		8	

FC: Field capacity; LSD: least significant difference; SEm.±: standard error of mean

Table 4. Pearson's correlation coefficient (n=18) of seed yield and physiological traits in Indian mustard under moisture stress condition

	YSI	SCMR at 45 DAS	SCMR at 60 DAS	MSI	ELWL	Transpiration rate	RWC	siliquae wall eight	Siliquae on main shoot
Yield	0.68**	0.25	0.3	0.25	-0.33	-0.26	0.46*	0.41	0.72**
YSI		0.49*	0.61**	0.60**	-0.42	-0.4	0.78**	0.77**	0.58**
SCMR at 45 DAS			0.43	0.56*	-0.4	-0.06	0.52*	0.2	0.34
SCMR at 60 DAS				0.58**	-0.58**	-0.26	0.67**	0.39	0.24
MSI					-0.27	-0.64**	0.81**	0.59**	0.48*
ELWL						-0.13	-0.51*	-0.28	0.06
Transpiration rate							-0.47*	-0.59**	-0.50*
RWC								0.68**	0.4
Siliqua wall weight									0.32

*Significant at p=0.05; **Significant at p=0.01 and 0.05; YSI: yield stability index; SCMR: SPAD chlorophyll reading; MSI: membrane stability index; ELWL: excised leaf water loss; RWC: relative water content

Relative water content (RWC): The relative water content in a leaf was recorded at 90 DAS for identification of drought tolerant genotypes (Table 2). Significantly higher RWC was recorded in DRMRCI 89 (91%) over check cultivars NRCDR 02, NRCHB 101 and RH 749; and DRMR 90 (89%) over check cultivar NRCDR 02 and none of the genotypes recorded higher RWC over check cultivar DRMRIJ 31 under normal moisture condition. Under deficit moisture, the higher RWC was recorded in DRMRCI 80 (80%), DRMRCI 89 (84%) and DRMRCI 90 (80%) over check cultivars NRCDR 02 (75%), NRCHB 101 (63%), DRMRIJ 31 (63%) and RH 749 (72%).

Rate of leaf transpiration: Lower transpiration rate is a desirable character under moisture stress condition (Table 2). At 90 DAS, significantly lower transpiration rate was recorded in DRMRCI 80 (19%), DRMRCI 89 (19%) and DRMRCI 90 (17%) compared to check cultivars (>22%) under normal moisture condition. Under deficit moisture, DRMRCI 78 (14%), DRMRCI 89 (13%) and DRMRCI 90 (14%) recorded markedly lower transpiration rate compared to the check cultivars (≥17%).

Siliquae wall weight: Siliquae wall weight recorded at harvest indicates the wall thickness and symbolize to drought tolerance (Table 3). The genotypes DRMRCI 90 (4.0 g/50 siliquae), DRMRCI 91 (4.1 g/50 siliquae) and DRMRCI 95 (4.1 g/50 siliquae) recorded significantly higher siliquae wall weight over the check cultivars (<3.7/50 siliquae) under normal moisture condition. Under deficit moisture, genotype DRMRCI 67 (3.4 g/50 siliquae), DRMRCI 68 (3.4 g/50 siliquae), DRMRCI 71 (3.3 g/50 siliquae), DRMRCI 72 (3.5 g/50 siliquae), DRMRCI 78 (3.4 g/50 siliquae), DRMRCI 80 (3.5 g/50 siliquae), DRMRCI 89 (3.4 g/50 siliquae), DRMRCI 90 (3.7 g/50 siliquae), DRMRCI 91 (3.5 g/50 siliquae), DRMRCI 93 (3.1 g/50 siliquae) and DRMRCI 95 (3.4 g/50 siliquae) recorded markedly higher siliquae wall weight compared to check cultivars (<2.8 g/50 siliquae).

Number of siliquae on main shoot: Number of siliquae on main shoot was recorded at harvest and found markedly higher in DRMRCI 66 (52), DRMRCI 67 (51), DRMRCI 71 (50), DRMRCI 72 (52), DRMRCI 78 (50), and DRMRCI 93 (50) compared to check cultivars NRCDR 02 (47) and NRCHB 101 (44) under normal moisture condition, remained on par with check cultivars DRMRIJ 31 and RH 749 (Table 3). Under deficit moisture, the genotype DRMRCI 66 (42), DRMRCI 67 (38), DRMRCI 68 (37), DRMRCI 71 (38), DRMRCI 72 (43), DRMRCI 78 (39), DRMRCI 80 (40), DRMRCI 89(42), DRMRCI 90 (38) and DRMRCI 93 (38) recorded significantly higher number of siliquae on main shoot compared to check cultivars NRCDR 02 (35), NRCHB 101 (30) and DRMRIJ 31 (35), however, not improved markedly over check cultivar RH 749 (41).

Seed yield: Under normal moisture condition, none of the genotypes recorded significantly higher seed yield over check cultivars NRCDR 02 (63 g/5 plants) and NRCHB 101 (59g/5 plants). Other two checks were on par with these cultivars (Table 3). Whereas, under deficit moisture, the genotype DRMRCI 66 (50 g/5 plants), DRMRCI 67 (50 g/5 plants), DRMRCI 72 (54 g/5 plants) and DRMRCI 80 (51 g/5 plants) recorded markedly higher seed yield over check cultivars (<45 g/5 plants).

Yield stability index (YSI): The yield stability index or stress intensity represents the per cent of seed yield under moisture stress condition compared to normal moisture condition in a given environment. The maximum YSI was recorded in DRMRCI 66 (76%), DRMRCI 67 (74%), DRMRCI 68 (75%), DRMRCI 72 (79%), DRMRCI 78 (73%), DRMRCI 80 (80%), DRMRCI 89 (81%), DRMRCI

90 (79%), DRMRCI 93 (73%) and DRMRCI 95 (73%) under deficit moisture condition compared to check cultivars (<71%) (Fig. 5).

Relationship between physiological traits and seed yield: Pearson's multiple correlation was performed to identify the significant relationship (p=0.01/0.05) between seed yield and different physiological traits under moisture stress condition in Indian mustard (Table 4). The seed yield showed significant and positive correlation with yield stability index (r=0.68), RWC (r=0.46) and number of siliquae on main shoot (r=0.72). The yield stability index had significant and positive correlation with SCMR, MSI (r=0.60), RWC (0.78), siliquae wall weight (r=0.77) and number of siliquae on main shoot (r=0.58). SCMR also significantly correlated with MSI and RWC. Under moisture stress, the MSI had positive relationship with RWC, siliquae number and wall thickness. Excised leaf water loss and transpiration rate had negative correlation with all the traits which indicated that increased ELWL and transpiration rate decrease the seed yield under moisture stress. RWC showed significant and positive relationship with seed yield, YSI and SCMR content and MSI, however, negatively correlated with ELWL and transpiration rate. The siliquae wall weight had significant and positive correlation with YSI, MSI and RWC (r=0.68), and negatively correlated with transpiration rate (r=-0.59). Similarly, number of siliquae on main shoot had significant and positive relationship with seed yield, YSI and MSI (r=0.48). The multiple correlations showed that SCMR, MSI, RWC, siliquae wall weight and siliquae number on main shoot had direct relationship with YSI and seed yield under moisture stress condition and represent as indicators of drought tolerance in Indian mustard.

The reduction in seed yield of rapeseed under moisture stress condition was reported by many researchers (Tohidi-Moghaddam *et al.,* 2011; Bitarafan and Shirami Rad, 2012). The physiological traits like; SCMR, membrane stability index, excised leaf water loss, leaf transpiration rate, relative water content and siliquae wall weight markedly varied in genotypes of Indian mustard under different levels of moisture, and ultimately influenced the yield stability index and seed yield. The higher values for these traits were recorded under normal moisture content which might be due to better soil and environmental condition for physiological and biochemical processes (Sanchez-Blanco *et al.,* 2002) and better nutrient availability (Rao *et al.*, 2012). However, the purpose of the study was to identify the traits which were comparatively stable and contribute to seed yield under moisture stress conditions. Earlier studies showed that rainfed conditions caused significant reduction in dry matter accumulation, chlorophyll content, relative water content, yield and oil content over irrigated condition in Indian mustard (Lallu and Kumar, 2012). The traits response to moisture stress were studied in the present investigation and found that higher SCMR with less per cent reduction, higher MSI, less ELWL, less transpiration rate, higher RWC and higher silique number and wall weight significantly contributed to seed yield of Indian mustard under moisture stress condition. The genotypes DRMRCI 72, DRMRCI 80, DRMRCI 89 and DRMRCI 90 showed higher SCMR with less reduction, higher MSI, RWC, YSI and siliquae wall weight, and less ELWL and transpiration rate and identified as drought tolerant. SCMR both at 45 and 60 DAS showed significant and positive correlation with the yield stability index. Moisture stress causes reduction in leaf chlorophyll content (Paknejad *et al.,* 2007; Sun *et al.,* 2011), damage the chlorophyll and thylakoid membranes (Anjum *et al.,* 2011), and change the ratio of chlorophyll 'a', 'b' and carotenoids (Anjum *et al.,* 2003; Farooq *et al.,* 2009). Therefore, for better yields under moisture stress, higher chlorophyll content might contribute to higher plant productivity (Rao *et al.,* 2012). The MSI showed positive and significant relationship with YSI and SCMR and consequently the seed yield. Higher the ELWL, lower the leaf water content and negatively correlated with SCMR, RWC, seed yield and YSI. Thus, less ELWL is desirable to maintain the leaf water potential and physiological functions which contribute to seed yield. Similarly, the rate of transpiration is also crucial in terms of leaf water loss as it influence the plant water use efficiency, and thereby seed yield in Indian mustard (Singh *et al.,* 2008). In the present study, the leaf transpiration rate was negatively correlated with MSI, RWC, siliquae wall weight and number of siliquae on main shoot. Relative leaf water content is an important physiological attribute which determines the tolerance of plants to drought stress (Sanchez-Blanco *et al.,* 2002) as it indicates the leaf water content and photosynthetic rate (Kumar *et al.,* 2011) and water potential of plants (Ober *et al.,* 2005). Siliquae wall weight is also an important trait having significant and positive correlation with YSI, MSI and RWC, whereas, negatively correlated with transpiration rate. Thus, increase in siliquae wall weight increased seed yield and membrane stability indices, retained more leaf water, decreased leaf transpiration rate and contribute to seed yield under moisture stress. There was differential response of genotypes to the seed yield and yield stability indexes. Seed yield may be less but the yield stability index was more in the genotypes having more chlorophyll content, MSI, RWC, siliquae number and wall weight, less ELWL and leaf transpiration rate and expressed significant correlation. It was also observed that seed yield of Indian mustard was significantly correlated with yield stability index, RWC and silique number on main shoot. Thus, the genotypes having more values of SCMR, MSI, RWC, siliquae number and wall weight and less ELWL and leaf transpiration were directly contributing to either yield stability or seed yield and may be used as indices for screening of large number of genotypes of Indian mustard for drought tolerance.

Thus, a good understanding of the physiological traits limiting yield provides an opportunity to the breeders to identify and select genotypes which are drought tolerant and produce higher yield under moisture stress conditions. Traits like SCMR, MSI, ELWL, transpiration rate, RWC, siliquae number and wall weight were identified as indices for screening genotypes of Indian mustard for drought tolerance. Based on this criterion, DRMRCI 72, DRMRCI 80, DRMRCI 89 and DRMRCI 90 genotypes were identified as drought tolerant in the present study which may be used to develop new cultivars with high yield potential and high yield stability under moisture stress environments.

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Growth and instability in edible oilseeds in India: A temporal analysis

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ABSTRACT

In the field crops section, oilseeds are the second most significant crop after the cereals making them a vital determinant of the agrarian economy. India is one of the leading producer nations of oilseeds globally, but domestic production of edible oil fails to match the rising demands, leading to a considerable rise in the edible oil imports over time. India imports 60 per cent of its annual edible oil requirement. The rich agro-ecological diversity of India is suitable to grow a variety of oilseeds. Once an oil-exporting nation, India has now turned to be an oil-importer country majorly due to widened demand-supply gap, with low productivity being the prime cause for the mismatch. This paper is envisioned to study the growth and instability pattern of edible oilseeds from 1970-71 to 2017-18. Area observed a declining trend, whereas production showed little growth due to low productivity. Soybean observed the highest growth among seven edible oilseeds. Sunflower showed the highest instability index followed by safflower. Period I exhibited the highest instability, which reduced in further periods as a result of the launch of various oilseed development schemes. Yield effect was the chief contributor to the growth in production of rapeseed-mustard, groundnut, and sesame, whereas area effect boosted the production of soybean, sunflower, safflower, and niger.

Keywords: CAGR, Decomposition, Edible Oilseeds, India, Instability

The Indian oilseed sector holds a significant place in the global oilseed map. Oilseeds are the second-most prominent crop in Indian agriculture and India is the fourth largest oilseed producing nation, but at the same time, it is the largest importer of vegetable oils (NFSM, 2018). India's edible oil imports are the second largest after crude oil; the country approximately spends over Rs. 70,000 crores to import about 15 million tons of edible oil for meeting the annual demand of 25 million tons (DAC&FW, 2019). Imports of soft oils account for 40% of the total edible vegetable oil imports whereas, the palm oil accounts for 60% of the total imports (SEAI, 2019). India's huge imports account for 60% of the nation's annual edible oil requirement, the primary cause for the substantial increase is the gap between the domestic demand and supply (Jha *et al.*, 2012).The per capita consumption of oilseeds rose from 3 kg per annum in 1950 (Hegde, 2012) to 18kg per annum in 2017-18 (NFSM, 2018), which is nearly 6 times. As the demand for edible oils is highly income and price elastic rising income levels and changing food habits of the rising population led to sky-rocketing demands (Srinivasan, 2005). India's self-sufficiency in food grain production has resulted in heaps of surplus rice and wheat stocks but faces a major shortage of oilseeds (Govindaraj *et al.*, 2016). Oilseeds in comparison to cereals and other crops are low yielding crops in India because the majority of the oilseeds (70%) are cultivated under rain-fed ecosystems. Oilseeds accounts for 13% of the Gross Cropped Area, 3% of the Gross National Product and 10% value of all agricultural commodities (Kumar *et al.*, 2020; Rao *et al.*, 2020). Oilseeds in India are grown over an area of 24.5 million ha, producing 31.5 million tons of the crop with a productivity of 1284 kg/ha. Majorly nine oilseeds are grown across different agro-climatic zones of the country, out of these seven are edible oilseeds namely- rapeseed-mustard, groundnut, soybean, sesame, sunflower, safflower and niger and two are non-edible oilseeds namely-castor and linseed. Rapeseed-mustard (27%), groundnut (27%) and, soybean (34%) account for more than 80% of the total oilseed production. From the initial years of independence till mid-sixties India was self-sufficient in edible oil and was also the exporter. Stagnant production and low productivity led to less supply in comparison to rising demands created a demand-supply gap in the 1970s (ICFA, 2018). To ease the supply chain, enhancement in production was initiated by the launch of various technological development programs over different periods. They were (i) AICRP on oilseeds (1967), (ii) Oilseed Growers Co-operative Project (1978), (iii) Technology Mission on Oilseeds (1986) later restructured as Integrated Scheme of Oilseeds, Pulses, Oilpalm and Maize (ISOPOM) (2004), (iv) Yellow Revolution (1986-87), and, (v) National Mission on Oilseeds and Oil Palm (NMOOP) (2014-15). The oilseed scenario in India had a very fluctuating trend from net exporter in the 1960s to a net importer in the 1980s, then again it became a net exporter in the 1990s and finally returning to net importer status again at present times. This pattern urges the need to study the growth pattern of oilseeds in India. This paper attempts to study the growth and instability in the area, production, and productivity of major edible oilseeds in India.

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MATERIALS AND METHODS

The study analyzed time series data of three variables-area, production, and productivity for the major seven edible oilseeds in India. The data is secondary and was collected from various publications *viz.*, Directorate of Economics and Statistics, Ministry of Agriculture and Farmers' Welfare, Government of India, Agriculture Statistics at a glance, and websites *viz.*, www.indiaagristat.com; www.agricoop.nic.in and www.dor-icar.org. The overall period taken for the study was from 1970-71 to 2017-18, which was further divided into five sub periods: sub period-I (1970-71 to 1979-80), sub period-II (1980-81 to 1989-90), sub period-III (1990-91 to 1999-00), sub period-IV (2000-01 to 2009-10) and sub period-V (2010-11 to 2017-18).

Compound annual growth rate: To estimate compound annual growth rate (CAGR) the exponential time trend equation was applied, in the functional form

$Y= A\ (1+r)^{t}$

Where,
Y= Time series data of area, production or yield of different edible oilseeds - for which growth rate is calculated,
A= Constant coefficient
r = Rate of annual increment or annual growth rate
t = time element

Using the compound formula, the linear form of the model was obtained by taking logarithms to base 'e'.

$\ln Y = \ln A + t \ln(1+r)$
or
$\ln Y = a + bt$
or
$r = [\text{antilog } b - 1] \times 100$

The values of compound growth rates obtained were also tested for their significance using the student 't' test.

Instability analysis: Instability is the deviation from the trend. The instability in area, production and productivity of oilseed was measured by Cuddy Della Valle Index (%) (Cuddy and Della Valle 1978) using the formula

Instability index = $CV\sqrt{(1-R^2)}$

Where,
CV= Co-efficient of variation [CV = (SD / MEAN) x 100]
R^2 = Adjusted coefficient of determination from a time-trend regression.

Decomposition analysis: Decomposition analysis was done to estimate the contribution of area, productivity and their interaction effect towards production of oilseeds.

$$\underbrace{\Delta P}_{\text{Change in production}} = \underbrace{A_0\,\Delta Y}_{\text{Yield effect}} + \underbrace{Y_0\Delta A}_{\text{Area effect}} + \underbrace{\Delta A\,\Delta Y}_{\text{Interaction effect}}$$

Where,
ΔP = Change in production
A_0 = Area in the base year
Y_0 = Production in base year
ΔA =Change in the area
ΔY = Change in yield.
$\Delta A \Delta Y$ = Interaction effect of area and yield

In the present study, the triennium average of area, production, and productivity were worked out for the five sub-periods and overall period to analyze the effect of area and yield on production.

RESULTS AND DISCUSSION

Trends in the area, production, and productivity of edible oilseeds: Growth analysis of area, production, and productivity of edible oilseeds in India is presented in table 1. All the oilseed crops observed significant growth in area, production, and yield. Almost all the crops except safflower showed an increasing trend in production and yield for the overall study period. Out of seven, four crops namely groundnut, sesame, safflower, and niger observed a negative growth rate for the overall period. Soybean noticed the highest overall growth rate in area (12.8%) and production (14.9%) respectively. Following soybean, rapeseed-mustard (3%), sunflower (2.3%), and groundnut (0.9%) observed high growth rates in production consecutively. Area under soybean, rapeseed-mustard, and sunflower cultivation expanded from 1970-71 to 2017-18 at the rate of 12.8%, 1.2%, and 1.9% respectively. Yield as compared to area and production showed a positive and increasing trend for all the oilseeds for the overall period.

In sub-period I, the majority of crops showed decreasing trend except for soybean, which indicated that India had to import edible oils to meet the demand of the increasing population. In the decade, where the majority of the crops observed negative growth rate, safflower observed positive growth rate which may be due to the government scheme AICRP-safflower launched in 1967.

In sub-period II, an increasing trend was exhibited by all the oilseeds. Government's initiative to boost oilseed production and improve productivity by dissemination of improved technology under schemes such as Oilseed Growers Co-operative Project and Technology Mission on Oilseeds resulted in positive growth in all the crops. Sunflower (25%) and soybean (15%) had been the major gainers of the schemes as their production increased, and area increased at rates of 26% and 14% respectively. In sesame though the area under cultivation continued to decrease (-0.35%), the production increased (5.26%) due to improvement in productivity of the crop. From sub-period III, it can be deduced that only rapeseed-mustard and soybean were the two major gainer crops as rest of the oilseeds witnessed negative growth. This trend may be due to substitution of these crops with soybean and rapeseed-mustard, evident from the increase in area under soybean cultivation from 2.5 million ha to 6.2 million ha and area under mustard increased from 5.7million ha to 6 million ha. The t-test showed that soybean, groundnut, sesame, and niger observed significant growth. In sub-period IV, the restructured scheme ISOPOM resulted in the positive growth of the majority of oilseeds. Rapeseed-Mustard was the most benefitted crop from the scheme as production increase from 4.1 million tons to 6.6 million tons. Droughts in the initial years i.e. 2001-02 and 2002-03 may have been the reason for the slow growth and negative growth of the majority of the oilseeds.

Sub-period V witnessed either slow or negative growth rates which may be the major reason for the tremendous increase in imports of edible oils. Sunflower emerged as the biggest loser of the decade with the highest negative growth rate in area (-13.8%) and production (-12.6%). Productivity of all the oilseed crops is low indicating it to be the major cause for the increased demand-supply gap of edible oils.

There have been some similar analysis done in oilseeds sector though not comprehensive as presented here (Kaushik, 1993; Chand and Raju, 2009; Sonnad *et al.,* 2011; Teja *et al.,* 2017; Sharma, 2018; Rao *et al.,* 2020; Kumar *et al.,* 2020).

Instability in the area, production, and productivity of edible oilseeds: The instability analysis of the area, production, and yield of edible oilseeds in India (Table 2) showed that for the overall period rapeseed-mustard, soybean, groundnut, and sesame, area was more stable than production and yield, while in the case of sunflower, safflower and niger yield showed more stability as compared to the rest two. Highest instability in production was observed by sunflower (63.2%) followed by safflower (49.3%) and soybean (30.8%).

In sub-period-I, the area was the most stable variable for all oilseeds except sunflower where yield was comparatively more stable. Soybean showed maximum variation both in the area (57%), production (76%) and yield (25.9%) followed by sunflower (46% and 55% respectively). The study of sub-period-II reveals that production continues to be the most unstable variable. The instability index ranged from 27% (Sunflower) to 13% (niger) in production.

In period III, the instability in area and production was less when compared to its previous period. Niger and soybean emerged as the most stable crops of the study decade. Followed by safflower, the sunflower was the second most unstable crop with 19.2% and 17.7% instability index in area and production respectively. In sub-period IV, high instability index for all three variables was observed. Groundnut and rapeseed-mustard are the most unstable crops of this period with instability index 24.5% and 19.2% respectively, whereas sunflower continued to show high variation, with instability in production increasing to 24%. The crops that noticed high instability in yield were groundnut (23.5%), safflower (16.6%), sesame (15.7%), and soybean (13%). Sub-period-V comparatively exhibited lesser fluctuation than period IV and III.

Estimation of the effect of yield, area, and interaction on the production of edible oilseeds: The contribution of yield and area to the total production of all the oilseeds were analyzed using decomposition analysis presented in Table 3 revealed that in rapeseed-mustard, yield effect (45.1%) was the major contributor for the overall period. For sub-period I, II and V yield effect and for sub-period III and IV led to a rise in rapeseed-mustard production. Area effect (56.1%) contributed the most to soybean production for the whole study period. For periods I, III, and IV the key contributor was area effect, while for periods II and V it was yield effect. In groundnut, yield (254%) was the sole contributor to growth in production for the overall period. Except for sub-period III, yield effect was the chief contributor, whereas in period III area effect (200%) led to growth in production. The overall growth in sesame production was attributed to yield effect (189%). In period III, IV and V area was the chief contributor, whereas for sub-period I and II yield effect was the prime reason for production enhancement. The sunflower production for the overall period as well as for the sub-periods was majorly due to area effect. The interaction effect was the prime contributor to the overall growth of safflower production. For period II, III, IV, and V area was major contributor and for the period I yield was the chief contributor. Area effect led to growth in niger production for the whole period and sub-periods I, III, IV, and V.

Overall, out analysis indicated that the growth pattern of edible oilseeds was erratic. The area under the cultivation of the majority of oilseeds decreased during the overall period. Production of edible oilseeds showed meager growth due to low productivity. Sunflower showed the highest instability index followed by safflower. Period I was the least stable sub-period due to widened demand-supply gap, the launch of development schemes for oilseeds in latter sub-periods resulted in instability reduction. Yield effect was the chief contributor to the growth in the production of rapeseed-mustard, groundnut, and sesame. For the crops soybean, sunflower, safflower, and niger area played a key role in the enhancement of production. India is a land of diverse agro-ecological areas appropriate for the growth of oilseeds. Cultivation of oil crops is less labor-augmenting, thus these crops can be managed in labour scarce areas. To meet the rising edible oil demands, the cultivation of oilseeds is very economical and remunerative for Indian farmers leading to the socio-economic upliftment of the farmers as well as lessen the demand-supply gap leading to a reduction in edible oil imports. The latest oilseed development programs such as NMOOP should be implemented more widely, with more focus on small and marginal farmers. Improved extension services such as cluster frontline demonstrations about new and improved seeds, planting techniques, etc. could provide farmers with better insight into such schemes.

Table 1 Compound annual growth rate of area, production and yield of edible oilseeds in India (Per cent)

Oilseed crop	Particulars	Overall period	I (1970-71 to 1979-80)	II (1980-81 to 1989-90)	III (1990-91 to 1999-00)	IV (2000-01 to 2009-10)	V (2010-11 to 2017-18)
	Area	1.23**	0.43	1.90	0.42	2.24	-1.78
Rapeseed-Mustard	Production	3.07**	-3.20	6.00**	1.02	4.66*	0.38
	Productivity	1.82**	-3.62	4.01**	0.61	2.37*	2.20
	Area	12.79**	31.53**	13.99**	9.27**	4.26**	0.92
Soybean	Production	14.88**	35.02**	15.11**	10.53**	6.57**	-1.89
	Productivity	1.91**	2.92	0.96**	1.15**	2.22**	-2.79
	Area	-0.84**	-0.22	2.50	-1.89**	-1.78	-2.23
Groundnut	Production	0.87**	-0.58	4.93	-3.52**	-1.65	1.13
	Productivity	1.72**	-0.35	2.37	-1.67**	6.48	2.98
	Area	-0.90**	-0.23	-0.35	-4.67**	1.22*	-3.40
Sesame	Production	0.62**	-4.68	5.26	-5.39**	1.28	-2.08
	Productivity	1.53**	-4.48	5.65*	-0.75	0.07	1.36
	Area	1.86**	-6.31	25.91**	-2.35	3.24	-13.77**
Sunflower	Production	2.26**	-8.29	25.33**	-2.27	2.79	-12.58**
	Productivity	0.38*	-2.27**	-0.48	0.06	-0.44	1.38
	Area	-2.86**	1.94*	1.08*	-6.28	-3.90**	-8.30**
Safflower	Production	-0.86*	3.94*	4.74	-6.83	-3.14	-7.74**
	Productivity	2.06**	1.94	3.66	-0.59	0.80	0.59
	Area	-0.90**	1.79**	0.38	-1.91**	-1.56*	-6.43**
Niger	Production	0.62**	-1.96	2.51	-2.26*	-1.21	-5.28**
	Productivity	1.53**	-3.59	2.09	-0.40	0.34	1.28

** at 1% significance level, *at 5% significance level

Table 2 Instability analysis of area, production, and productivity of edible oilseeds in India (Per cent)

Oilseed crop	Particulars	Overall period	I (1970-71 to 1979-80)	II (1980-81 to 1989-90)	III (1990-91 to 1999-00)	IV (2000-01 to 2009-10)	V (2010-11 to 2017-18)
	Area	15.37	5.17	8.91	5.55	16.13	6.03
Rapeseed-Mustard	Production	18.57	15.18	17.19	10.78	19.26	11.71
	Productivity	10.46	14.72	8.05	11.98	7.98	7.48
	Area	17.74	56.92	10.43	5.28	4.87	6.48
Soybean	Production	30.83	76.13	20.52	9.02	11.90	15.37
	Productivity	18.07	25.90	14.02	8.85	13.06	16.69
	Area	11.44	2.72	7.71	2.83	6.58	8.10
Groundnut	Production	19.46	13.64	20.32	13.86	24.54	21.77
	Productivity	19.29	12.36	14.08	13.59	23.53	17.14
	Area	10.10	3.85	7.60	6.42	6.14	7.72
Sesame	Production	16.32	15.45	14.50	10.45	16.77	9.43
	Productivity	12.20	14.34	11.15	10.88	15.70	4.61
	Area	64.95	45.94	27.00	17.73	23.03	9.16
Sunflower	Production	63.19	55.00	26.93	19.20	24.10	9.72
	Productivity	16.78	8.26	16.03	8.23	12.95	8.74
	Area	30.66	10.48	8.99	17.29	4.97	9.62
Safflower	Production	49.29	21.44	17.91	37.32	19.03	15.59
	Productivity	21.91	16.44	18.49	29.52	16.60	13.64
	Area	15.50	7.09	6.51	3.32	6.05	8.04
Niger	Production	23.53	16.04	13.88	9.56	11.31	8.18
	Productivity	11.25	11.31	10.15	7.84	7.92	6.71

Table 3 Decomposition analysis of area, production, and productivity of edible oilseeds in India (Percent)

Oilseed crop	Particulars	Overall period	I (1970-71 to 1979-80)	II (1980-81 to 1989-90)	III (1990-91 to 1999-00)	IV (2000-01 to 2009-10)	V (2010-11 to 2017-18)
	Yield effect	45.19	150.35	67.04	-115.11	38.52	630.82
Rapeseed-Mustard	Area effect	21.59	-55.37	22.26	221.65	51.60	-486.01
	Interaction effect	33.22	5.01	10.69	-6.54	9.89	-44.81
	Yield effect	0.13	3.44	57.07	17.23	32.39	137.53
Soybean	Area effect	56.13	64.98	35.91	66.21	51.71	-49.08
	Interaction effect	43.74	31.58	7.02	16.56	15.90	11.55
	Yield effect	254.45	109.53	57.07	-118.65	112.95	142.31
Groundnut	Area effect	-72.81	-8.52	35.91	200.76	-8.14	-33.17
	Interaction effect	-81.64	-1.00	7.02	17.90	-4.81	-9.15
	Yield effect	189.80	160.38	125.69	-6.83	24.95	-808.48
Sesame	Area effect	-38.70	-61.21	-19.65	104.53	71.36	838.44
	Interaction effect	-51.10	0.83	-6.04	2.29	3.69	70.04
	Yield effect	1.91	-104.60	-9.37	19.26	28.85	1.08
Sunflower	Area effect	93.74	252.88	142.93	83.96	61.44	99.50
	Interaction effect	4.35	-48.28	-33.56	-3.22	9.70	-0.58
	Yield effect	-263.31	49.40	-14.48	-2.46	-606.78	25.77
Safflower	Area effect	166.50	41.45	118.26	102.01	574.70	85.30
	Interaction effect	196.81	9.15	-3.78	0.45	132.07	-11.07
	Yield effect	-115.80	-23.61	56.60	22.67	-5228.93	-28.40
Niger	Area effect	157.98	129.39	37.51	80.60	4720.45	119.73
	Interaction effect	57.82	-5.78	5.89	-3.27	608.47	8.67

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Changes in agricultural scenario of Madhya Pradesh with special reference to soybean in changed climatic scenario: A study on farmers' perception

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ABSTRACT

This study examined soybean growers' perception about climate change and variability, and their adaptation strategies in response to the perceived impacts of climate change. The multi-stage sampling method was employed to select 280 rural farmers in Dewas, Indore and Dhar districts located in Malwa plateau and Nimar valley of Madhya Pradesh. The results revealed that the crop diversification is lost over a period of time and monocropping of soybean became popular in the study area. The introduction of soybean was found to be instrumental for enhancement in the cropping intensity of the area. Among abiotic weather-related stresses perceived by majority of farmers were delayed arrival of monsoon, uneven and erratic rainfall, reduced number of rainy days, increased temperature and sunshine hours, and the reduced humidity. Majority of farmers perceived a decrease in annual rainfall. They also perceived that the biotic stresses (weeds, insects and diseases) had increased significantly over a period of time. All these factors were responsible for low yields. Survey also indicated that the mechanization increased substantially, and short duration varieties replaced the long duration soybean varieties. To reduce the perceived impacts of climate change, farmers adopted various farm-level adaptation strategies. The results of this study will provide baseline information for local governments, researchers, and policy-makers on farmers' perception of climate change and adaptation strategies.

Keywords: Soybean, Climate change, Madhya Pradesh, Farmers' perception, Central India

Madhya Pradesh is also known as 'Soy State' as it occupies premier position in soybean production with more than 50% share in area and production of soybean in the country. Soybean is a *numero uno* crop as far as its commercial cultivation in Madhya Pradesh is concerned. Historically the research and development work on soybean for its trials and introduction was initiated at the end of 18th century (Dupare *et al.*, 2008). However, the commercial cultivation of soybean in the Malwa Plateau of Central India gained momentum after 1980s consequent to development of high yielding yellow seeded soybean varieties. The Indian Council of Agricultural Research (ICAR) initiated an All India Coordinated Research Project on Soybean (AICRPS) way back in 1967 initially from IARI, New Delhi and later on shifted to Govind Ballabh Pant University of Agriculture and Technology (GBPUA&T), Pantnagar. More AICRPS centers were subsequently added to explore the feasibility of introducing soybean at various locations. The Jawaharlal Nehru Krishi Vishwa Vidyalay (JNKVV) has done remarkable work for development and dissemination of technologies as well as package of practices right from its inception and witnessed the whole journey of introduction as well as commercial cultivation of soybean by the farmers of Madhya Pradesh. The university is credited with more than 70% of the soybean varieties developed in the country since the inception of AICRPS.

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Madhya Pradesh having vast geographical area has been a producer of various crops including cereals, pulses, oilseeds, cotton, fruits, vegetables, etc. since last 5-6 decades. Earlier reports suggest that before the introduction and popularity of soybean, major crops in Malwa region were pearl millet, sorghum, maize, green gram, black gram, sugarcane, pigeon pea, sesame, linseed, etc. during *kharif* season, and wheat and gram during *rabi* season. According to Chand (2007), soybean was introduced in Madhya Pradesh to occupy *kharif* season fallow lands kept for preserving moisture for *rabi* crops. Such fallow lands were also available in Maharashtra state. Introduction of short duration, new varieties of soybean did not affect the sowing time of the second crop (*rabi* crop). However, currently this scenario has changed rapidly with fast expansion of area under soybean for the past five decades. The soybean has established as a major *kharif* crop in the vast fallow lands available in the region (Verma and Singh, 2017), looking at its suitability in black cotton soils and its promotion initially by Oilseed Federation consequent to the successful work of varietal development programme carried out under AICRP on soybean (Dupare *et al.,* 2008).

With the concerted efforts of soybean research system, farmers, extension workers as well as Oilseed Federation and soybean-based industries, which ensured remunerative prices for soybean, soybean established as a popular *kharif* crop of Central India. Eventually, the crop in addition to occupying fallow lands replaced other less profitable *kharif* crops like sorghum, pearl millet, green gram, black gram and minor millets (Birthal *et al.,* 2010; Sharma *et al.,* 2015; Sharma, 2016). The Malwa region of Madhya Pradesh has been the epicenter of soybean revolution in the country (Tiwari *et al.,* 1999). The crop is also reported to be instrumental in socio-economic transformation of millions of small and marginal farmers in the region (Dupare *et al.,* 2008; Badal *et al.,* 2000; Sharma *et al.,* 2016). On an average, soybean is being grown on an area of 11-12 million hectares (m ha) producing about 11-13 million tonnes (m t) of soybean in the country. The crop is an integral part of cropping system followed by the farmers of Malwa region and presently is the sole *kharif* season crop. It is a boon for those farmers having irrigation facilities, who prefer short duration varieties to facilitate growing three crops in succession i.e. soybean-potato/onion/garlic-wheat/gram.

The average productivity of soybean in the country has stagnated at 1 to 1.1 tonne/ha during the present decade and is perceived to be mainly due to adverse effect of climate particularly long dry spells during the crop season coupled with less rainy days and delayed / erratic distribution of monsoon. The weather data of last decade indicate significant variation in most of the aspects of weather parameters during the monsoon season particularly the increase in temperature, reduction in humidity, long dry spells, heat waves, high intensity rains, terminal drought, rains during maturity period of crops etc. (Mall, 2006; Guhathakurta and Rajeevan, 2008; Dash *et al.,* 2009; Dash and Mamgain, 2011; Jain and Kumar, 2012; Birthal *et al.,* 2015; Oza and Kishtawal, 2015; Mishra *et al.,* 2016; Kumar *et al.,* 2010). Studies conducted on climatic adversities have also indicated these changes (Mishra *et al.,* 2016; Rama Rao *et al.,* 2018). In this scenario it was thought important to seek feedback from farmers of Central India about their perception of climatic changes and changes in their cropping pattern along with adaptation strategies followed by them. Therefore, a study was conducted in order to address these issues keeping in mind the central focus on farmers' perspectives of the region.

MATERIALS AND METHODS

The present study was conducted in three major soybean growing districts covering Malwa (Dewas and Indore districts) and Nimar valley (Dhar district) of Madhya Pradesh state in Central India. The sample for the study consisted of 280 soybean growers drawn randomly from six selected villages (50 farmers each from four villages from Indore and Dewas districts and 40 each from two villages of Dhar). In addition to basic information of the respondents on cropping pattern followed by them during the past five decades, open-ended questions were also included in the interview schedule related to long-term changes in rainfall and temperature, farmers' adaptations to respond to the climate changes. The data were collected using random sampling procedure by a pre-tested structured interview schedule. The response of farmers on season-wise crops grown, pattern of arrival of monsoon and its distribution, receipt of total rainfall, prevailing temperature, humidity and sunlight/photo period along with changes in agricultural practices like sowing method, sowing time, crop duration, insect/disease load, weed infestation etc. were recorded. Their perceptions on measures followed by them for minimizing the impact of climate change during the period 1960-2010 were recorded decade-wise. Open ended questions related to the farmers' experience and their opinion about the prevailing climatic situation as well as its impact on crops were also included. After the data collection, the entire interview schedules were coded with serial numbers and the response of farmers were computed. For some parameters, the qualitative data were converted into quantifiable data. The quantitative data were tabulated and analyzed after applying statistical tools like percentage, mean, standard deviation etc. Since, soybean has established itself as a *kharif* crop in the area during 1980s, replacing other *kharif* season crop, the data for soybean crop was considered only for the period thereafter.

RESULTS AND DISCUSSION

An effort was made to study the perception of the respondent farmers regarding changes in overall farming scenario including decade-wise changes in cropping pattern, prevailing weather conditions, infestation of insect-pest-disease and weed infestation and management strategies followed by them and the same are discussed.

Changes in cropping pattern

a. Changes in *kharif* crops: Decade wise analysis of the data (presented in Figure 1a) related to the perception of farmers about the change in most preferred *kharif* crop witnessed by them during the last six decades revealed that during sixties and seventies, majority of the farmers used to grow more than seven crops during *kharif* season, which included cotton (28%), groundnut (29%), pigeon pea (29%), sorghum (85%), green gram (9%), black gram (6%), maize (52%). But after the introduction and commercial adoption of soybean during eighties, the crops like groundnut, pigeon pea, sorghum, green gram, black gram were gradually rejected by farmers with the concomitant increase in area of soybean crop. Crops like cotton, a cash crop for majority of farmers could manage to survive in the area (particularly in Nimar valley) and maize being used for food as well as fodder for animals is still being grown by few farmers. The area under soybean crop was negligible during the seventies, but was rapidly adopted resulting in significant increase in area (69% farmers during eighties, 79% during nineties, 94%

at the last decade of 20th century and 100% during 2001-2010). It is also interesting to see that vegetable crop like chilli is being grown by a few farmers of Nimar valley during last two decades. Presently, soybean, cotton, maize and chillis are found to be most common and popular crops grown by the farmers of Madhya Pradesh.

b. Changes in *rabi* crops: The perceptions of farmers for growing *rabi* crops showed similar trends (Fig. 1b). It was observed that chickpea, wheat, lentil, and sugarcane were most popular and were the major crops grown by the farmers during sixties. Out of these, majority of farmers (86%) had preferred to grow wheat consequent to creation of irrigation facilities and they are still continuing the cultivation of wheat. In contrast, chickpea, the most common *rabi* crop up to eighties (more than 75%) gradually reduced, but continued to grown as a major *rabi* crop by a few farmers (37%) and is preferred by only those farmers who do not have adequate irrigation facility. Farmer with irrigation facility diversified to more remunerative vegetable crops like potato, onion and garlic which increased the area during 1980-2010. Following this trend, farmers had given more importance to potato (increase in the farmers' inclination from 7% during 1980s to 54% presently). Similar trend of farmers' perception was also seen in case of garlic and onion which were able to arouse the interest and inclination of farmers as *rabi* crop. The results also indicated an increase in the number of farmers who preferred to grow *rabi* crops. During 1960s, very few farmers used to grow *rabi* crops (129% cropping intensity during 1960s) but, it reached to 248% during 2010.

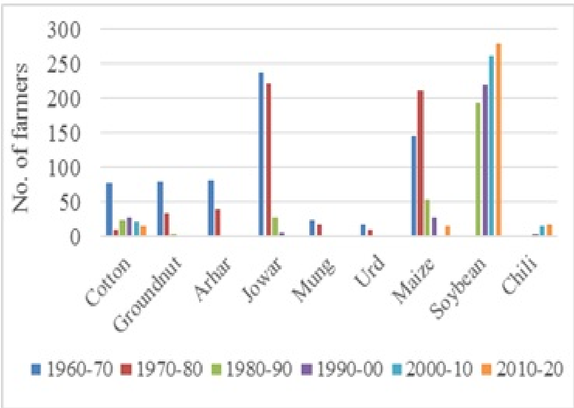

Fig 1a. Changes in *kharif* crops grown

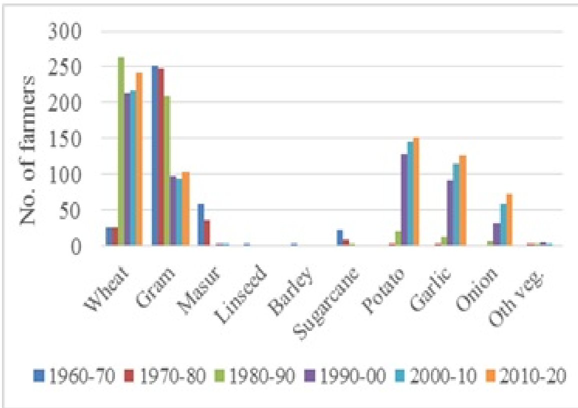

Fig. 1b. Changes in *rabi* crops grown

Changes in abiotic parameters

a. Changes in monsoon pattern and rainfall: Changes have been noted in the time of arrival of monsoon, distribution of rainfall and receipt of rainfall in the state of Madhya Pradesh (Fig. 2a to 2c). The farmers reported that the monsoon which used to hit the state in the first week of June has gradually shifted its arrival till the last week and sometimes up to even first week of July. They had also pointed out the unusual situation of the year 2017 in which farmers could sow their *kharif* crops in the month of August after the receipt of sufficient rains. Similarly, majority of the farmers felt that the distribution of monsoon during the last 10 years has mostly been erratic and uneven. As far as total receipt of rainfall is concerned, the respondents were of the opinion that the quantity of rainfall showed declining trend.

b. Changes in temperature, humidity and sunshine hours: According to the respondents, the day temperature during the *kharif* season of last two decades has increased to a considerable extent (Fig. 2d). Similarly, they perceived that the atmospheric humidity followed decreasing trend (Fig. 2e). Further, farmers pointed out that earlier during the sixties, they used to have more rainy days and less sunlight during the *kharif* season. Now, almost all the respondents perceived that the number of days with more photo period had increased coupled with less rainy days (Fig. 2f).

The analysis in the present study indicated that the change point year of the significant upward shift changes was 1963 for annual mean temperature time series. Geoscience (2013) and Duhan *et al.* (2013) reported that the annual, maximum and minimum temperatures increased by 0.6, 0.6 and 0.62°C, respectively over the past 102 years (1901 to 2002). Farmers' had perceived climate variability, and identified increasing temperature, delayed onset, intermittent dry spells and decreasing soil moisture as the critical factors affecting their cultivation. These results revealed that the farmers' perceptions were in accordance with the real trends analysis done on meteorological variables (Dhanya and Ramchandran, 2015). Majority of the farmers opined that the rainy season was reducing, unreasonably and unpredictably for the past two decades, and heat was becoming excruciating. Meteorological data provided no actual evidence to support farmer perceptions of decreasing rainfall, a similar case was reported earlier by Simelton *et al.* (2013). Farmers had fairly high level of perception about climate change and its various dimensions. Further, age, education, occupation, farming experience, knowledge about coping strategies, and mass media ownership and exposure were found to be significantly related with farmers' perception about climate change (Ansari *et al.,* 2018). Perception of farmers towards climatic change indicated reduction in annual rainfall, delayed onset of rainfall and early withdrawal of rainfall. Poor crop yield, reduced irrigation and drinking water availability, reduction in forest area and low availability of fodder for livestock as the changes in agricultural activities due to climate change. Adaptation strategies followed by farmers to face climate change varied from changing cropping pattern, crop diversification, and reduction in livestock to growing low input and crops requiring low water (Waris, 2019).

Change in technology/agronomic practices

a. Changes in method of sowing: The data (Table 1) related to changes in sowing methods followed by the farmers during last sixty years indicated that use of bullock drawn implements (plough, Dufan/Tifan, sarta/pora etc) was the most common sowing method followed by the farmers during 1960s and the same was continued up to 2000 by a few farmers. In addition, some farmers used to follow the broadcast method of sowing mainly in absence of adequate implements. However, this method was soon discontinued after 1970s with large number of farmers sowing with bullock drawn implements (90%, 97%, 99%, 91% and 32% during 1960, 1970, 1980, 1990, and 2000, respectively). The use of tractor and mechanization made its entry during 1990s and completely revolutionized the technique of sowing. During 1990s, only 8% farmers had access to tractor and tractor-drawn seed drill machines, which immediately became popular among the entire farming community. The percentage of farmers who used tractor-drawn implements for sowing during the year 2000 was 88% and reached to 98% during 2010. This has solved the most crucial problem of the large and commercial farmers who own more than 5 hectares of land. Majority of the farmers under study belonged to Malwa and Nimar valley having vertisols and its associated soils, the sowing window in that area is very narrow; therefore, farmers are forced to complete the sowing of their *kharif* season crop within a few days. This major operation earlier involved lot of time, labor and resources. It was learnt that the farmers who own the tractor rent it out to other farmers for sowing and other farming operations.

b. Changes in sowing time: Farmers of the region sow their *kharif* crop immediately after onset of monsoon (Table 1) and observed to be in consonance with that of Figure 1a. More than 95% of the farmers feel that they used to complete sowing of *kharif* crop in the first week of June during 1960s and 1970s. After the shift in arrival of monsoon during 1980s and 1990s, majority of the farmers (91% and 65% respectively) had to perform the sowing operation during second week of June. Those farmers (around 10%) who had large holdings had to continue the sowing operations for few more days (up to last week of June) in the absence of tractor and tractor drawn sowing equipment. Due to mechanization, sowing became easier for the farmers and about 80% of them were found to complete their sowing in the second week of June during the decade of 2000 (Dupare *et al*., 2011).

c. Changes in crop duration: Drastic change was observed in the preferences of farmers about the duration of crop/varieties during the *kharif* season. The farmers of the region (98% and 95%) in the initial period i.e. 1960-1970 used to grow the crop and varieties with maturity duration of more than 110 days (Table 1). But during the 1980s, their liking for long duration varieties reduced and majority of them (66% and 58%) preferred varieties maturing in 100-110 days. During same period, the R&D system of soybean was successful in developing relatively short duration soybean varieties with high yielding attributes. These varieties made inroads in the cropping systems of the area. The percentage of farmers preferring such varieties rose from about 21% during 1990 to 73% during 2000. Rest of the farmers either preferred to continue with the long duration varieties or such varieties which even shortened maturity period of up to 90 days (Billore *et al.,* 2004). With the changes in prolonged photoperiod coupled with terminal drought, temperature rise, less rainy days, excessive heat and early withdrawal of monsoon, majority of the farmers (81%) preferred short duration varieties (less than 90 days).

d. Changes in insect load: According to farmers' opinion, significant changes occurred with respect to insect load. The insect load was reported to be less during earlier period i.e. 1960s, 1970s, 1980s and even up to 1990 as has been reflected by the response of more than 92%, 95%, 85% and 71% of the farmers for the corresponding periods. But after 1990s, there was a sudden shift in insect load from less to high and even very high level in recent period. More than 54% and 66% of the respondents expressed that the insect load during the decade of 2000 and 2010 increased to high levels. Also, a sizeable number of farmers (31%) were of the opinion that their crop was attacked by insect from high to very high levels (Table 2).

e. Changes in disease load: Over the period of last sixty years, the changes with respect to disease load on *kharif* crop followed the same trend as that of insects. According to majority of farmers (75% and 71%), there used to be very less infestation of diseases on the crops including soybean during 1960s and 1970s but with very less severity (Table 2). Even during 1980s and 1990s, the management of disease in major *kharif* crops was not a big challenge as the infestation was less making no serious threat for yield of soybean. The farmers (59%) perceived that the problem of concern for diseases started since 2000, the period in which the severity of diseases reached to high levels. By the end of 2010, the problem of disease loads further increased its severity as more than 91% of the farmers believe that the incidence of disease is a major problem in soybean and can cause considerable yield loss if not properly and timely managed.

f. Changes in weed infestation: The yield losses due to weeds has been reported to be as high as 70% in soybean crop (Billore, 2010). Surprisingly, farmers believed that weeds were not a major problem till 1980s as majority of them (97%, 98%, 80% and 72% said that they used to have less infestation of weeds in their *kharif* crops (Table 2). But after the period followed by 1990, the problem of weeds became major in the area. More than 70% farmers perceived that the prevalence of different weeds started increasing to high levels and level of weed infestation has increased to very high levels during the period after 2010, as reported by more than 55% farmers. This could be attributed to the monoculture of soybean.

Strategies followed by the farmers for management of biotic factors

a. Strategies followed by farmers for management of insects and diseases: As the insect & diseases were not a serious problem during 1960s and appeared occasionally and with less to very less intensity, farmers used to manage the same through traditional ways like spray of cow urine, neem and/or tobacco extracts and dusting of ash. Therefore, majority of the farmers (more than 90%) did not pay any attention for control of pest and diseases during the period 1960s to 1980s. The use of chemicals for management of pests and diseases in soybean started becoming popular only after 1990s. Meanwhile, the R&D system of soybean came out with a number of recommended fungicides/chemicals either in the form of seed treatment or in the form of foliar spray. The farmers started using them as better alternative instead of traditional ways and the number of such farmers increased (Table 3) during the last three decades. It is interesting to see that farmers are using both traditional practices along with use of chemicals for management of diseases in soybean.

b. Strategies followed by farmers for management of weeds: The problem of weed management became more severe during the last 30 years and continued to cause heavy yield losses if not managed in time. Farmers followed several measures starting from field preparation to control weeds. Cent percent farmers' followed the age old traditional and cultural practice of deep summer ploughing followed by criss-cross harrowing, which helps to destroy the debris of weed seed (Table 3). After the crop is sown, the farmers followed other possible weed control measures such as manual weeding, use of hoe (*desi dora/kulpa*), and recommended herbicides.

c. Strategies followed by farmers for nutritional management: Table 3 also depicts the application of nutrition to *kharif* grown crops by the farmers of Madhya Pradesh. From the data, it is clear that application of Farm Yard Manure (FYM) was the only source of nutrition used by the majority of farmers during the period 1960s to 1980s. Those who did not have FYM had not applied any fertilizers to their *kharif* crop during this period. At the time of field preparation during summer, these farmers believed to have applied FYM before the onset of monsoon. But after 1980s, the use of FYM started decreasing as only 22%, 20% and 12% of the farmers were found applying the FYM to their kharif crops during the subsequent period of 1990s, 2000, and 2010 respectively. Interestingly, the figures for the application of chemical fertilizer during the same period increased (48% during 1990, 96% during 2000 and 2010). According to farmers, the productivity of soybean started decreasing during the last 20-30 years. Therefore, farmers had started application of nutrients through chemical fertilizers for increasing the yield.

d. Strategies/practices followed by the farmers for overall crop management: The traditional practice of manual weeding was found to be most popularly used by the farmers (more than 95% farmers during 1960s and 1970s) till 1980s and later that became less common. It is now being perceived as more laborious, costly and difficult to follow because of lack of availability of labor. But the traditional practice of hoeing is still continued to be the best alternative method followed by majority of the farmers since last sixty years even after the availability of crop specific recommended herbicides during nineties. Majority of the farmers (78% and 97% during 2000 and 2010) were found dependent on herbicides (both pre-emergence as well as post emergence) along with use of dora/kulpa whenever and wherever possible based on the prevailing climatic situation (Table 3). Overall, the farmers were found to adapt a mix of cultural and chemical control measures and sometime combination of both for weed management in soybean. However, it was interesting to note that the farmers were relying on use of only one type of most popular post-emergence herbicide i.e. Imazethapyr in spite of the availability of various other chemicals including those from the pre-emergence herbicides.

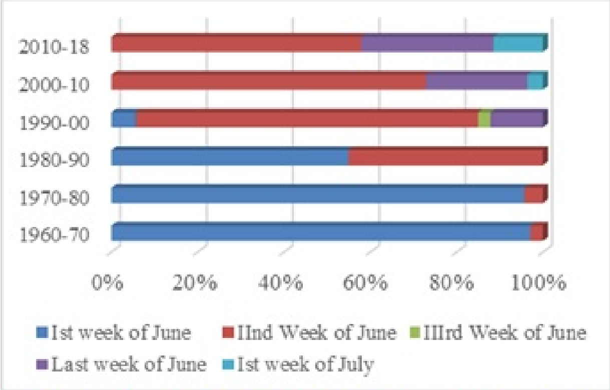

Fig 2a. Farmers Perception on change in arrival of monsoon

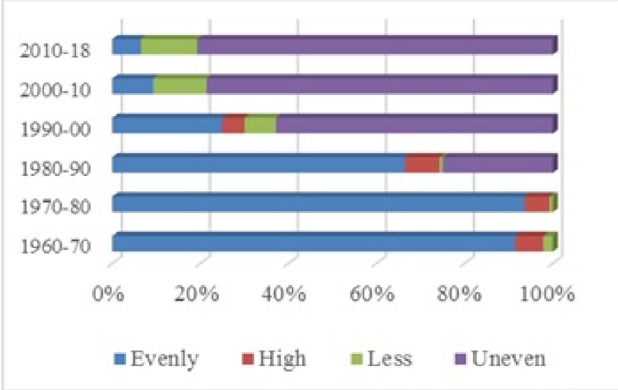

Fig 2b. Farmers perception on distribution of monsoon rainfall

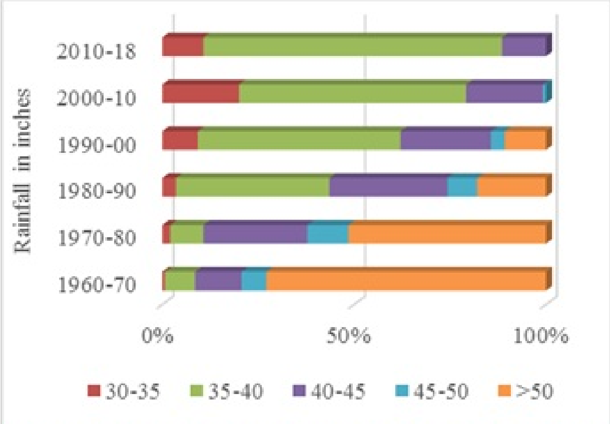

Fig 2c. Farmers perception on changes in receipt of rainfall

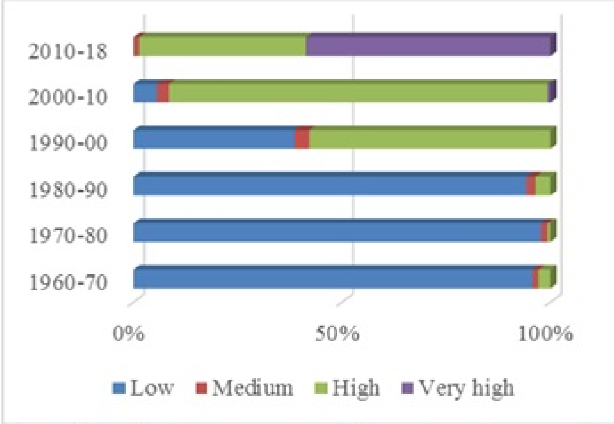

Fig 2d. Farmers perception on change in temperature

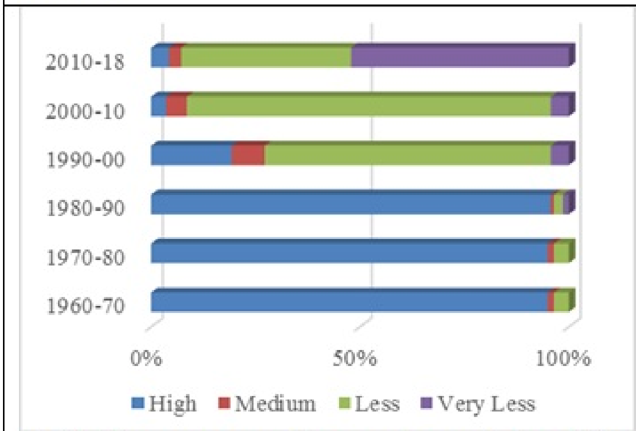

Fig 2e. Farmers perception on change in humidity

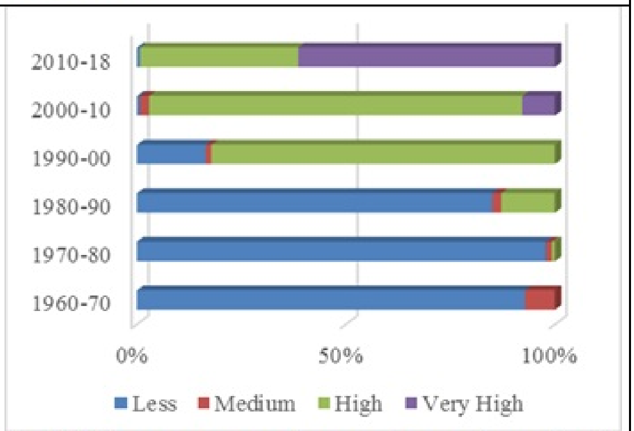

Fig 2f. Farmers perception on change in sunlight

Table 1 Changes in sowing methods, sowing time and crop duration preferred by farmers over the period (n = 280)

Method	1960	1970	1980	1990	2000	2010
(a) sowing methods followed by the farmers						
Broadcasting	28 (10.00)	8 (2.86)	2 (0.71)	-	-	-
Bullock drawn implements	252 (90.00)	272 (97.14)	278 (99.29)	256 (91.43)	90 (32.14)	6 (2.14)
Tractor operated seed drill	-	-	-	24 (8.57)	190 (87.86)	274 (97.86)
(b) sowing time followed by the farmers						
June 1st Week	272 (97.17)	266 (95.00)	24 (8.57)	64 (22.86)	2 (0.71)	12 (4.29)
June 2nd Week	4 (1.43)	8 (2.86)	254 (90.71)	184 (65.71)	222 (79.29)	52 (18.57)
June 3rd Week	4 (1.43)	2 (0.71)	2 (0.71)	8 (2.86)	20 (7.14)	6 (2.14)
June 4th week	-	4 (1.43)	-	24 (8.57)	34 (12.14)	184 (65.71)
July 1st week	-	-	-	-	2 (0.71)	26 (9.29)
(c) crop duration preferred by the farmers						
<90 days	-	4 (1.43)	4 (1.43)	4 (1.43)	24 (8.57)	228 (81.43)
91-100 days	2 (0.71)	10 (3.57)	20 (7.14)	60 (21.43)	204 (72.86)	38 (13.57)
101-110 days	4 (1.43)	-	184 (65.71)	164 (58.57)	10 (3.57)	14 (5.00)
111-120 days	274 (97.86)	266 (95.00)	72 (25.71)	52 (18.57)	42 (15.00)	-

Data given in parenthesis are percentage.

Table 2 Changes in load of insect, disease and weed experienced by farmers over the period (n=280)

Insect load	1960	1970	1980	1990	2000	2010
(a) Insect load experienced by the farmers						
Very less	16 (5.71)	6 (2.14)	6 (2.14)	8 (2.86)	-	-
Less	260 (92.86)	268 (95.71)	238 (85.00)	200 (71.43)	98 (35.00)	6 (2.14)
Medium	4 (1.43)	6 (2.14)	36 (12.86)	30 (10.71)	28 (10.00)	2 (0.71)
High	-	-	-	42 (15.00)	152 (54.29)	184 (65.71)
Very high	-	-	-	-	2 (0.71)	88 (31.43)
(b) Disease load experienced by the farmers						
Very Less	210 (75.00)	200 (71.43)	96 (34.29)	12 (4.29)	6 (2.14)	2 (0.71)
Less	58 (20.71)	76 (27.14)	144 (51.43)	218 (77.86)	86 (30.71)	-
Medium	-	2 (0.71)	14 (5.00)	30 (10.71)	22 (7.86)	22 (7.86)
High	12 (4.29)	2 (0.71)	26 (9.29)	20 (7.14)	166 (59.29)	190 (67.86)
Very high	-	-	-	-	-	66 (23.57)
(c) Weed infestation experienced by the farmers						
Less	272 (97.14)	276 (98.57)	226 (80.71)	202 (72.14)	72 (25.71)	14 (5.00)
High	8 (2.86)	4 (1.43)	54 (19.29)	78 (27.86)	196 (70.00)	110 (39.29)
Very high	-	-	-	-	12 (4.29)	156 (55.71)

Data given in parenthesis are percentage.

Table 3 Strategies adapted by the farmers for crop management (n = 280)

Method	1960	1970	1980	1990	2000	2010
a) Strategies for insect control						
Cow urine, Neem, tobacco extract/Ash	24 (8.57)	30 (10.71)	8 (2.86)	14 (5.00)	6 (2.14)	10 (3.57)
No control	256 (91.43)	250 (89.29)	272 (97.14)	62 (22.14)	20 (7.14)	14 (5.00)
Chemical	-	-	-	204 (72.86)	260 (92.86)	266 (95.00)
b) Strategies for weed control						
Plough/Harrow	280 (100.00)	280 (100.00)	280 (100.00)	280 (100.00)	280 (100.00)	280 (100.00)
Weeding	268 (95.71)	266 (95.00)	86 (30.71)	14 (5.00)	6 (2.14)	-
Hoeing	240 (85.71)	210 (75.00)	190 (67.86)	262 (93.57)	152 (54.29)	6 (2.14)
Hoe+herbicide	-	-	-	-	94 (33.57)	136 (48.57)
Herbicide	-	-	-	36 (12.86)	126 (45.00)	138 (49.29)
c) Strategies for nutritional management						
FYM	158 (56.43)	198 (70.71)	258 (92.14)	62 (22.14)	58 (20.71)	34 (12.14)
Fertilizer	-	-	-	82 (29.29)	270 (96.43)	270 (96.43)
No Nutrition	122 (43.57)	82 (29.29)	22 (7.86)	136 (48.57)	6 (2.14)	10 (3.57)
d) Strategies for crop management						
FYM	185 (56.43)	198 (70.71)	258 (92.14)	62 (22.14)	58 (20.71)	34 (12.14)
FYM+Fertilizer	-	-	-	30 (10.71)	66 (23.57)	158 (56.43)
Critical irrigation	-	-	8 (2.86)	52 (18.57)	74 (26.43)	26 (9.29)
Mechanization	-	-	24 (8.57)	66 (23.57)	152 (54.29)	204 (72.86)
Improved varieties	-	8 (2.86)	26 (9.29)	64 (22.86)	114 (40.71)	270 (96.43)
Herbicide	-	-	-	4 (1.43)	204 (72.86)	266 (95.00)

Data given in parenthesis are percentage.

Subsequent to weather changes (particularly in temperature, humidity, rainfall pattern and its distribution *vis-à-vis* receipt of total rainfall coupled with drought, etc.) farmers claim that they were managing their crop yield by adopting various adaptation strategies. Subsequent to farm mechanization post 1990s, majority of farmers got rid of animals resulting in less availability of organic manure. After the introduction and popularity of chemical fertilizers this trend was found declining after 2000. Majority of the farmers were applying the plant nutrition through both organic as well as inorganic sources (23% and 56% respectively during 2000 and 2010).

Application of need based irrigation in *kharif* crops was not a prerequisite till 1970s. The data of farmers' response indicate that owing to long dry spell during the crop growth period, handful of farmers (2.86%) started this practice to save their crop from severe drought. The practice was subsequently followed by 18.57% during 1990s, 26% during 2000 and 9% during 2010. Therefore, the trend conforms the effect of the climate changes, which were more prominently seen during last 20 years and has forced the farmers to apply need-based irrigation at critical stages in order to save their *kharif* crop.

More prominent changes have also been noted with regard to mechanization in soybean crop which had been initially adopted during 1980s by a few large holding farmers (8.57%). Soon, the use of tractor and associated farm machinery/implements like (MB plough, cultivator, seed drills, tractor-drawn power sprayers, combine harvesters etc) have made their inroads in other farming community. The per cent of farmers who followed mechanization has increased over the years (23%, 54% and 72% respectively during, 1990, 2000 and 2010). It was also found that the farmers who did not own a tractor/tractor drawn implements also resorted to mechanization by custom hiring from other fellow farmers.

Climatic adversaries have also brought out changes in use of improved varieties among the farming community. Looking at the data, it was found that a steady increase in adoption of improved soybean varieties suitable to the needs of farmers and in line with climatic factors, particularly the arrival and distribution of rainfall. During 1970s, only 3% of the farmers were found adopting the newly released soybean varieties, which increased to 9%, 22%, 40% and 96% respectively during 1980s, 1990s, 2000 and 2010. The change in these improved varieties basically involved use of short duration varieties which brought down the maturity duration from 120 days to less than 90 days.

As far as the weed management is concerned, it was observed that a few progressive farmers (1%) have started using herbicides initially during 1990s and the same was increasingly followed by majority of the farmers (73% during 2000 and 95% during 2010) to manage the weeds. Majority of the farmers adopted herbicides and intercultural operations like hoeing (depending on the climatic suitability). Shortage of labor is also one of the major factors which promoted use of herbicides for control of weed.

The major change experienced by the farmers during last 20-30 years was the increase in insect-pest load on soybean (Table 2). Majority of the farmers perceived that soybean crop is now infested by a number of insects with infestation levels being high to very high. Therefore, the farmers have learned to follow the plant protection measures like spraying of recommended insecticides at appropriate time using required spray solution. Before 1980s, farmers did not pay any attention for control of insect-pests. However, majority of the farmers (52%) during 1990s had followed plant protection schedule for control of major insects particularly green semilooper, gram pod borer, stem fly, tobacco caterpillar and girdle beetle. During last 20 years, almost all farmers were managing the insect-pests using 3-4 sprays of recommended plant protection chemicals.

Few farmers have also started cultivation of organic soybean production. The state government and department of agriculture of Madhya Pradesh started promoting "Organic Soybean Production". Few farmers (mainly small and marginal categories) who were mainly dissatisfied with the yield losses due to adverse climatic conditions came in contact with contract farming project of some corporate/soy-based industries and they shifted to organic production of soybean after getting themselves registered and proper training by appropriate agencies.

The present study has highlighted that although farmers' perception about climate change is fairly high, they also display fairly good understanding of various dimensions that contribute to climate change such as increase in temperature, erratic and sporadic rainfall behavior, increase in duration of heat stress due to high temperature, biotic stresses and several other effects. However, many farmers still display low perceptions and are not adequately equipped with knowledge of adaptation, mitigation and resilience strategies in order to foster the adverse impacts of climate change on agriculture. Therefore, it is of significant importance to create awareness by way of sustained and high-voltage communication campaigns to educate the farmer about climate change and adaptation strategies. The focus of these campaigns should be on young, educated small and medium farmers and mobilize extension services providers to contribute in mitigating adverse impact of climate change on agriculture productivity.

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Impact assessment of frontline demonstrations on mustard (*Brassica juncea* L.) under North Gujarat agro-climatic region

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ABSTRACT

Rapeseed-mustard is an important oilseed crop of India, but its productivity is low due to lack of awareness about improved varieties, production and protection technologies. Castor-Mustard Research Station, S.D. Agricultural University, Sardarkrushinagar, Gujarat conducted 87 Frontline Demonstrations in the farmer's fields on mustard variety GDM 4 and NRCHB 101 over three consecutive years during *rabi* seasons of 2015-16 to 2017-18 under North Gujarat Agroclimatic region. The results revealed that mustard varieties GDM 4 and NRCHB 101 out yielded by 17.2% and 16.1% over local farmers' practices based on three years average yield performance. Furthermore, the mustard variety GDM 4 and NRCHB 101 recorded higher B:C ratio with the mean value of 3.58 and 3.53 as well as higher additional net monetary returns of ₹ 11289 and 10311 per ha over farmers' practices.

Keywords: Economics, Extension gap, Front line demonstration, Mustard, Seed yield

Oilseed crops occupy a significant role in Indian agricultural economy, only next to food grains. Rapeseed-mustard is the second most important edible oilseed crop of India after groundnut and it accounts for nearly 30 per cent of the total oilseeds production of the country. In India, rapeseed-mustard is grown over an area of 6.12 million hectares with an annual production of 9.26 million tonnes during 2018-19. In Gujarat, mustard production is about 3.48 lakh tonnes from an area of 1.95 lakh hectares with average productivity of 1784 kg/ha during 2018-19 (Anonymous, 2019). The major mustard producing districts *viz*., Banaskantha, Patan, Mehsana, Kachchh, Sabarkantha, Aravalli and Gandhinagar are located in North Gujarat Agroclimatic region which covered 95 per cent mustard growing area of Gujarat. In Banaskantha district, mustard is grown in area of 1.40 lakh ha and production is 2.57 lakh tonnes with average productivity of 1833 kg/ha. The major constraints for low mustard yield in these districts are cultivation of mustard in marginal lands, non-adoption of improved production technologies, lack of adoption of improved high yielding varieties, intensive cropping with imbalance fertilization and an overall lack of awareness among farmers about improved packages of practices. Furthermore, farmers are interested on growing high value crops such as castor, groundnut and cotton in some pockets of this region. To overcome these production constraints and popularize latest technologies among farmers, frontline demonstrations (FLDs) were conducted. Improved production technologies were demonstrated on the farmers' fields under the close supervision of the agricultural scientists to show the productivity potential and profitability under real farm situations. The present study was conducted at assess the impact of FLDs on mustard (*Brassica juncea* L.) with varieties, GDM 4 and NRCHB 101 in North Gujarat region.

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MATERIALS AND METHODS

The study was carried out by Castor-Mustard Research Station, S.D. Agricultural University, Sardarkrushinagar in four districts *viz.,* Banaskantha, Patan, Mehsana and Sabarkantha situated in the North Gujarat Agro-climatic region, Gujarat. The region is characterized by subtropical monsoon type and falls under semi-arid region. Generally, monsoon commences in the first and second week of July and retreats by the middle of September and most of the rainfall is received from the South-West monsoon in the months of July and August. Winter is fairly cold and dry. The winter season sets in the middle of October and continues till the middle of February. Eighty seven frontline demonstrations (FLDs) on mustard variety GDM 4 and NRCHB 101 were conducted with one acre area of each demonstration during rabi season of 2015-16 to 2017-18. The sowing was done during mid October under irrigated conditions and harvested during second fort night of February to first fortnight of March every year. The critical inputs i.e. seed, fertilizer and need based plant protection chemicals were supplied to farmers. Regular visits of the demonstration fields by the scientists ensured proper guidance to the farmers. The selected farmers were trained and detailed information was provided for successful mustard cultivation as per recommended package of practices. Field days and farmers meetings were organized to provide the opportunities for other farmers to witness the benefits of demonstrated varieties and technologies. Two days training on mustard production was also organized during the crop season for extension personnel of state department of agriculture to disseminate the knowledge among farmers. The data were collected from both the FLD plots as well as farmers' practice plots. The cost of cultivation, gross monetary returns, net monetary returns and benefit cost ratio were worked out (Samui *et al.,* 2000) for evaluation of economic feasibility of the technologies in comparison with farmers' practices. Additional net monetary returns (ANMR) were estimated based on the differences between the net returns of demonstration plot and farmers' practice plots. Furthermore, extension gap (EG) was workout using the following formula (Yadav *et al*., 2004).

EG (kg/ha)=
Demonstration plot yield (kg/ha) - Farmers practice plot yield (kg/ha)

RESULTS AND DISCUSSION

Yield performance: The seed yield of demonstrated plots and farmers' practice are presented in Table 1. Data revealed that average seed yield of both the varieties under demonstration plots was higher as compared to farmers' practice plots during all the three years. The average seed yield of GDM 4 ranged from 1653 to 2201 kg/ha and NRCHB 101 ranged from 1705 to 2125 kg/ha as compared to 1421 to 1861 kg/ha obtained in farmers' practices. Based on 87 FLDs conducted in four districts of North Gujarat, the mean seed yield of GDM 4 (2009 kg/ha) and NRCHB 101 (1983 kg/ha) were much higher as compared to farmers' practices (1713 kg/ha). The corresponding increment in seed yield of GDM 4 and NRCHB 101 were to the tune of 17.2% and 16.1% as compared to farmers' practices. The higher yield in FLDs plots may be due to increased knowledge and adoption of full package of practices viz. timely sowing, line sowing, use of recommended dose of fertilizers, thinning, better weed management and need based plant protection measures. The lower seed yield of mustard under farmers' practices plots compared to FLD plots was due to use of local or old varieties, not adopting optimum plant population, thinning, interculturing, weed control and balanced fertilization of crop. These results were in agreement with the findings of Singh *et al.* (2007), Singh *et al.* (2011) and Dhaliwal *et al.* (2018). Extension gap of both the varieties ranged from 232-344 kg/ha in different years with mean seed yield of 296 kg/ha (GDM 4) and 270 kg/ha (NRCHB 101). These gaps may be attributed to the genetic differences between improved varieties and the cultivars used by farmers in terms of yield, lack of awareness of farmers about improved production technology, and proper agronomic management of crop. The results were in close conformity with the findings of Dhaliwal *et al.* (2018) and Sandhu and Dhaliwal (2019). However, the adoption levels for the improved technology in oilseeds necessitates the need for better dissemination (Kiresur *et al.,* 2001).

Economics: The economic analysis of frontline demonstrations is important for assessing the advantage of adoption of newer technologies and for understanding the economic feasibility of improved technologies. The data on economics of the FLDs on mustard are presented in Table 2. The net returns from FLD plots varied from ₹ 43937 to 65506/ha as compared to ₹ 34388 to 53011/ha from farmers' practice plots. However, average benefit: cost ratio of GDM 4 (3.58) and NRCHB 101 (3.53) was higher as compared to farmer's practice (3.09). Three years average additional net monetary returns of GDM 4 and NRCHB 101 in demonstration plots were ₹ 11289 and 10311/ha respectively, which was basically due the in the increased yield levels in demonstration plots. Similar results were reported by Ajrawat *et al*. (2013), Singh *et al*. (2018) and Dhaliwal *et al.* (2018).

Table 1 Yield performance of mustard in frontline demonstrations

Year	Variety	Demo. (Nos.)	Yield (kg/ha)		Yield increase over FP (%)	Extension Gap (kg/ha)
			IP	FP		
2015-16	GDM 4	15	2201	1857	18.52	344
	NRCHB 101	15	2125		14.43	268
2016-17	GDM 4	44	2174	1861	16.81	313
	NRCHB 101	44	2118		13.80	257
2017-18	GDM 4	28	1653	1421	16.32	232
	NRCHB 101	28	1705		19.98	284
Mean	GDM 4		2009	1713	17.2	296
	NRCHB 101		1983		16.1	270

Table 2 Economic analysis of frontline demonstartions on mustard

Year	Variety	Gross monetary return (₹/ha)		Net monetary return (₹/ha)		B: C ratio		ANMR in Demonstartion (₹/ha)
		IP	FP	IP	FP	IP	FP	
2015-16	GDM 4	86389	72887	65506	53011	4.14	3.67	12495
	NRCHB 101	83419		62536		3.99		9525
2016-17	GDM 4	80437	68849	58229	46405	3.62	3.07	11824
	NRCHB 101	78373		56164		3.53		9759
2017-18	GDM 4	66107	56843	43937	34388	2.98	2.53	9549
	NRCHB 101	68207		46037		3.08		11649
Mean	GDM 4	77644	66193	55891	44601	3.58	3.09	11289
	NRCHB 101	76666		54912		3.53		10311

Note: IP = Improved practice of demonstartion plot and FP= Farmers practice plot; ANMR = Additional net monetary returns.

Therefore, it could be concluded that the mustard variety GDM 4 produced higher seed yield and net returns in frontline demonstrations on farmers' field as compared to farmers' practice in the four districts of North Gujarat over three years. The increase in seed yield was owing to the adoption of latest variety, timely sowing, thinning, balanced fertilization, weed management and need based plant protection measures. Hence, mustard variety GDM 4 is most suited in North Gujarat agro-climatic region under irrigated condition.

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Frontline demonstrations on Indian mustard (*Brassica juncea*) for showcasing production potential and economics in hot sub humid (moist) eco-region

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ABSTRACT

The production of Indian mustard (*Brassica juncea*) is lower due to non-adoption of recommended high yielding varieties and improved technologies by the farming community in eastern plains of Uttar Pradesh, India. To educate farmers on the improved technologies, 92 frontline demonstrations (FLDs) were conducted in farmers' fields by KVK, Deoria, Uttar Pradesh, India. The technologies demonstrated included improved varieties, thinning, irrigation, date of sowing, seed treatment, spacing, balanced use of fertilizers, intercultural operations and plant protection measures. The improved technology showed increase in the yield of mustard between 22.3-43.3% over local checks. Technology gap was highest in Pusa Jaikisan (1767 kg/ha) and lowest in Pusa Bold (341 kg/ha) variety. The extension gap was highest with Pusa Jaikisan (447 kg/ha) and lowest with Pusa Bold (434 kg/ha). Technology index was highest (50.5%) with Pusa Jaikisan and lowest (13.9 %) with Pusa Bold. Lower, values of technology index indicates higher feasibility of the technology in eastern plains of Uttar Pradesh.

Keywords: FLD, Extension gap, Indian mustard, Technology index

Rapeseed mustard belongs to family Cruciferae and is the third most important oil seed crop of India in terms of area after soybean (37.10%) and groundnut (27.34%), contributing nearly 25.12% of the total oil seed production of the country. Mustard oil is the main cooking medium commonly used in northern India and oil cake is mostly used as cattle feed (Shekhawat, 2012). The crop is grown both in subtropical and tropical regions. India produces 6.82 million tons of mustard from an area of 5.76 million hectares (DES, 2016). The average yield varies from 1,000 to 1,200 kg/ha. Rajasthan is the largest producer of rapeseed-mustard followed by Uttar Pradesh, Haryana, Madhya Pradesh, West Bengal, Gujarat and Assam. There has been tremendous increase in area and production of rapeseed-mustard during the last two decades mainly in the states of Rajasthan, Haryana, West Bengal and Gujarat. Growth in XII plan over XI plan in area, yield and production of rapeseed-mustard was +0.23, +7.20 and +7.40, respectively (NFSM, 2018). In spite of commendable increase in yield, still there is possibility of enhancing rapeseed-mustard yield in Rajasthan. Keeping this in view, frontline demonstrations (FLDs) were conducted in farmers' field to show the productivity potential and profitability of new varieties and production practices of mustard in eastern Uttar Pradesh.

MATERIALS AND METHODS

Performances of high yielding varieties of Indian mustard namely Pusa Bold and Pusa Jaikisan against traditional variety was evaluated through frontline demonstrations (FLDs) at farmers' field during rabi season of 2010-11 and 2011-12. The study was carried out by the Krishi Vigyan Kendra, Malhana, Deoria under Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh. A total of 32 and 11 FLDs were conducted with Pusa Jaikisan, 33 and 16 with Pusa Bold varieties during year 2010-11 and 2011-12, respectively. The crop management technologies demonstrated in FLDs and farmer practices are given in Table 1. The crop was sown in the last week of October and harvested in the first week of March. Improved varieties (Pusa Bold and Pusa Jaikisan) were compared with traditional varieties grown by the farmers. The soils of the study area are very deep, loam to silty loam in texture and moderately well to well drained with ground water irrigation facility. Soils are medium in fertility status. Climate of the district is characterized by dry summer and cool winter with high rainfall during kharif season. The performance of varieties was evaluated based on the growth and yield data recorded at harvest. Comparison was made with traditional and local varieties, grown by the farmers. Critical inputs in the form of quality seeds of recommended high yielding varieties were provided to the farmers. The subject matter specialists of KVK ensured that farmers followed the recommended field operations like sowing, thinning, irrigations, fertilizer application, weeding spraying, harvesting, threshing and storage. Farmers trainings, field visits and field days were organized. The technology gap, extension gap and technological index (Samui *et al*., 2000) were calculated by using formula as given below:

Technology gap (A) = Potential yield - Demonstration yield

Extension gap (B) = Demonstration yield - Yield of traditional variety

Technology index (C) = (Potential yield - Demonstration yield/ Potential yield) x 100

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Table 1 Agronomical practices demonstrated in FLDs as compared to farmers' practices

Practice	Demonstrations practice	Farmers' Practice
Farming situation	Irrigated and sandy loam	Irrigated and Sandy loam
Varieties	Pusa Bold & Pusa Jaikisan	Traditional Variety
Date of sowing	22 -30th October	5-12th Nov
Method of sowing	Line sowing	Broadcasting
Seed rate (kg/ha)	3-4	4-5
Irrigation (No.)	01	01
Fertilizers (kg/ha)	80 N, 60 P & 40 K	80 N, 60 P & 40 K
Thinning	25 DAS	No thinning
Date of harvesting	5-12th March	5-12th March

RESULTS AND DISCUSSION

Plant growth attributes: The results of growth and yield attributes of mustard in demonstrated (Pusa Jaikisan and Pusa Bold) and traditional varieties are presented in Table 2. The results showed marked difference in growth characters of Pusa Jaikisan and Pusa Bold compared with traditional variety. The linear growth as well as total number of primary and secondary branches/plant were recorded at harvest stage and were found higher in Pusa Jaikisan and Pusa Bold as compared with the traditional varieties. The plant height was higher in Pusa Jaikisan (159.15 cm) and Pusa Bold (160.05 cm) compared with traditional varieties (141.04 cm). Pooled data analysis for two years showed a remarkable difference in number of primary and secondary branches/ plant in improved varieties Pusa Jaikisan and Pusa Bold. Number of primary branches/plant increased by 10.9% in Pusa Jaikisan and 11.6% in Pusa Bold over the local checks. Numbers of secondary branches/plant increased by 7.6% in Pusa Jaikisan and by 10.5% in Pusa Bold over local check. Similar results were recorded (Table 2) in yield attributing parameters viz., siliqua/plant, seeds/siliqua as well as test weight.

FLDs were conducted in 43 farmers' fields (13 ha area) with Pusa Jaikisan variety and 49 farmers' fields (13.6 ha area) with Pusa Bold variety (Table 2). The average yield of Pusa Jaikisan variety under FLDs was 1430 kg/ha in year 2010-11 and 2035 kg/ha in year 2011-12 which was 24.3% and 43.3% higher than local variety in eastern region of Uttar Pradesh. Yield gap analysis done by Mitra *et al*. (2010) and Meena *et al.* (2010) in different parts of country indicated the superiority of improved technologies over traditional technologies. Yield enhancement through frontline demonstration in Indian mustard was reported by Meena *et al*. (2018), Hiremath *et al*. (2007), Dhaka *et al.* (2010) and Kumar *et al.* (2010). The average yield of Pusa Bold variety under FLDs was 2348 kg/ha in year 2010-11 and 1870 kg/ha in year 2016-17. Pusa Bold variety gave 22.29% higher yield in year 2010-11 and 30.76% higher yield in year 2011-12 as compared to traditional varieties. Better performance and it's on farm showcasing over local varieties (Shekar and Vaibhav) was enough to attract farming community to grow mustard crop.

Further analysis of data showed that the yield of mustard for Pusa Jaikisan and Pusa Bold varieties increased successively which clearly speaks of the positive impact of FLD over traditional varieties (Table 3) in this region. The results indicated that the FLDs had given a good impact among the farmers community of Deoria District as indicated by the spread of the recently introduced high yielding varieties in the farmers' fields.

Extension gap, technology gap and technological index: The technology gap ranged between 1767 and 341 kg/ha. The technology gap observed may be attributed to the dissimilarity in the soil fertility status and weather conditions. The extension gap ranged from 447 and 434 kg/ha (Table 4) emphasizing the need to educate the farmers through various means for the adoption of HYV. Meena *et al*. (2010) reported an extension gap ranging from 336 kg/ha to 464 kg/ha in mustard in south-eastern part of Rajasthan. Similar extension gap in frontline demonstration of mustard was reported by Afzal *et al.* (2013). As the area under high yielding varieties and adoption of latest production technologies increases, the extension gap may reduce over a period of time.

The technological index showed the feasibility of the technology in farmer's field. The lower the value of technology index, higher is the feasibility of the technology (Sagar and Chandra 2004). The benefit cost ratio of frontline demonstration (Table 5) was substantially higher than control plots i.e. traditional varieties during two years of demonstration.

Economic analysis: Economic analysis of FLDs showed average net profit of ₹40814/- with Pusa Bold followed by ₹30248/- with Pusa Jaikisan and ₹20144/- with local/traditional varieties on per hectare basis. Similar results were reported by Singh *et al.* (2014) in Chickpea. The net profit was almost doubled under Pusa Bold variety and one and a half times higher in case of Pusa Jaikisan. Pooled data indicated a benefit cost ratio of 4.0:1, 3.6:1 and 3.0:1 for Pusa Jaikisan, Pusa Bold and traditional varieties, respectively. Similar findings were reported by Balai *et al.* (2012) in mustard and Sharma (2003) in Moth bean. Pusa Jaikisan variety was found to be economically most beneficial in eastern uplands of Utter Pradesh. The higher cost of cultivation of Pusa Bold reduces the B: C ratio but gave higher net and gross returns as compared to Pusa Jaikisan. The favorable benefit cost ratio proved the economic viability of the intervention made under demonstration and convinced the farmers on the utility of intervention.

Table 2 Growth parameters (Plant height, primary branches and secondary branches) under FLDs and traditional variety

Variety/Characters	Pusa Jaikisan			Pusa Bold			Local		
	2010-11	2011-12	Pooled	2010-11	2011-12	Pooled	2010-11	2011-12	Pooled
Plant height (cm)	158.30	160.0	159.15	159.40	161.70	160.05	140.08	142.00	141.04
Primary branches	4.48	4.50	4.49	4.50	4.55	4.52	4.10	3.98	4.05
Secondary branches	8.60	8.69	8.64	8.90	8.85	8.87	7.94	8.12	8.03
Siliqua/plant	256	260	258	270	258	264	212	214	213
Seed/ siliqua	10.14	10.24	10.19	10.50	10.20	10.35	9.99	10.01	10.00
1000 seed weight (g)	5.44	5.48	5.46	5.55	5.49	5.52	4.98	5.10	5.04

Table 3 Variety, number of FLDs, area and yield of mustard grown under FLD and existing practices

Variety	Year	No. of FLDs	Area(ha)	Yield (kg/ha)			% increase yield over existing
				Potential	Demo	Local	
PusaJaikisan	2010-11	32	10	3500	1430	1150	24.3
Pusa Bold	2011-12	33	10	2450	2348	1920	22.29
Pus Jaikisan	2010-11	11	03	3500	2035	1420	43.30
Pusa Bold	2011-12	16	3.6	2450	1870	1430	30.76

Table 4 Yield, extension gap, technology gap and technology index of mustard grown under FLDs and existing practices

Variety	Year	Yield (kg/ha)			Extension gap (kg/ha)	Technology gap (kg/ha)	Technological index (%)
		Potential	Demo	Local			
PusaJaikisan	2010-11	3500	1430	1150	280	2070	59.14
PusaJaikisan	2011-12	3500	2035	1420	615	1465	41.85
Pooled		3500	1732.5	1285	447	1767	50.50
Pusa Bold	2010-11	2450	2348	1920	428	102	4.16
Pusa Bold	2011-12	2450	1870	1430	440	580	23.67
Pooled		2450	2109	1675	434	341	13.91

Table 5 Average gross return, net profit and B:C ratio of mustard grown under FLDs and traditional varieties

Variety	Av. Cost of cultivation			Av. Gross Return (₹)			Av. Net profit (₹)			B:C Ratio		
	2010-11	2011-12	Pooled	2010-11	2011-12	Pooled	2010-11	2011-12	Pooled	2010-11	2011-12	Pooled
Pusa Jaikisan	7680	12950	10315	34320	46805	40563	26640	33855	30248	4.4:1	3.6:1	4.0:1
Pusa Bold	13200	17624	15412	56352	56100	56226	43152	38476	40814	4.2:1	3.1:1	3.6:1
Local	7570	12403	9987	27600	32660	30130	20030	20257	20144	3.6:1	2.6:1	3.0:1

Our study indicated that high yield varieties with improved production technologies demonstrated in FLDs increased the yield of mustard in hot sub-humid (moist) eco-region of Utter Pradesh. The results further indicated the possibility of increasing mustard yield by 22.29 to 43.30% with the use of HYVs (Pusa Jaikisan and Pusa Bold), techniques of crop production and its better management. Our study also indicated that there is a need to adopt multi-pronged strategy involving KVKs, agricultural department and national institutes for enhancing mustard production through adoption of improved technologies in eastern plains of UP.

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Cluster front line demonstrations in summer sesamum - Impact on livelihood outcome

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ABSTRACT

Sesamum is an important oilseed crop grown in Krishna district, Andhra Pradesh in summer under irrigated conditions for additional income. During 2010-11, the area under sesamum cultivation in the district was 699 ha with 135 tonnes of production and 193 kg/ha productivity. In many parts of the district, it was observed that due to lack of knowledge on latest high yielding varieties (HYVs) and integrated crop management (ICM) practices, farmers realized lower yields. Hence, the area under sesamum was replaced by short duration pulses such as blackgram and greengram. This resulted in decrease in the area under sesamum in the district. As a result, the area recorded under sesamum cultivation was nil in Krishna district during 2016-17. Pulses can be grown throughout the year, but sesamum is grown only as summer crop in the district. Sesamum is considered as a nutritional powerhouse and a great non-dairy source of calcium. It is an excellent source of calcium, copper, manganese, magnesium, iron, phosphorus, vitamin B1, zinc, molybdenum, selenium, and dietary fibre. The crop has its own importance, hence the area under this crop need to be retained.

Keywords: Blackgram, Cluster frontline demonstrations, Krishna district, Summer sesamum

In order to create awareness and show the productivity potential and profitability of improved varieties, cluster frontline demonstrations (CFLDs) on sesamum were conducted during summer season. ICM practices along with high yielding sesamum variety YLM 66 was demonstrated. YLM 66 has light brown colour seed, tolerant to powdery mildew and leaf spot with crop duration of 75 days and potential yield of 16q/ha. The new technology of ICM in sesamum was compared against farmer's practice of growing blackgram. We assumed that the main objective of a farmer to choose a crop was to maximize the net income. In fact, net income is a deciding factor for a farmer whether to adopt a new technology or not. Hence, an attempt was made through CFLDs to showcase the livelihood outcome in terms of income from ICM in sesamum in comparison to farmers' practice of growing blackgram.

MATERIALS AND METHODS

A total of 40 CFLDs in sesamum each in an area of 1 ha were organized during 2018 in Jaggaiahpet, Vastavai and Penugranchiprolu mandals of Krishna district in Andhra Pradesh.

The soils, where demonstrations were conducted were red chalka. Along with the varietal introduction the integrated crop management practices (ICM) were demonstrated. ICM included high yielding variety, seed treatment with mancozeb @ 3.2g/kg seed, application of pre-emergence herbicide pendimethaline @ 2.25litre/ha and need based inter cultivation practices to arrest the weed problem and soil test based fertilizer application. As a check, farmers' practice of growing blackgram was considered and the economics of both the practices were calculated and compared to find the livelihood outcome in terms of income to convince the farmers about the new technology. Cost of cultivation, gross and net monetary returns were calculated. The formulas used for calculation of cost components and returns were as follows:

Cost A1 = Hired human labour + Own human labour + Hired bullock labour + Own bullock labour + Hired machinery services + Own machinery services + Seeds + FYM + Fertilizers + Plant protection chemicals + Depreciation + Land revenue + Interest on working capital

Cost A2 = Cost A1 + Rent paid for leased in land

Cost B = Cost A1/Cost A2 + Rental value of own land + Interest on fixed capital excluding land value

Cost C = Cost B + Imputed value of family labour

Return on investment = Gross returns / Total cost of cultivation
Net returns = Gross returns - Total cost of cultivation

Total cost of cultivation = Total fixed costs + Total variable costs

Farm business income = Gross income - Cost A1
Family labour income = Gross income - Cost B
Farm investment income = Farm business income - Imputed value of family labour

After the conduct of CFLDs, participant farmers' perceptions of CFLDs on ICM in sesamum in comparison with farmers' practice of growing blackgram were recorded. Frequency and percentages were calculated.

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RESULTS AND DISCUSSION

In demonstration plot, the total variable cost incurred was ₹16,470/ha, total fixed cost incurred was ₹30,007.60/ha and total cost of cultivation was ₹46,477.60/ha. In farmers' practice, total variable cost incurred was ₹20,405/ha, total fixed cost was ₹30,059.80/ha and total cost of cultivation was ₹50,464.80/ha (Table 1). Total fixed cost remain constant for a given period of time irrespective of the crop grown, while total variable cost varies with the crop grown. The findings indicated that sesamum could be cultivated with less total cost of cultivation than blackgram. The findings are in conformity with that reported by Raj *et al.* (2013), Lakshmi *et al.* (2017), Patil *et al.* (2018) and Venkata Subbaiah and Jyothi (2019).

In demonstration plot, cost A1 and cost A2 accounted for ₹22,699/ha, cost B was ₹44,102.60/ha and cost C was ₹46,477.60/ha. In farmers practice, cost A1 and cost A2 accounted for ₹26,649/ha, cost B was ₹48,219.80/ha and cost C was ₹50,464.80/ha (Table 2). Cost A1 and cost A2 were same as the respondents cultivated on own lands and there was no land leased and rent paid. The cost components calculated revealed that sesamum could be cultivated with less cost than blackgram.

Table 1 Details of cost of cultivation

Particulars	Demonstration: ICM in sesamum (₹/ha)	Farmers' practice: Blackgram (₹/ha)
Cost of cultivation		
Human labour	7250	7570
Bullock labour	--	--
Tractor power	1875	1875
Seed	1450	1825
FYM & fertilizer	1975	2125
Plant protection chemicals	1025	4040
Other miscellaneous expenses	2895	2970
Interest on working capital @ 7%	144.11	178.54
Sub total of variable cost (I)	16470.00	20405.00
Land revenue	250	250
Rental value of own land	18750	18750
Depreciation	5979	5994
Interest on fixed capital @ 12%	5028.60	5065.80
Sub total of fixed cost (II)	30007.60	30059.80
Total cost of cultivation (I+II)	46477.60	50464.80

Table 2 Details of cost components and returns

Particulars	Demonstration: ICM in Sesamum (₹/ha)	Farmers' practice: Blackgram (₹/ha)
Cost components		
Cost A1	22699.00	26649.00
Cost A2	22699.00	26649.00
Cost B	44102.60	48219.80
Cost C	46477.60	50464.80
Returns		
Yield (kg/ha)	1489	1165
Sale price (₹/kg)	80.00	70.00
Gross return (₹/ha)	119120.00	81550.00
Total cost (₹/ha)	46477.60	50464.80
Net returns (₹/ha)	72642.40	31085.20
Return on investment	2.56	1.62
Farm business income (₹/ha)	96421.00	54901.00
Family labour income (₹/ha)	75017.40	33330.20
Farm investment income (₹/ha)	94046.00	52656.00

The average yield recorded in demonstration plot was 1489 kg/ha with gross returns ₹ 1,19,120/ha, total cost of ₹46,477.60/ha, net returns of ₹72,642.40/ha, return on investment was 2.56 and farm business income was ₹96,421/ha, family labour income was ₹75,017.40/ha and farm investment income was ₹94,046/ha. The average yield recorded in farmers' practice of growing blackgram was 1165 kg/ha with gross returns of ₹81,550/ha, total cost of

₹50,464.80/ha, net returns of ₹31,085.20/ha, return on investment of 1.62, farm business income of ₹54,901/ha, family labour income of ₹33,330.20/ha and farm investment income of ₹52,656/ha (Table 3).The findings are in conformity with that reported by Balai *et al.* (2013), Gorfad *et al.* (2016), Naveen *et al.* (2017), Lakshman and Pati (2018), Jatav *et al.* (2019), Jyothi and Venkata Subbaiah (2019), Thakur *et al.* (2019) and Nagaveni *et al.* (2020).

The findings indicated that one rupee invested in sesamum gave ₹ 2.56, while one rupee invested in blackgram gave ₹1.62. This clearly indicates that growing sesamum following ICM practices is more beneficial for farmers than growing blackgram during early summer in the area. As a result of CFLDs on sesamum, the participant farmers and fellow farmers realized the livelihood outcome in terms of higher income by growing sesamum with ICM practices compared to blackgram in summer under irrigated conditions in the selected areas of Kishna district.

The participant farmers were enquired about their perception about CFLDs on ICM in sesamum in comparison with farmers' practice of growing blackgram. More than half of the respondents perceived that labour requirement was less (55.00%) in practicing ICM in sesamum, followed by more return on investment (62.50%), low risk (72.50%), cost effectiveness (80.00%), easy to cultivate (87.50%). All the respondents realized higher net returns from ICM in sesamum as compared with farmers' practice of growing blackgram (Table 3).

Self realization is the most important parameters that reinforces action. Now that the farmers are aware of the livelihood outcome in terms of income benefits of growing sesamum HYVs following ICM practices, they expressed that they would continue to grow sesamum in summer under irrigated conditions instead of a short duration pulse. The CFLDs also motivated the fellow farmers to adopt the demonstrated technology.

Table 3 Participant farmers' perception about CFLDs on ICM in sesamum in comparison with farmers' practice of growing blackgram

Category	Frequency & percent (n=40)
Labour required is less	22 (55.00)
Return on investment is more	25 62.50)
Low risk	29 (72.50)
Cost effective	32 (80.00)
Easy to cultivate	35 (87.50)
More net returns	40 (100.00)

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Diversity studies in groundnut (*Arachis hypogaea* L.) genotypes

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ABSTRACT

An experiment was conducted to assess the diversity that exists among seventy-five genotypes (COG 17001 to COG 17075) with five checks [CO7, VRI 8, TMV (Gn) 13, TMV 14 and ICGV 07222] of groundnut. Observations recorded for seventeen agronomic traits were subjected to Mahalanobis D^2 analysis. Statistical analysis revealed that maximum diversity between the genotypes was contributed by kernel yield per plant (g). Variability contributed by this trait in PCA had high factor loading (0.0382). The principal component analysis indicated that, the first six principal components had Eigen value more than one and exhibited 76.98% of maximum variability among eighty genotypes for seventeen characters.

Keywords: D^2 analysis, Diversity, Groundnut, Principal component analysis

Groundnut (*Arachis hypogaea* L.) is the major oilseed cum annual legume crop in the world belonging to fabaceae family with the native of Brazil. Chromosome number is 2n=4x=40 with the combination of A and B genomes. It is a multipurpose crop as oilseed, green manure, human and animal feed (Pande *et al.,* 2003; Upadhyaya *et al.,* 2006). Oil content of the kernels ranges from 44 to 55%, therefore it known as "King of Oilseeds". The total groundnut production in the world during the year 2016 -17 was 37.1 million metric tonnes from 26.4 million hectares with average productivity of 1400kg/ha. India become the world leader in groundnut farming, with 5.22 million hectares of cultivated area and production about 7.56 million tonnes. It thrives best in *kharif* season than in *rabi* season. It is classified into bunch type, spreading type and semi spreading type according to their growth habit. Being a self-pollinated crop, it has low variability with poor adaptability. Hence, various strategies were applied to generate variation in groundnut through many breeding methods *viz.,* selection, artificial hybridization, mutation etc. The genotypes developed by using foregoing methods can be subjected to various statistical analysis to capture the real genetic makeup of the plants. Therefore, present study was carried out to estimate the diversity of different groundnut genotypes.

The experiment was carried out with seventy-five genotypes (COG 17001 to COG 17075) with five checks *viz.,* CO7, VRI 8, TMV (Gn) 13, TMV 14 and ICGV 07222. It was conducted during *kharif* 2018 in randomized block design with two replications at Department of Oilseeds, Tamil Nadu Agricultural University, Coimbatore with the Latitude and Longitude of 11°02'S and 76°92'W respectively. Each genotype was planted in 4 rows of 4m length with the spacing of 30 x 10 cm. All the cultural practices were carried out as per the recommended package of practices for groundnut. Five plants per genotype were chosen and traits were recorded. Mean value of them were used for statistical analysis. Characters recorded included plant height (cm), number of primary branches/plant, days to flowering, days to fifty per cent flowering, number of pods/plant, plant dry weight (g), pod length (cm), pod width (cm), oil content (%), hundred pod weight (g), shelled weight (g), shelling per centage (%), mature kernel weight (g), sound mature kernel per centage (%), hundred kernel weight (g), pod yield/plant (g) and kernel yield/plant (g).The D^2 statistics was proposed by Mahalanobis (1928) by measuring group distances of multiple traits. Genotypes were clustered (inter and intra clusters) based on their relative distances according to Radhakrishna Rao (1952). Agglomerative hierarchical method with Euclidean distance and Principal Component Analysis were used in this study to group the genotypes.

The results obtained from D^2 analysis are presented in Tables 1 to 3. Eighty genotypes were clustered into eleven clusters. Each cluster had different numbers of genotypes based on their origin and relationships. Average intra and inter cluster distance ranged from 2.93 - 15.92 and 5.90 - 18.35 respectively (Table 1). Cluster XI showed highest intra cluster distance of 15.92 and cluster I showed lowest intra cluster distance of 2.93. For inter cluster distance, cluster I and X had highest inter distance of 18.35 and least inter cluster distance observed between II and VI (5.90).

Mean values for observed characters in the clusters are presented in Table 2. Cluster I exhibited high mean value for plant dry weight (82.7g), pod length (3.3cm), pod width (1.3cm), mature kernel weight (57.8g), sound mature kernel percentage (92.4%). Cluster III showed highest mean value for plant height (45.1cm). Cluster IV showed highest mean value for oil content (50.7%). Cluster V showed highest mean value for number of pods/plant (41.8), hundred kernel

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weight (49.8g), single plant yield (38.7g), kernel yield/plant (23.8). Cluster VI recorded highest mean value for days to flowering (33.5days), days to fifty per cent flowering (36 days), and shelling percentage (73.1%). Cluster VIII recorded highest mean value for number of primary branches/plant (5.9). Cluster XI showed highest mean value for hundred pod weight (106.1g) and shelled weight (69.1g). Towards genetic divergence, maximum per centage of contribution were given by kernel yield/plant (g) (30%) followed by hundred pod weight (g) (20.85%) and plant dry weight (g) (10.06%) (Table 3). Diversity was low for many of the traits as indicated by their lower per centage contribution: Pod width (cm) (1.96%), number of pods per plant (1.87%), days to flowering (days) (1.33%) and oil content (%) (1.17%). Plant height (cm) and days to fifty per cent flowering (days) contributed lowest percentage 0.57% and 0.25% respectively towards genetic divergence. Genetic diversity among groundnut genotypes was carried out by using agglomerative hierarchical method which measures Euclidean distance for seventeen quantitative characters using Statistical Tools for Agricultural Research (STAR). The genotypes were grouped into different clusters and sub clusters which is presented in Table 4. All genotypes were divided into three major clusters with respect to their relationship. Result of phenotypic genetic diversity in groundnut genotypes were in accordance with what has been reported by Sardar *et al.* (2017), Venkatesh *et al.* (2016), Bhakal and Lal (2015) and Zaman *et al.* (2010).

Table 1 Intra (diagonal) and inter cluster average distances among eleven clusters for seventeen characters in eighty genotypes

Clusters	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI	Cluster VII	Cluster VIII	Cluster IX	Cluster X	Cluster XI
Cluster I	2.93	11.57	8.82	10.51	10.88	11.82	13.75	13.25	11.88	18.35	13.58
Cluster II		4.22	8.10	6.29	7.91	5.90	9.15	10.41	7.03	10.74	12.66
Cluster III			4.53	7.66	8.12	10.08	11.46	11.05	10.23	15.24	12.63
Cluster IV				4.57	8.95	7.96	9.51	12.15	10.05	12.23	12.74
Cluster V					4.66	9.23	12.68	11.84	8.30	13.30	12.81
Cluster VI						4.79	8.48	10.21	7.40	11.21	12.96
Cluster VII							4.98	8.02	9.11	9.90	15.37
Cluster VIII								4.99	8.28	12.88	15.25
Cluster IX									5.27	11.22	13.88
Cluster X										5.34	17.73
Cluster XI											15.92

Table 2 Cluster mean values for seventeen characters of eighty genotypes in eleven clusters

Clusters	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12	C 13	C 14	C 15	C 16	C 17
Cluster I	37.0	5.4	31.8	35.0	36.4	82.7	3.3	1.3	49.6	98.3	62.8	48.5	63.9	57.8	92.4	32.8	22.5
Cluster II	39.5	4.6	31.0	35.0	37.1	45.3	2.5	1.2	46.9	93.8	62.0	47.5	66.1	51.5	83.1	30.9	20.7
Cluster III	45.1	5.3	30.8	34.3	40.6	60.2	2.8	1.1	49.9	102.8	56.0	44.3	54.5	45.3	80.9	38.7	21.2
Cluster IV	39.2	4.3	30.3	34.3	37.2	57.3	2.4	1.1	50.7	100.5	66.3	46.0	66.1	53.0	80.2	33.2	20.9
Cluster V	36.9	4.9	31.0	34.0	41.8	41.1	3.2	1.2	50.0	99.5	63.5	49.8	63.9	52.5	82.7	38.7	23.8
Cluster VI	35.7	4.7	33.5	36.0	30.5	41.3	2.6	1.2	48.7	92.5	67.5	48.8	73.1	56.0	83.1	25.5	19.7
Cluster VII	32.6	4.6	32.5	35.3	32.6	49.3	2.3	1.1	48.0	78.8	51.0	31.0	64.8	37.8	74.3	22.8	14.3
Cluster VIII	35.7	5.9	32.5	35.3	39.4	45.2	2.9	1.2	47.4	78.8	56.3	24.3	71.5	37.5	67.1	28.0	17.0
Cluster IX	36.0	5.2	31.8	35.0	32.4	37.6	3.0	1.2	46.8	81.0	55.0	41.8	67.9	48.3	87.8	23.8	17.3
Cluster X	26.7	3.6	30.3	34.5	35.5	31.9	2.6	1.1	49.1	71.0	49.8	43.8	70.1	32.5	65.5	22.5	14.6
Cluster XI	37.3	5.0	31.8	35.2	37.6	53.6	2.9	1.2	49.0	106.1	69.1	47.6	65.8	56.4	81.7	35.4	22.5

1-Plant height, 2-Number of primary branches, 3-Days to first flowering, 4-Fifty per cent flowering, 5-Number of pods per plant, 6-Plant dry weight, 7-Pod length, 8-Pod width, 9-Oil content, 10-Hundred pod weight, 11-Shelled weight, 12-Hundred kernel weight, 13-Shelling per centage, 14-Mature kernel weight, 15-Sound mature kernel per centage, 16-Single plant yield, 17-Kernel yield per plant

Table 3 Per cent contribution of seventeen characters to genetic divergence of eighty genotypes in *kharif* season

Characters	No. of First Rank	Per cent Contribution (%)
Plant height (cm)	18	0.57
Number of primary branches	143	4.53
Days to flowering (days)	42	1.33
Fifty percent flowering (days)	8	0.25
Number of pods per plant	59	1.87
Plant dry weight (g)	318	10.06
Pod length (cm)	203	6.42
Pod width(cm)	62	1.96
Oil content (%)	37	1.17
Hundred pod weight (g)	659	20.85
Shelled weight (g)	91	2.88
Shelling per cent (%)	65	2.06
Mature kernel weight (g)	193	6.11
Sound mature kernel percentage (%)	143	4.53
Hundred kernel weight (g)	64	2.03
Single plant yield (g)	107	3.39
Kernel yield per plant (g)	948	30.00
Total	3160	100

Table 4 Distribution of eighty genotypes into eleven clusters based on seventeen characters

Clusters	Genotypes
Cluster I	COG17061, COG17066
Cluster II	COG17037, COG17075
Cluster III	COG17044, COG17046
Cluster IV	COG17049, COG17070
Cluster V	COG17002, COG17055
Cluster VI	COG17019, COG17073
Cluster VII	COG17033, COG17050
Cluster VIII	COG17032, COG17035
Cluster IX	COG17029, COG17030
Cluster X	COG17015, COG17016
Cluster XI	COG17001, COG17003, COG17004, COG17005, COG17006, COG17007, COG17008, COG17009, COG17010, COG17011, COG17012, COG17013, COG17014, COG17017, COG17018, COG17020, COG17021, COG17022, COG17023, COG17024, COG17025, COG17026, COG17027, COG17028, COG17031, COG17034, COG17036, COG17038, COG17039, COG17040, COG17041, COG17042, COG17043, COG17045, COG17047, COG17048, COG17051, COG17052, COG17053, COG17054, COG17056, COG17057, COG17058, COG17059, COG17060, COG17062, COG17063, COG17064, COG17065, COG17067, COG17068, COG17069, COG17071, COG17072, COG17074, CO 7, ICGV 07222, VRI 8, TMV 13, TMV 14.

Table 5 Eigen values, proportions of variability and quantitative characters contributed to the first six PCs of eighty groundnut genotypes

Traits	Principal Components					
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Eigen Values	2.4197	1.4292	1.2302	1.2011	1.0806	1.0319
Proportion of Variance (%)	34.44	12.02	8.90	8.49	6.87	6.26
Cumulative Proportion (%)	34.44	46.46	55.36	63.84	70.71	76.98
Plant height (cm)	-0.1065	0.1999	0.4758	0.2003	0.1043	-0.1060
Number of primary branches	0.0306	0.1526	0.3563	-0.2094	0.5974	0.0561
Days to flowering (days)	-0.0226	0.6476	-0.0886	0.1156	0.0248	0.0511
Days to fifty per cent flowering (days)	-0.0463	0.6298	-0.1245	0.1346	-0.0352	0.0353
Number of pods per plant	-0.1684	0.1570	0.1309	-0.5537	-0.2389	-0.4550
Plant dry weight (g)	-0.0515	-0.1356	0.5880	0.0352	0.2128	0.0446
Pod length (cm)	-0.2640	0.0638	-0.0712	0.0162	0.1421	0.2092
Pod width (cm)	-0.2306	0.0698	0.0879	-0.0363	-0.1026	0.3628
Hundred pod weight (g)	0.3628	-0.0842	-0.0499	-0.0210	0.0275	0.2316
Shelled weight (g)	-0.3607	-0.1147	-0.1615	0.0770	0.2311	-0.0134
Shelling per centage (%)	0.1307	-0.0451	-0.2555	0.1679	0.4345	-0.5855
Mature kernel weight (g)	-0.3682	-0.0645	-0.0617	0.2935	0.0881	-0.1322
Sound mature kernel per centage (%)	-0.1498	0.0249	0.1544	0.5175	-0.1733	-0.1961
Hundred kernel weight (g)	-0.3152	-0.1769	-0.1578	0.1019	0.0891	0.0651
Oil content (%)	0.0711	-0.0908	0.3127	0.2834	-0.4294	-0.1215
Single plant yield (%)	-0.3712	0.0249	0.0523	-0.3029	-0.1387	-0.0958
Kernel yield per plant (g)	-0.3771	0.0382	0.0265	-0.0639	-0.0711	-0.3415

Principal component analysis was done to extract the characters which contributing most of the variation. Eigen value greater than one in PC component was taken into account to assess the variability in genotypes. The PCA explained that, first six principal components had Eigen value more than one and exhibited 76.98% of maximum variability among eighty genotypes for seventeen characters (Table 5). First PC was mainly loaded by number of primary branches per plant (0.030), oil content (%) (0.071), shelling percentage (%) (0.130) and these characters contributed 34.4% variability. Similarly, each PC contributed variability for different traits. Makinde and Ariyo (2010) reported similar results in their study with groundnut genotypes.

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Evaluation of field efficacy of microbial and chemical insecticides for the management of defoliator pests in castor

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ABSTRACT

Field studies were conducted to evaluate the efficacy of microbial and chemical insecticides against castor semilooper (*Achaea janata*) and tobacco caterpillar (*Spodoptera litura*) in castor during *kharif* 2019-20. Bioefficacy of two microbials *viz.,* DOR Bt-127 SC formulation @ 3 ml/l and commercial formulation of *Bacillus thuringiensis* var. kurstaki @ 1 g/l and chemical insecticides *viz.,* flubendiamide 39.35SC @ 0.2 ml/l and thiodicarb 75WP @ 1 g/l were evaluated against the pests. Comparing all treatments, the newer insecticide, flubendiamide 39.35SC @ 0.2 ml/l recorded significantly lower infestation of semilooper larval population up to 14 days after the spray treatment (DAT) in both first (0.18 larvae/plant) and second spray (0.11 larvae/plant). In microbials, in both first and second spray treatments at 3 DAT, mortality of the semilooper larvae was high with minimum larval population in DOR Bt-127 SC formulation (0.68 larvae/plant). Reduction in *S. litura* population was also high in flubendiamide 39.35 SC @ 0.2 ml /l spray followed by DOR Bt-127 SC formulation. The defoliation by both the defoliators was less than 10% in flubendiamide sprayed plots after second spray at 14 DAT. In microbial insecticides sprayed plots also the defoliation by both the defoliators was low (12.8 to 14.4%). The effect of spray treatments on the semilooper larval parasitisation by the parasitoid, *S. maculipennis* recorded that the microbials were very safe and the larval parasitisation was very high in DOR Bt-127 SC formulation (40.2%) and commercial Btk (28.8%) when compared to chemical pesticides (9.2 to 11.6%). Seed yield obtained was high in flubendiamide (1105 kg/ha) and DOR Bt-127 SC formulation (1078 kg/ha) treatments followed by commercial Btk sprayed plots whereas the lowest yield was recorded in untreated control (642 kg/ha). When comparing the cost involved and return, the net return was high in DOR Bt-127 SC (₹22,794/ha) and flubendiamide (₹22,215/ha) sprayed plots. Highest cost benefit ratio (1:1.96) was realized with DOR Bt-127 SC formulation followed by flubendiamide (1:1.87).

Keywords: Castor, Defoliators, Bt, Insecticides, Management, Safety to natural enemies

Castor (*Ricinus communis* L.) is an important oilseed crop grown in several states of India. The crop is predominantly grown under rainfed conditions. India is the world leader, having maximum area of 8.90 lakh ha with production of 20.6 lakh tonnes and productivity of 1899 kg/ha (Indiastat, 2018-19). The major problem in castor production is due to the damage by foliage feeders. Castor semilooper, *Achaea janata* L. and tobacco caterpillar, *Spodoptera litura* (F.) are regular and serious defoliator pests belong to the family noctuidae and voracious feeders which lead economic yield losses in castor. Castor semilooper and the tobacco caterpillar the pests activity starts in August and peak during September to November in Tamil Nadu. Both the pests are nocturnal in habit and larvae are nocturnal feeders hide during daytime in soil crevices. Semilooper larvae feed voraciously on the leaves, making small holes initially and then lead to complete defoliation of the plant, leaving only bare stems and veins. Castor is the most preferred host for tobacco caterpillar, though it is highly polyphagous pest. Young larvae feed gregariously on the leaf surface initially and then disperse to the plant. Feeding is initially by skeletonizing leaving the outline of leaf veins on the plant, and caterpillars eat the entire leaves. Both the defoliators occurs during the vegetative to early reproductive phase of castor crop (Lakshminarayana and Raoof, 2005; Pathak, 2009) in October to November months leads to extensive defoliation as the larvae are nocturnal and voracious feeders.

Many synthetic insecticides used for controlling these defoliators pests in castor, are not safe to the parasitoids, *Snellenius* (*Microplitis*) *maculipennis* Zepligate which is a potential and unique larval parasitoid of the castor semilooper and occurs naturally in many fields that are not sprayed with chemical insecticides. The activity of parasitoids in parasitizing 75% of the semilooper larvae in the field was reported by Vimala Devi *et al.* (1996). Use of microbial insecticides is the alternate eco-friendly pest management strategy for these defoliators and to conserve the parasitoids. The bacterial microbial insecticide with *Bacillus thuringiensis* var. *kurstaki* has been in use for long period as a safe stomach poison inducing immediate cessation of feeding for the control of many lepidopteran pests. Sujatha and Lakshminarayana (2005) reported the susceptibility of castor semilooper, to insecticide crystal proteins derived from *Bacillus thuringiensis.* Several such microbial insecticides are developed and its efficacy on

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serious pests is under test. The Indian Institute of Oilseeds Research, Hyderabad has developed a Bt microbial insecticide as DOR Bt-127 SC formulation. In view of studying the economic significance on management of defoliator pests in castor, field studies were undertaken to evaluate the efficacy of DOR Bt with commercial Bt and chemical insecticides to find out a suitable component in pest management.

Field studies were conducted to evaluate the efficacy of microbial and chemical insecticides against *A. janata* and *S. litura* in castor hybrid DCH-519 during *kharif* 2019-20 at the research farm of Tapioca and Castor Research Station, Yethapur, Salem district of Tamil Nadu. The experiment was laid out in a Randomized Block Design in a plot size of 4.5 m x 6 m with spacing of 90 cm x 60 cm. with five treatments and replicated four times. All the agronomic practices were followed as per the recommendations except for pest management. Bioefficacy of two microbials *viz.,* DOR Bt-127 SC formulation @ 3 ml/l and commercial formulation of *Bacillus thuringiensis* var. *kurstaki* (Delfin WG®) @ 1 g/l and chemical insecticides *viz.,* flubendiamide 39.35 SC @ 0.2 ml/l and thiodicarb75 WP@ 1 g/l were tested against *A. janata* and *S. litura* and compared with untreated control. The treatments were imposed twice with an interval of 15 days during the third week of October and in the first week of November after observing early instars and grown up larvae with heavy infestation levels of defoliator pests. Observations were recorded on larval population/plant from ten randomly selected plants from each replication in each treatment at one day before and 3, 7 and 14 days after spraying and the mean larvae/plant and the per cent mortality was worked out. The extent of defoliation was recorded as Percent leaf area infested/plant. Observation on the cocoon of larval parasitoid of semilooper, *S. maculipennis* and the percentage parasitisation were also recorded. Based on that the efficacy of microbial insecticides was worked out. Finally the yield was recorded on the net plot area and then converted the yield to kg/ha. The economics *viz.,* gross return, net returns and cost benefit ratio were worked out. The data obtained were subjected to statistical analysis and by following the ANOVA, difference between the data were determined using least significant difference.

The mean semilooper larval population in different treatments after the first and second spray are presented in Table.1. The initial pre-treatment semilooper larval population ranged from 2.9 to 3.8 larvae/plant in the trial plots. After imposition of the first spray, 3 days after treatment (DAT), the mortality of the semilooper was significantly high with lowest larval population (1.17 larvae/plant) in flubendiamide 39.35 SC @ 0.2 ml/l treatment when compared to microbial insecticides and other treatments. Comparing all treatments, the newer insecticide, flubendiamide 39.35 SC @ 0.2 ml/l spray recoded significantly lower infestation of up to 14 days DAT in both first (0.18 larvae/plant) and second spray (0.11 larvae/plant). In microbials, in both first and second spray treatments at 3DAT, mortality of the semilooper larvae was high with minimum larval population (0.68 larvae/plant) in DOR Bt-127 SC formulation when compared to the recommended chemical insecticide and untreated check. Vimala Devi and Hari (2010) also reported the efficacy of DOR Bt isolate in semilooper management. At 7 DAT, semilooper population was low in commercial Btk and DOR Bt-127 SC formulation which recorded 0.36 and 0.39 larvae /plant respectively. The results from pooled mean data revealed that flubendiamide 39.35 SC @ 0.2 ml/l was superior with least population after first spray (0.81 larvae/plant) and second spray (0.31 larvae/plant) over microbials and untreated check followed by DOR Bt-127 SC formulation (1.03 and 0.46 larvae/plant). Per cent reduction of semilooper population over untreated control indicated that flubendiamide reduced the semilooper population upto 85.58 % followed by DOR Bt-127 SC formulation (78.60%), while commercial Btk and thiodicarb recorded 68.84% and 66.05% reduction respectively (Table 1). Deshmukh and Deshpande (1989) and Vimaladevi *et al.* (1996) reported that the population reduction was significant in Bt sprayed plots. Lakshmi Narayanamma *et al.* (2010) also reported 79.9 per cent field mortality of late instar *A. janata* larvae due to Bt spray.

The mean pre-treatment population of *S. litura* ranged from 2.18 to 2.67 larvae/plant in different treatments. After imposition of treatments, significant reduction in *S. litura* population was noticed in flubendiamide 39.35 SC @ 0.2 ml/l sprayed plots (1.03 larvae/ plant) at 3 DAT of first spray. Among the microbial insecticide treatments, the mean population of S. litura was low in DOR Bt-127 SC treatment both in first spray (0.72 larvae/plant) and after second spray (0.34 larvae/plant) when compared to commercial Btk. Per cent reduction over control indicated that flubendiamide reduced the *S. litura* population up to 84.27% followed by DOR Bt-127 SC formulation (73.03%). Among the treatments, when comparing the pooled mean data, flubendiamide was superior in reducing the population of S. litura after first spray (0.42 larvae/plant) and second spray (0.51 larvae/plant) followed by DOR Bt-127 SC formulation and commercial Btk at 0.72 and 1.08 larvae/plant in first spray and 0.34 and 0.75 larvae/plant in second spray respectively. While untreated control recorded high population of 2.59 to 2.67 larvae/plant (Table 2).

The defoliation by both the defoliators was low less than 10% in flubendiamide sprayed plots after second spray at 14 DAT. In microbial insecticides sprayed plots also the defoliation by both the defoliators was low (12.8 to 14.4%) when compared to untreated check (46.8%). Defoliation damage reduction over control was high (79.1%) in flubendiamide sprayed plots followed by the microbial insecticides DOR Bt-127 SC formulation and commercial Btk (72.6 and 69.2 respectively). The result is in accordance with the findings of Ahuja *et al.* (1998) and Lakshmi Narayanamma *et al.* (2010). The effect of spray treatments on the semilooper larval parasitisation by the parasitoid, *S. maculipennis* recorded that the microbials were very safe and the larval parasitisation was very high in DOR Bt-127 SC formulation (40.2 %) and commercial Btk (Delfin) (28.8%) when compared to chemical pesticides sprayed plots (9.2 to 11.6%) (Table 3). Basappa and Lingappa (2004) and Duraimurugan *et al.* (2015) also reported the safety of the Bt formulations for semilooper larval parasitoid.

All the treatments evaluated resulted in significantly higher seed yield over untreated control. Seed yield obtained was high in flubendiamide (1105 kg/ha) and DOR Bt-127 SC formulation (1078kg/ha) treatments followed by commercial Btk sprayed plots whereas the lowest yield was recorded in untreated control (642 kg/ha). When the cost involved and returns were compared, the net return was high in DOR Bt-127 SC (₹22,794/ha) and flubendiamide (₹22,215/ha) sprayed plots. Highest cost benefit ratio (1:1.96) was realized with DOR Bt-127 SC formulation followed by flubendiamide (1:1.87) (Table 4). The results from this field experiment revealed that, though the chemical insecticide, flubendiamide 39.35SC performed well in defoliator management, it was hazardous to larval parasitoids. The microbial insecticide DOR Bt-127 SC formulation @ 3ml/l was found safer to semilooper larval parasitoid with increased parasitization, and was superior to commercial Bt formulation in management of defoliators without population build up of the pests.

Table 1 Evaluation of DOR-Bt 127SC formulation against castor semilooper (*Achaea janata*) in castor

Treatment	Castor semilooper (No. of larvae/plant)											
	After first spray						After second spray					
	PTC	3 DAT	7 DAT	14 DAT	Mean	PRC	PTC	3 DAT	7 DAT	14 DAT	Mean	PRC
DOR Bt 127 SC @ 3 ml/l	3.4	2.29	0.68	0.24	1.03	69.25	1.15	0.91	0.39	0.07	0.46	78.60
Commercial Btk @ 1g/l	3.8	2.40	1.12	0.52	1.35	59.70	1.80	1.10	0.72	0.19	0.67	68.84
Flubendiamide 39.35 SC @ 0.2 ml/l	2.9	1.17	0.33	0.18	0.81	75.82	1.10	0.33	0.42	0.11	0.31	85.58
Thiodicarb 75 WP @ 1 g/l	3.6	2.60	1.40	0.98	1.66	50.44	1.67	0.98	0.92	0.28	0.73	66.05
Untreated Control	3.1	3.47	3.35	3.22	3.35	-	2.58	2.32	2.38	1.75	2.15	-
CD (P=0.05)	NS	0.81	0.74	0.34	-	-	0.79	0.43	0.49	0.33	-	-
CV (%)	-	10.7	15.2	11.4	-	-	8.2	14.3	11.5	18.5	-	-

PTC - Pre treatment count; DAT - Days after treatment; PRC- Per cent reduction over control

Table 2 Evaluation of microbial and chemical insecticides against tobacco caterpillar (*Spodoptera litura*) in castor

Treatment	Tobacco caterpillar (No. of larvae/plant)											
	After first spray						After second spray					
	PTC	3 DAT	7 DAT	14 DAT	Mean	PRC	PTC	3 DAT	7 DAT	14 DAT	Mean	PRC
DOR Bt 127 SC @ 3 ml/l	2.18	1.31	0.52	0.32	0.72	73.03	0.98	0.42	0.39	0.20	0.34	86.87
Commercial Btk @ 1g/l	2.46	1.62	0.98	0.65	1.08	59.55	1.46	1.07	0.72	0.47	0.75	71.04
Flubendiamide 39.35 SC @ 0.2 ml/l	2.03	1.03	0.66	0.46	0.42	84.27	0.60	0.94	0.42	0.16	0.51	80.31
Thiodicarb 75WP @ 1 g/l	2.67	1.89	1.38	0.76	1.34	49.81	1.23	1.58	0.92	0.60	1.03	60.23
Untreated Control	2.65	3.94	2.61	1.47	2.67	-	2.68	2.94	2.38	2.46	2.59	-
CD (P=0.05)	NS	0.90	0.56	0.32	-	-	0.69	0.62	0.49	0.51	-	-
CV (%)	-	12.4	15.2	20.6	-	-	13.8	18.2	11.5	15.3	-	-

Table 3 Field efficacy of microbial and chemical insecticides on defoliation and semilooper larval parasitization

Treatments	Defoliation (%)			Semilooper larval Parasitization (%)	Semilooper parasitization reduction over control (%)
	7 DAT	14 DAT	Reduction over control (%)		
DOR-Bt 127 SC @ 3 ml/l	14.2	12.8	72.6	40.2	37.7
Commercial Btk @ 1 g/l	16.7	14.4	69.2	28.8	55.3
Flubendiamide 39.35 SC @ 0.2 ml/l	10.8	9.8	79.1	9.2	85.7
Thiodicarb 75 WP @ 1g/l	24.4	21.7	53.6	11.6	82.0
Untreated Control	40.2	46.8	-	64.5	-
CD (P=0.05)	5.29	4.60	-	-	-
CV (%)	16.16	14.15	-	-	-

Table 4 Economics of microbial insecticides against castor defoliators

Treatments	Yield (kg/ha)	Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	C:B ratio
DOR-Bt 127 SC@3 ml/l	1078	23560	46354	22794	1:1.96
Commercial Btk @ 1 g/l	995	24510	42785	17250	1:1.74
Flubendiamide 39.35 SC@ 0.2 ml/l	1105	25300	47515	22215	1:1.87
Thiodicarb 75 WP@ 1 g/l	885	25800	38055	12255	1:1.47
Untreated Control	642	22100	27606	5506	1:1.29
CD (P=0.05)	124.52	-	-	-	-
CV (%)	8.59	-	-	-	-

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INDIAN SOCIETY OF OILSEEDS RESEARCH

Instructions to Authors for Preparation of Manuscript for Journal of Oilseeds Research

Prospective author(s) are advised to consult **Issue No. 27(1) June, 2010 of the Journal of Oilseeds Research** and get acquainted with the minor details of the format and style of the Journal. Meticulous compliance with the instructions given below will help quick handling of the manuscript by the reviewers, editor and printers. **Manuscripts are considered for publication in the Journal only from members of the ISOR.**

General

Full-length articles, short communications, book reviews and review articles are published in the Journal. Review articles and book reviews are published usually by invitation. Full length articles and short communications should report results of original investigations in oilseeds, oil bearing plants and relevant fields of science. Choice of submitting the paper(s) either as full length paper or short communication rests with the authors. The Editor(s) or Reviewer(s) will examine their suitability or otherwise only in that specific category. Each article should be written in English correctly, clearly, objectively and concisely. All the statements made in the manuscript should be clear, unambiguous, and to the point. Plagiarism is a crime and therefore, no part of the previously published material can be reproduced exactly without prior permission from the original publisher or author(s) as deemed essential and the responsibility of this solely rests on the authors. Also, authors shall be solely responsible for the authenticity of the results published as well as the inferences drawn thereof. Telegraphic languages should be avoided. The data should be reported in a coherent sequence. Use active voice. Active voice is clear, unambiguous and takes less space. Use past tense while reporting results. Do not repeat ideas in different forms of sentences. Avoid superfluous sentences such as `it is interesting to note that', `it is evident from the table that' or `it may be concluded that' etc. Use % for percent, %age for percentage, / for per, @ for at the rate of hr for hours, sec for seconds. Indicate date as 21 January 2010 (no commas anywhere). Spell out the standard abbreviations when first mentioned eg. Net assimilation rate (NAR), general combining ability (GCA), genetic advance (GA), total bright leaf equivalents (TBLE), mean sum of squares (MSS).

Manuscript

Language of the Journal is English. Generally, the length of an article should not exceed 3,000 words in the case of full-length article and 750 words in the case of short communication. However completeness of information is more important. Each half-page table or illustration should be taken as equivalent to 200 words. It is desirable to submit manuscript in the form of soft copy either as an e-mail attachment to editorisor@gmail.com (preferred because of ease in handling during review process) or in a **compact disk (CD) (in MS Word document; double line space; Times New Roman; font size 12).** In exceptional cases, where the typed manuscript is being submitted as hard copy, typing must be done only on one side of the paper, leaving sufficient margin, at least 4 cm on the left hand side and 3 cm on the other three sides. Faded typewriter ribbon should not be used. Double space typing is essential throughout the manuscript, right from the **Title** through **References** (except tables), foot note etc. Typed manuscript complete in all respects, is to be submitted to the Editor, Journal of Oilseeds Research, Directorate of Oilseeds Research, Rajendranagar, Hyderabad-500 030. Every page of the manuscript, including the title page, references, tables, etc. should be numbered. Punctuation marks help to show the meanings of words by grouping them into sentences, clauses, and phrases and in other ways. These marks should be used in proper manner if the reader of a paper is to understand exactly the intended meaning. Receipt of the manuscript (in the form of either soft or hard copy) will be acknowledged by the editorial office of the Society, giving a manuscript number which should be quoted in all subsequent correspondence regarding that particular article.

Full-length Articles

Organization of the Manuscript

Before reading the instructions given below, the author(s) would better have a close look at the latest issue of the Journal.

Full-length article comprises the following sections.

(a) Short title
(b) Title
(c) Author/Authors
(d) Institution and Address with PIN (postal) code
(e) Abstract (along with key words)
(f) Introduction
(g) Materials and Methods
(h) Results and Discussion
(i) Acknowledgments (if any)
(j) References
(k) Tables and figures (if any)

Guidelines for each section are as follows:

All these headings or matter thereof should start from left hand side of the margin, without any indent.

Short Title

A shortened title (approximately of 30 characters) set in capital letters should convey the main theme of the paper.

Title

Except for prepositions, conjunctions, pronouns and articles, the first letter of each word should be in capital letter. The title should be short and should contain key words and phrases to indicate the contents of the paper and be attractive. Jargons and telegraphic words should be avoided. In many cases, actual reading of the paper may depend on the attractiveness of the title.

Author/Authors

The name(s) of author(s) should be typed in capital letters a little below the title, starting from the left margin. Put an asterisk on the name of the corresponding author. **Give the Email ID of the corresponding author** as a footnote.

Institution and Address

This matter will come below the name(s) of the author(s). Name of the Laboratory/Department, followed by the name of the Institution/Organization/University where the work reported in the paper was carried out shall come below the name(s) of author(s). Complete postal address, which should include city/town, district, and state, followed by PIN (postal) code is to be furnished. In case any author has left the above address, this should be indicated as a footnote.

Abstract

The paragraph should start with the word Abstract (in bold font). The abstract should comprise brief and factual summary or salient points of the contents and the conclusions of the investigation reported in the paper and should refer to any new information therein. As the abstract is an independent entity, it should be able to convey the gist of the paper in a concise manner. It will be seen by many more people than will read the paper. The abstract, as concise as possible, should not exceed 250 words in length. Everything that is important in the paper must be reflected in the abstract. It should provide to the reader very briefly the rationale, objectives or hypothesis, methods, results and conclusions of the study described in the paper. In the abstract, do not deflect the reader with promises such as 'will be discussed' or 'will be explained'. Also do not include reference, figure or table citation. At first mention in the abstract, give complete scientific name for plants and other organisms, the full names of chemicals and the description of soil order/series. Any such names or descriptions from the abstract need not be repeated in the text. It must be remembered that the abstracting journals place a great emphasis on the abstract in the selection of papers for abstracting. If properly prepared, they may reproduce it verbatim.

"Key words" should, follow separately after the last sentence of the abstract. "Key words" indicate the most important materials, operations, or ideas covered in the paper. Key words are used in indexing the articles.

Introduction (To be typed as side-heading, starting from the left-hand margin, a few spaces below the key words)

This section is meant to introduce the subject of the paper. Introduction should be short, concise and indicate the objectives and scope of the investigation. To orient readers, give a brief reference to previous concepts and research. Limit literature references to essential information. When new references are available, do not use old references unless it is of historical importance or a landmark in that field. Emphasis should be given among other things on citing the literature on work done under Indian conditions. Introduction must include: (a) a brief statement of the problem, justifying the need for doing the work or the hypothesis on which the work is based, (b) the findings of others that will be further developed or challenged, and (c) an explanation of the approach to be followed and the objectives of the research described in the paper. If the methods employed in the paper are new, it must be indicated in the introduction section.

Materials and methods (To be typed as side-heading, starting from the left-hand margin, a few spaces below the introduction)

This part of the text should comprise the materials used in the investigation, methods of experiment and analysis adopted. This portion should be self-explanatory and have the requisite information needed for understanding and assessing the results reported subsequently. Enough details should be provided in this section to allow a competent scientist to repeat the experiments, mentally or in fact. The geographical position of soil site or soils used in the experiment or site of field trial should be identified clearly with the help of coordinates (latitude & longitude) and invariably proper classification according to Soil Taxonomy (USDA), must be indicated to the level of Great-group, Suborder or Order as far as possible. Specify the period during which the experiment(s) was conducted. Send the article after completion of the experiment(s) not after a gap of 5 years. Instead of kharif and rabi use rainy and winter season respectively. Please give invariably the botanical names for local crop names like raya, bajra moong, cholam etc. Botanical and zoological names should confirm to the international rules. Give authorities. Go through some of our recent issues and find out the correct names. Give latest correct names from authentic source. For materials, give the appropriate technical specifications and quantities and source or method of preparation. Should a product be identified by trade name, add the name and location of the manufacturer or a major distributor in parenthesis after the first mention of the product. For the name of plant protection chemicals, give popular scientific names (first letter small), not trade names (When trade name is given in addition, capitalize the first letter of the name). Known methods of analysis should be indicated by referring to the original source, avoiding detailed description. Any new technique developed and followed should be described in fair detail. When some specially procured or proprietary materials are used, give their pertinent chemical and physical properties. References for the methods used in the study should be cited. If the techniques are widely familiar, use only their names in that case.

Results and Discussion (To be typed as a side-heading, a few spaces below the matter on "Materials and Methods")

This section should discuss the salient points of observation and critical interpretation thereof in past tense. This should not be descriptive and mere recital of the data presented in the tables and diagrams. Unnecessary details must be avoided but at the same time significant findings and special features should be highlighted. For systematic discussion, this section may be divided into sub-sections under side-heading and/or paragraph side heading. Relate the results to your objectives. While discussing the results, give particular attention to the problem, question or hypothesis presented in the introduction. Explain the principles, relationships, and generalizations that can be supported by the results. Point out any exceptions. Explain how the results relate to previous findings, support, contradict or simply add as data. Use the Discussion section to focus on the meaning of your findings rather than recapitulating them. Scientific speculation is encouraged but it should be reasonable and firmly founded in observations. When results differ from previous results, possible explanations should be given. Controversial issues should be discussed clearly. References to published work should be cited in the text by the name(s) of author(s) as follows: Mukherjee and Mitra (1942) have shown or It has been shown (Mukherjee and Mitra, 1942)..... If there are more than two authors, this should be indicated by et al. after the surname of the first author, e.g., Mukherjee et al. (1938).

Always conclude the article by clearly crystallizing the summary of the results obtained along with their implications in solution of the practical problems or contribution to the advancement of the scientific knowledge.

Acknowledgments (To be typed as given above, as a side-heading, well below the concluding portion of Conclusions)

The author(s) may place on record the help, and cooperation, or financial help received from any source, person or organization. This should be very brief, and omitted, if not necessary.

References (To be typed as above, as side heading below Acknowledgement)

The list of references must include all published work referred to in the text. Type with double line spacing. Do not cite anonymous as author; instead cite the name of the institute, publisher, or editor. References should be arranged alphabetically according to the surnames of the individual authors or first authors. Two or more references by the same author are to be cited chronologically; two or more in the same year by the letters a, b, c, etc. All individually authored articles precede those in which the individual is the first or joint author. Every reference cited in the article should be included in the list of References. This needs rigorous checking of each reference. Names of authors should not be capitalized.

The reference citation should follow the order: author(s), year of publication, title of the paper, periodical (title in full, no abbreviations, italics or underlined), volume (bold or double underlining), starting and ending pages of the paper. Reference to a book includes authors(s), year, title (first letter of each word except preposition, conjunction, and pronouns in capitals and underlined), the edition (if other than first), the publisher, city of publication. If necessary, particular page numbers should be mentioned in the last. Year of publication cited in the text should be checked with that given under References. Year, volume number and page number of each periodical cited under "References" must be checked with the original source. The list of references should be typed as follows:

Rao C R 1968. *Advances in Statistical Methods in Biometrical Research*, pp.40-45, John Wiley & Sons, New York.
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Reference to unpublished work should normally be avoided and if unavoidable it may be mentioned only in the text.

Short Communication

Conceptually short communication is a first report on new concept, ideas and methodology which the author(s) would wish to share with the scientific community and that the detailed paper would follow. Short Communication is akin to an advance booking for the report on the findings. Short communications may include short but trend-setting reports of field or laboratory observation(s), preliminary results of long-term projects, or new techniques or those matters on which enough information to warrant its publication as a full length article has still not been generated but the results need to be shared immediately with the scientific community. The style is less formal as compared with the "full-length" article. In the short communications, the sections on abstract, materials and methods, results and discussion, and conclusion are omitted; but the material is put concisely in the same sequence but without formal sections. The other instructions are the same as in the case of the full-length articles.

Tables

Tables should not form more than 20% of the text. Each table should be typed on separate sheet and should have on the top a table number (in Arabic numerals *viz.* 1, 2, 3 etc.) and a caption or title which should be short, but sufficiently explanatory of the data included in the table. Information in the table should never duplicate that in the text and vice versa. Symbols (asterisks, daggers, etc. or small letters, *viz.*, a, b, etc.) should be used to indicate footnotes to tables. Maximum size of table acceptable is what can be conveniently composed within one full printed page of the journal. Over-sized tables will be rejected out-right. Such tables may be suitably split into two or more small tables.

The data in tables should be corrected to minimum place of decimal so as to make it more meaningful. Do not use full stop with CD, SEm±, NS (not C.D., S.E.m±, N.S.). Do not put cross-rules inside the table. Tables should be numbered consecutively and their approximate positions indicated in the margin of the manuscript. Tables should not be inserted in the body of the text. Type each table on a separate sheet. Do not use capital letters for the tabular headings, do not underline the words and do not use a full-stop at the end of the heading. All the tables should be tagged with the main body of the text i.e. after references.

Figures

Figures include diagrams and photographs. Laser print outs of line diagrams are acceptable while dot-matrix print outs will be rejected. Alternatively, each illustration can be drawn on white art card or tracing cloth/ paper, using proper stencil. The lines should be bold and of uniform thickness. The numbers and letterings must be stenciled; free-hand drawing will not be accepted. Size of the illustrations as well as numbers, and letterings should be sufficiently large to stand suitable reduction in size. Overall size of the illustrations should be such that on reduction, the size will be the width of single or double column of the printed page of the Journal. Legends, if any, should be included within the illustration. Each illustration should have a number followed by a caption typed/ typeset well below the illustration.

Title of the article and name(s) of the author(s) should be written sufficiently below the caption. The photographs (black and white) should have a glossy finish with sharp contrast between the light and the dark areas. Colour photographs/ figures are not normally accepted. One set of the original figures must be submitted along with the manuscript, while the second set can be photocopy. The illustrations should be numbered consecutively in the order in which they are mentioned in the text. The position of each figure should be indicated in the margin of the text. The photographs should be securely enclosed with the manuscript after placing them in hard board pouches so that there may not be any crack or fold. Photographs should preferably be 8.5 cm or 17 cm wide or double the size. The captions for all the illustrations (including photographs) should be typed on a separate sheet of paper and placed after the tables.

Expression of Plant Nutrients on Elemental Basis

The amounts and proportions of nutrient elements must be expressed in elemental forms e.g. for ion uptake or in other ways as needed for theoretical purposes. In expressing doses of nitrogen, phosphatic, and potassic fertilizers also these should be in the form of N, P and K, respectively. While these should be expressed in terms of kg/ha for field experiments, for pot culture studies the unit should be in mg/kg soil.

SI Units and Symbols

SI Units (System International d 'Unities or International System of Units) should be used. The SI contains three classes of units: (i) base units, (ii) derived units, and (iii) supplementary units. To denote multiples and sub-multiples of units, standard abbreviations are to be used. Clark's Tables: Science Data Book by Orient Longman, New Delhi (1982) may be consulted.

Some of these units along with the corresponding symbols are reproduced for the sake of convenience.

Names and Symbols of SI Units

Physical Symbol for SI Unit Symbol Remarks quantity physical quantity for SI Unit

Primary Units					
length	l		time	t	
metre	m		second	s	
mass	m		electric current	I	
kilogram	kg		ampere	A	
Secondary Units					
plane angle	radian	rad	Solid angle	steradian	sr
Unit Symbols					
centimetre	cm		microgram	μg	
cubic centimetre	cm^3		micron	μm	
cubic metre	m^3		micronmol	μmol	
day	d		milligram	mg	
decisiemens	dS		millilitre	mL	
degree-Celsium	°C [=(F-32)x0.556]		minute	min	

gram	g	nanometre	nm
hectare	ha	newton	N
hour	h	pascal	Pa
joule J	(= 10^7 erg or 4.19 cal.)	second	s
kelvin	K (= °C + 273)	square centimetre	cm^2
kilogram	kg	square kilometre	km^2
kilometre	km	tonne	t
litre	L	watt	W
megagram	Mg		

Some applications along with symbols

adsorption energy	J/mol (=cal/molx4.19)	leaf area	m^2/kg
cation exchange capacity	cmol (p+)/kg (=m.e./100 g)	nutrient content in plants (drymatter basis)	μg/g, mg/g or g/kg
Electrolytic conductivity	dS/m (=mmhos/cm)	root density or root length density	m/m^3
evapotranspiration rate	$m^3/m^2/s$ or m/s	soil bulk density	Mg/m^3 (=g/cm^3)
heat flux	W/m^2	specific heat	J/kg/K
gas diffusion	$g/m^2/s$ or $m^3/m^2/s$ or m/s	specific surface area of soil	m^2/kg
water flow	$kg/m^2/s$ (or) m^3m^2s (or) m/s	thermal conductivity	W/m/K
gas diffusivity	m^2/s	transpiration rate	$mg/m^2/s$
hydraulic conductivity ion uptake	m/s	water content of soil	kg/kg or m^3/m^3
(Per kg of dry plant material)	mol/kg	water tension	kPa (or) MPa

While giving the SI units the first letter should not be in capital i.e cm, not Cm; kg not Kg. There should not be a full stop at the end of the abbreviation: cm, not cm. kg, not kg.; ha, not ha.

In reporting the data, dimensional units, viz., M (mass), L (length), and T (time) should be used as shown under some applications above. Some examples are: 120 kg N/ha; 5 t/ha; 4 dS/m etc.

Special Instructions

I. In a series or range of measurements, mention the unit only at the end, e.g. 2 to 6 cm2, 3, 6, and 9 cm, etc. Similarly use cm2, cm3 instead of sq cm and cu m.

II. Any unfamiliar abbreviation must be identified fully (in parenthesis).

III. A sentence should not begin with an abbreviation.

IV. Numeral should be used whenever it is followed by a unit measure or its abbreviations, e.g., 1 g, 3 m, 5 h, 6 months, etc. Otherwise, words should be used for numbers one to nine and numerals for larger ones except in a series of numbers when numerals should be used for all in the series.

V. Do not abbreviate litre to` l' or tonne to `t'. Instead, spell out.

VI. Before the paper is sent, check carefully all data and text for factual, grammatical and typographical errors.

VII. Do not forget to attach the original signed copy of `Article Certificate' (without any alteration, overwriting or pasting) signed by all authors.

VIII. On revision, please answer all the referees' comments point-wise, indicating the modifications made by you on a separate sheet in duplicate.

IX. If you do not agree with some comments of the referee, modify the article to the extent possible. Give reasons (2 copies on a separate sheet) for your disagreement, with full justification (the article would be examined again).

X. Rupees should be given as per the new symbol approved by Govt. of India.

Details of the peer review process

Manuscripts are received mainly through e-mails and in rare cases, where the authors do not have internet access, hard copies of the manuscripts may be received and processed. Only after the peer review the manuscripts are accepted for publication. So there is no assured publication on submission. The major steps followed during the peer review process are provided below.

Step 1. *Receipt of manuscript and acknowledgement*: Once the manuscript is received, the contents will be reviewed by the editor/associate editors to assess the scope of the article for publishing in JOR. If found within the scope of the journal, a Manuscript (MS) number is assigned and the same will be intimated to the authors. If the MS is not within the scope and mandate of JOR, then the article will be rejected and the same is communicated to the authors.

Step 2. *Assigning and sending MS to referees*: Suitable referees will be selected from the panel of experts and the MS (soft copy) will be sent to them for their comments - a standard format of evaluation is provided to the referees for evaluation along with the standard format of the journal articles and the referees will be given 4-5 week time to give their comments. If the comments are not received, reminders will be sent to the referees for expediting the reviewing process and in case there is still no response, the MS will be sent to alternate referees.

Step 3. *Communication of referee comments to authors for revision*: Once the referee comments and MS (with suggestions/ corrections) are received from the referees, depending on the suggestions, the same will be communicated to the authors with a request to attend to the comments. Authors will be given stipulated time to respond and based on their request, additional time will be given for attending to all the changes as suggested by referees. If the referees suggest no changes and recommend the MS for publication, then the same will be communicated to the authors and the MS will be taken up for editing purpose for publishing. In case the referees suggest that the article cannot be accepted for JOR, then the same will be communicated to the authors with proper rationale and logic as opined by the referees as well as by the editors.

Step 4. *Sending the revised MS to referees*: Once the authors send the revised version of the articles, depending on the case (like if major revisions were suggested by referees) the corrected MS will be sent to the referees (who had reviewed the article in the first instance) for their comments and further suggestions regarding the acceptability of publication. If only minor revisions had been suggested by referees, then the editors would look into the issues and decide take a call.

Step 5. *Sending the MS to authors for further revision*: In case referees suggest further modifications, then the same will be communicated to the authors with a request to incorporate the suggested changes. If the referees suggest acceptance of the MS for publication, then the MS will be accepted for publication in the journal and the same will be communicated to the authors. Rarely, at this stage also MS would be rejected if the referees are not satisfied with the modifications and the reasoning provided by the authors.

Step 6. *Second time revised articles received from authors and decision taken*: In case the second time revised article satisfies all the queries raised by referees, then the MS will be accepted and if not satisfied the article will be rejected. The accepted MS will be taken for editing process where emphasis will be given to the language, content flow and format of the article.

Then the journal issue will be slated for printing and also the pdf version of the journal issue will be hosted on journal webpage.

Important Instructions

- Data on field experiments have to be at least for a period of 2-3 years
- Papers on pot experiments will be considered for publication only as short communications
- Giving coefficient of variation in the case of field experiments Standard error in the case of laboratory determination is mandatory. For rigorous statistical treatment, journals like Journal of Agricultural Science Cambridge, Experimental Agriculture and Soil Use and Management should serve as eye openers.

SPECIAL ANNOUNCEMENT

In a recently conducted Executive Committee meeting of the Indian Society of Oilseeds Research, it was decided to increase the scope of the Journal of Oilseeds Research by accommodating vibrant aspects of scientific communication. It has been felt that, the horizon of scientific reporting could be expanded by including the following types of articles in addition to the Research Articles, Shor Communications and Review Articles that are being published in the journal as of now.

Research accounts (not exceeding 4000 words, with cited references preferably limited to about 40-50 in number): These are the articles that provide an overview of the research work carried out in the author(s)' laboratory, and be based on a body of their published work. The articles must provide appropriate background to the area in a brief introduction so that it could place the author(s)' work in a proper perspective. This could be published from persons who have pursued a research area for a substantial period dotted with publications and thus research account will provide an overall idea of the progress that has been witnessed in the chosen area of research. In this account, author(s) could also narrate the work of others if that had influenced the course of work in authors' lab.

Correspondence (not exceeding 600 words): This includes letters and technical comments that are of general interest to scientists, on the articles or communications published in Journal of Oilseeds Research within the previous four issues. These letters may be reviewed and edited by the editorial committee before publishing.

Technical notes (less than 1500 words and one or two display items): This type of communication may include technical advances such as new methods, protocols or modifications of the existing methods that help in better output or advances in instrumentation.

News (not exceeding 750 words): This type of communication can cover important scientific events or any other news of interest to scientists in general and vegetable oil research in particular.

Meeting reports (less than 1500 words): It can deal with highlights/technical contents of a conference/ symposium/discussion-meeting, etc. conveying to readers the significance of important advances. Reports must

Meeting reports should avoid merely listing brief accounts of topics discussed, and must convey to readers the significance of an important advance. It could also include the major recommendations or strategic plans worked out.

Research News (not exceeding 2000 words and 3 display items): These should provide a semi-technical account of recently published advances or important findings that could be adopted in vegetable oil research.

Opinion (less than 1200 words): These articles may present views on issues related to science and scientific activity.

Commentary (less than 2000 words): This type of articles are expected to be expository essays on issues related directly or indirectly to research and other stake holders involved in vegetable oil sector.

Book reviews (not exceeding 1500 words): Books that provide a clear in depth knowledge on oilseeds or oil yielding plants, production, processing, marketing, etc. may be reviewed critically and the utility of such books could be highlighted.

Historical commentary/notes (limited to about 3000 words): These articles may inform readers about interesting aspects of personalities or institutions of science or about watershed events in the history/development of science. Illustrations and photographs are welcome. Brief items will also be considered.

Education point (limited to about 2000 words): Such articles could highlight the material(s) available in oilseeds to explain different concepts of genetics, plant breeding and modern agriculture practices.

Note that the references and all other formats of reporting shall remain same as it is for the regular articles and as given in Instructions to Authors

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