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Review

Production, varietal improvement programme and seed availability of annual oilseeds in India: Current scenario and future prospects

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ABSTRACT

Oilseeds are important components of Indian Agriculture. The demand for oilseeds and edible oils would be 61.5 million tonnes and 17.2 million tonnes, respectively, during 2021-22 and the projected supply of oilseeds be only 39.20 million tonnes against the highest ever production of oilseeds in India i.e. 33.42 m t during 2019-20. As the level of self sufficiency is around 40%, there has been a large import of vegetable oils valued at `81,097 crores during 2020-21 to meet the consumption requirement of the country. Therefore, it is imperative to evolve new climate resilient technologies to increase production. Use of high yielding varieties and quality seeds with a contribution of 15%-20% each to the yield, is the first and foremost approach to enhance oilseeds production. The present paper reviews the current scenario of *kharif* and *rabi* annual oilseeds, development of varieties, their induction in to the seed chain and seed production during the last decade (2010-11 to 2019-20). Oilseeds area, production and yield showed inconsistent trend during the decade. The highest area (28.05 m ha), production (33.42 m t) and yield (1284 kg/ha) were recorded during 2013-14, 2019-20 and 2017-18, respectively. Area under sesame, niger, linseed, sunflower, safflower and castor substantially decreased during 2019-20 and consequently the production also decreased as compared to the base year (2010-11). Nevertheless, there was increase in yield/ha of these crops barring soybean. A total of 299 varieties of nine oilseed crops were developed during the last 11 years. This includes 23 bio-fortified varieties having nutritionally superior-edible oil such as high oleic acid in groundnut and safflower, high linoleic acid in linseed, low erucic acid (and concomitant increase in oleic acid) in oil and/or low glucosinolates in seed meal in rapeseed-mustard and KIT and lipoxygenase free soybean. Seed production chain of oilseeds during 2020-21 consisted of 261 varieties/hybrids comprising 62 of groundnut, 48 of soybean, 64 of rapeseed-mustard, 29 of sesame, 26 of linseed, 9 of niger, 7 of sunflower, 12 of safflower and 4 of castor including 152 varieties released during the last 10 years (up to 2020). There has been a continuous surge in the requirement for seeds of oilseed crops from 2010-11 (57.88 lakh q) until 2018-19 (58.56 lakh q). Seed requirement during 2019-20 was lower (55.61 lakh q) by 3.9% (2.27 lakh q). The highest seed requirement (67.13 lakh q) for seeds was during 2014-15, an increase of about 16.0%. Seed availability during the decade was always higher except for 2014-15 and 2015-16 which recorded 7.7% and 13.6% shortfall, respectively. The seed replacement rate was more than ideal except for groundnut, castor and sunflower and varietal replacement rate was also high. Bridging the huge yield gap and bringing additional lands in non-traditional areas and/or seasons and utilization of rice fallows are some of the options for enhancing oilseeds production. The latter, needs systematic and concerted efforts to identify suitable varieties and develop matching technologies involving time and cost. Efforts should be made, in the first instance, to reduce yield gap to below 20% in the next 3-4 years by facilitating access of farmers to timely availability of various critical inputs including credit, regular and timely technical backstopping and attractive remunerative prices to the crop produce through market interventions. This would lead to gear up additional production of oilseeds up to 9.0 m t in the immediate future.

Keywords: Bio-fortified varieties, Nutritional quality, Oilseeds, Seed availability, Seed requirement, Seed replacement rate, Varietal replacement rate

Oilseeds are important components of Indian agriculture with a share of 15.7% to the total arable land (Anonymous, 2020a). Vegetable oils and fats are integral part of daily diet as they provide the required energy for various metabolic activities of the body besides improving texture and taste of food. The consumption of edible oils is highly income and price elastic. Nevertheless, it continues to grow due to surge in *per capita* consumption of vegetable oils per annum that increased from 13.1 kg in 2009-10 to 18.1 kg in 2018-19 (Anonymous, 2020a). The projected demand of oilseeds and edible oil during 2021-22 is 61.5 m t and 17.2 m t, respectively, against the projected supply of only 39.20 m t (Anonymous, 2020b). The highest ever production of oilseeds achieved in India, was 33.42 m t, during 2019-20 (State-wise 4th advance estimates of production of commercial crops for 2019-20 (https://www.agricoop.nic.in, visited on September 27, 2020). The NCAER has estimated average annual growth rate in oilseeds production of 3.47%-4.29% (Anonymous, 2019a). Net availability from domestic production of vegetable oils in the country in

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2018-19 was 10.35 m t in comparison to the requirement (25.55 m t) which indicated self sufficiency level of about 40% (Anonymous, 2020a). During 2020-21, vegetable oils to the tune of 1354 m t worth ₹ 82097 crores were imported (http://agriexchange.apeda.gov.in, visited on April 24, 2021). Therefore, it is imperative to evolve new climate resilient technologies to increase production of oilseeds at least to reduce import of vegetable oils, in near future. Use of high yielding varieties and quality seeds with a contribution of 15%-20% each to yield is the first and foremost approach to enhance oilseeds production. Varietal improvement or evolving new varieties is a continuous and dynamic programme, in view of, coevolving and emerging new biotic (diseases, insects and weeds) and abiotic (temperature extremities, moisture, heat, frost, salts) stresses accentuated by climate change and intensive cropping. The focal point of the varietal improvement programme, in general, is up-scaling genetic ceiling to yield, *viz*., genetic enhancement, combining high yield and also incorporating resistance/tolerance of the existing biotic and abiotic stresses. Induction of newly released varieties in to the seed chain is vital for their reach to the end-users, i.e. the farmers. The present paper reviews the trends in oilseeds production, status of development and release of varieties and their induction in the seed chain, seed production during the decade (2010-11 to 2019-20) in India and also discusses the future prospects.

Oilseeds in India

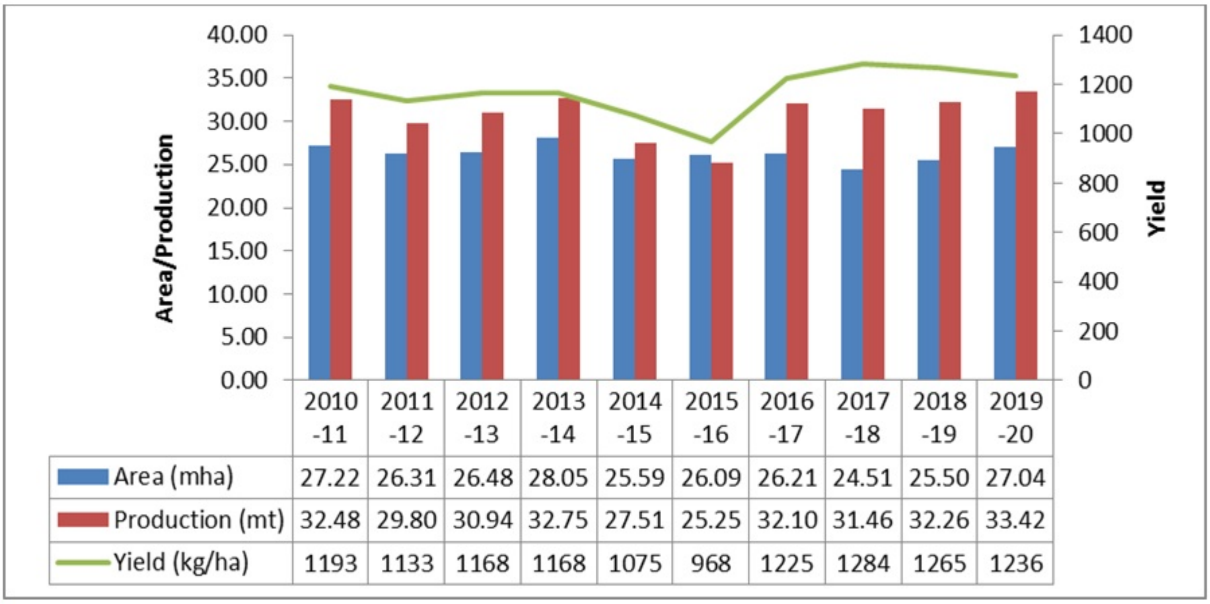
India accounted for 6.5% of global oilseeds output during 2019-20 (Anonymous, 2020c). Oilseeds in India are grown during rainy (*kharif*) as well winter (*rabi*) seasons and comprise nine annual crops., *viz.,* groundnut (*Arachis hypogaea* L.), soybean (*Glycine max* L.), rapeseed (*Brassica rapa* L. var. yellow sarson/brown sarson/toria; *Brassica napus* L. ssp. *oleifera* DC var. annua L.; *Eruca sativa* Mill.) - mustard (*Brassica juncea* (L.) Czern. & Coss.; *Brassica nigra* [L.] Koch; *Brassica carinata* A. Braun), sesame (*Sesamum indicum* L.), linseed (*Linum usitatissimum* L.), niger (*Guizotia abyssinica* L. f. Cass.), sunflower (*Helianthus annuus* L.), safflower (*Carthamus tinctorius* L.) and castor (*Ricinus communis* L.). Of these, groundnut, soybean, castor, sesame, niger and sunflower are grown mainly during *kharif,* while rapeseed-mustard, linseed and safflower are *rabi* season crops. Nevertheless, groundnut, castor, sesame and sunflower are also grown during *rabi* or summer season. Major share of area of groundnut and sunflower is during *kharif* and *rabi* season, respectively. *Kharif* oilseeds accounted for 74.1% and 72.0% of the oilseeds acreage and production, respectively, during 2019-20. Conversely, contribution of *rabi* oilseeds was only 25.9% to acreage and 28.0% to production of oilseeds in the country. Of the nine annual oilseed crops, castor and linseed are considered as non-edible oilseeds and accounted for 4.6% and 5.9% of the total oilseeds acreage and production, respectively during 2019-20. Groundnut, soybean and rapeseed-mustard during 2019-20 contributed 87.9% and 91.0% to oilseeds acreage and production, respectively (4^{th} advance estimates for 2019-20, www.agricoop.nic.in, visited on September 27, 2020). Further, contribution of castor and sesame was 4.0% and 6.0%, respectively, to oilseeds acreage and 5.5% and 2.2% to production, respectively. Other crops such niger, linseed, sunflower and safflower together contributed only 2.0% to acreage and 1.3% to production of the oilseeds, during 2019-20. Oilseeds are grown in India under diverse agro-climatic conditions mostly under fragile, nutrient-starved and rainfed conditions as only 28.4% of the total cultivated area under these crops is irrigated (Anonymous, 2020a).

The major oilseeds growing states are Madhya Pradesh, Rajasthan, Maharashtra and Gujarat which contributed about 74.1% to the area and 74.7% to the production in the country during 2019-20. Madhya Pradesh is the leading state and accounted for about 27.6% and 19.7%, respectively, to area and production of oilseed crops [Dr. Rajani Bisen, PC (I/c), Sesame & Niger, JNKVV, Jabalpur, personal communication]. Yield of oilseeds varied substantially from 589 kg/ha in Himachal Pradesh to 2501 kg/ha in Tamil Nadu with an overall national average of 1236 kg/ha. Besides Tamil Nadu (2501 kg), Gujarat (2323 kg), Telangana (1886 kg), Haryana (1782 kg), Punjab (1455 kg) and Rajasthan (1282 kg) had higher yield/ha than the national average. During the last decade (2010-11 to 2019-20), oilseeds area varied from 24.51 m ha (2017-18) to 28.05 m ha (2013-14). There was no definite trend in acreage (Fig.1) and area declined by 10.0% during 2017-18 and 0.7% during 2019-20 over the base year (2010-11). But during 2013-14 area was higher by about 3.0% in comparison to the base year. The production also followed almost the similar trend except in 2019-20 when it attained the highest registering an increase of 2.9% over that of 2010-11.

Seed yield ranged between 968 to 1284 kg/ha in total oilseeds. Since 2010-11, it consistently declined up to 2015-16 showing the highest decline of 18.9%. Thereafter, it showed an increasing trend until 2017-18 registering the highest seed yield (1284 kg/ha), which was higher by 7.6% but showed declining trend during the subsequent two years (Fig.1). Yield increase was only 3.6% in 2019-20 over that of base year.

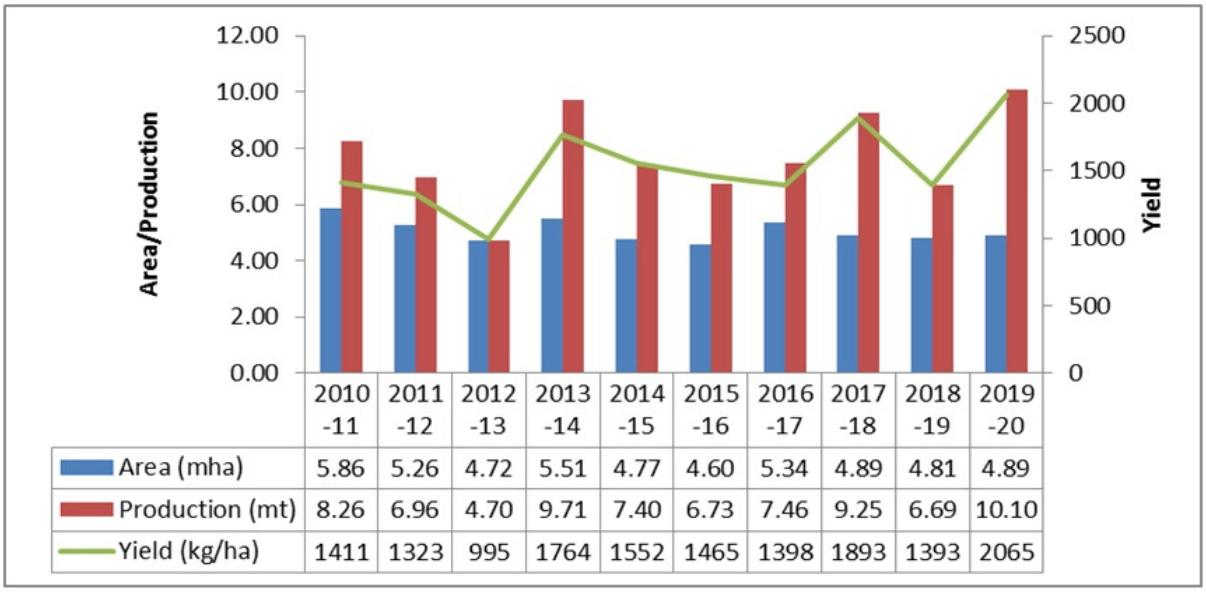
***Kharif* oilseeds**

Groundnut accounted for 30.2% and 18.1% of the total oilseeds production and acreage, respectively, in the country during 2019-20. Principal groundnut growing states are Gujarat, Andhra Pradesh, Rajasthan and Karnataka accounting for 74.7% area and 74.0% production. Of these, Gujarat is the major state with a contribution of 34.2% and 42.5% to the groundnut area (1.67 m ha) and production (4.6 m t), respectively in the country. Groundnut area during the last 10 years showed variable but declining trend and it reduced by 21.5% during 2015-16 and by 16.6% during 2019-20 as compared to the base year. Production varied from 4.70 m t (2012-13) to 10.10 m t during 2019-20. Production peaked thrice during 2013-14, 2017-18 and 2019-20 (Fig. 2), showing an increase of 17.6%, 12.0% and 22.3%, respectively, over the base year. Groundnut yield/ha varied from 995 kg (2012-13) to 2065 kg (2019-20). Tamil Nadu had the highest yield/ha (2840 kg) followed by Gujarat (2749 kg), Telangana (2382 kg), West Bengal (2212 kg) and Rajasthan (2191 kg). Other states showed lower seed yield/ha than the national average. Overall, during the last 10 years, area declined by 16.6%, whereas, production increased by 22.3% and yield by 46.4%. The irrigated area of groundnut during this period increased from 21.8% during 2010-11 to 28.9% during 2015-16 (Anonymous, 2020a).



	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20
Area (mha)	27.22	26.31	26.48	28.05	25.59	26.09	26.21	24.51	25.50	27.04
Production (mt)	32.48	29.80	30.94	32.75	27.51	25.25	32.10	31.46	32.26	33.42
Yield (kg/ha)	1193	1133	1168	1168	1075	968	1225	1284	1265	1236

Fig. 1. Trends in area, production and yield of oilseeds during the last decade



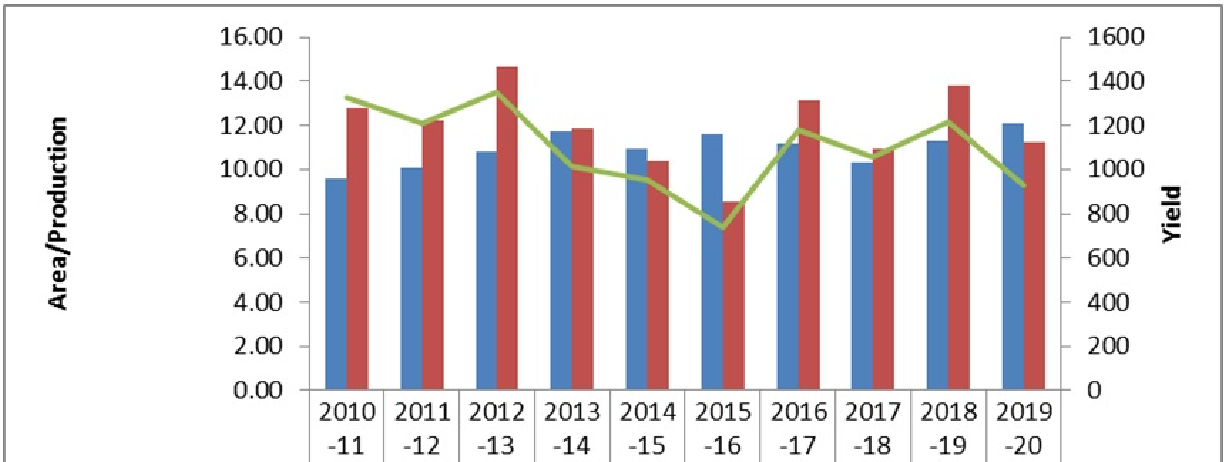
	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20
Area (mha)	5.86	5.26	4.72	5.51	4.77	4.60	5.34	4.89	4.81	4.89
Production (mt)	8.26	6.96	4.70	9.71	7.40	6.73	7.46	9.25	6.69	10.10
Yield (kg/ha)	1411	1323	995	1764	1552	1465	1398	1893	1393	2065

Fig. 2. Trends in area, production and yield of groundnut during the last decade

Contribution of soybean to total oilseed production and acreage during 2019-20 was 33.6% and 44.7%, respectively. Madhya Pradesh is the leading state in area (6.2 m ha) and production (5.2 m t) of soybean in the country with a contribution of 47.9% to area and 48.5% to production. Other major soybean growing states include Maharashtra and Rajasthan which have accounted for 36.7% and 8.5%, respectively, to crop area and 35.4% and 9.7% to production, respectively. These three states together contributed 93.0% and 93.6% to the acreage and production, respectively. During 2019-20, among the states having substantial area under this crop, Telangana had the highest seed yield (1808 kg/ha) followed by Maharashtra (1138 kg/ha) and Karnataka (1137 kg/ha). Madhya Pradesh had lower seed yield (831 kg/ha) than the national average (928 kg/ha). During the last decade, area fluctuated between 10.11 m ha in 2011-12 to 12.09 m ha during 2019-20 (Fig.3) but always remained higher (5.3%-25.9%) than that of base year (9.60 m ha). The production during the same period ranged between 8.57 m t during 2015-16 and 13.79 m t during 2018-19 (Fig. 3) and was higher by 8.2% during 2018-19 over that of base year. Seed yield/ha varied from 738 kg (2015-16) to 1353 kg (2012-13) during the period considered in the study.

In comparison to base year (2010-11), overall changes during 2019-20 were: area increased by 25.9%, production decreased by 11.9% and seed yield decreased by 30.1%. Wide variations in area, production and yield of soybean were due to the fact that this crop is grown predominantly as rainfed and only 0.9% of total area under the crop was irrigated during 2015-16.

Sesame accounted for 2.2% of the oilseeds production and was fourth major contributor, next only to groundnut, soybean and rapeseed-mustard in 2019-20. Uttar Pradesh with an acreage of 3.56 lakh ha, accounted for 22.0% of the total cropped area under sesame in the country (1.62 m ha) during 2019-20. Other major sesame growing states were Madhya Pradesh, Rajasthan and West Bengal contributing 19.4%, 17.3% and 16.2%, respectively, to the total area. All these four states had a share of about 74.9% in acreage and 68.8% in production. On production front, West Bengal had the highest contribution (31.1%) followed by Madhya Pradesh (16.8%), Gujarat (14.5%) and Rajasthan (12.2%). Among the states cultivating sesame at least on 20000 ha area, seed yield/ha varied widely from 184 kg in Uttar Pradesh to 885 kg in West Bengal, with national average of 463 kg. Other states having relatively higher seed yield/ha were Karnataka (806 kg), Gujarat (652 kg) and Tamil Nadu (627 kg). The area under sesame declined gradually from 2.08 m ha during 2010-11 to 1.62 m ha during 2019-20 with concomitant decrease in production also. The production ranged from 0.69 m t from 1.71 m ha during 2012-13 to 0.89 m t from 2.08 m ha during 2010-11 (Fig. 4). Sesame yields also varied from 402 kg/ha (2012-13) to 502 kg/ha (2018-19). The highest increase in seed yield over the base year was 17.0% during 2017-18. Overall, changes during the last decade in area (-22.1%) and production (-15.7%) were only negative but seed yield recorded positive (+7.9%) value during 2019-20 over those of 2010-11.



	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20
Area (mha)	9.60	10.11	10.84	11.72	10.91	11.6	11.18	10.33	11.33	12.09
Production (mt)	12.74	12.21	14.67	11.86	10.37	8.57	13.16	10.93	13.79	11.22
Yield (kg/ha)	1327	1208	1353	1012	951	738	1177	1058	1217	928

Fig.

Fig. 3. Trends in area, production and yield of soybean during the last decade

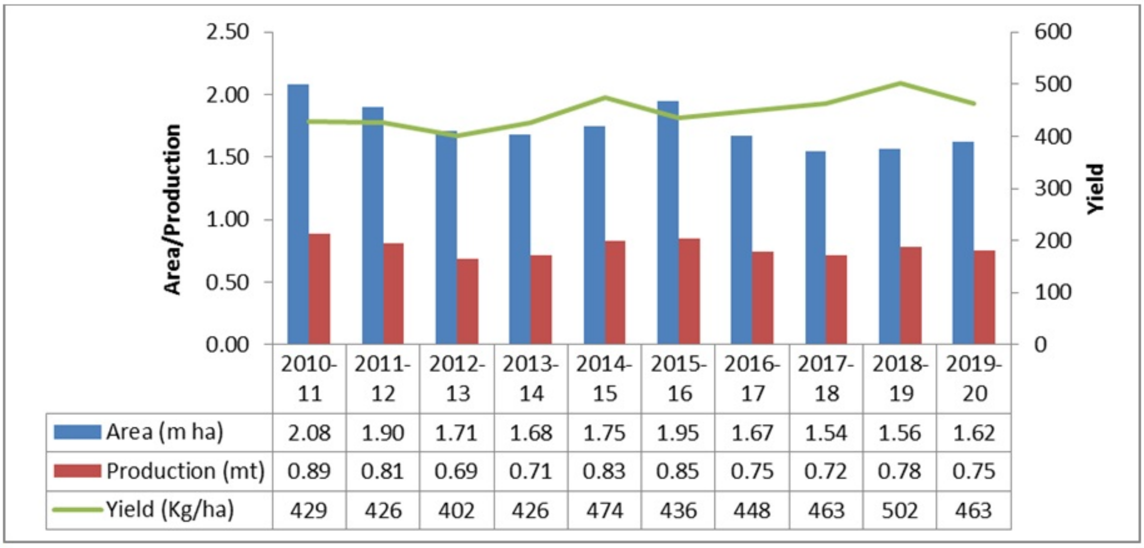


Fig. 4. Trends in area, production and yield of sesame during the last decade

Castor is an important commercial crop globally. India ranked first in acreage and production of the crop and a major exporter of castor oil. Gujarat is the leading state in cultivation of this crop and accounted for 70.3% and 77.5% of the national acreage and production in 2019-20. Rajasthan, Andhra Pradesh and Telangana were the other major states which together contributed 25.8% to acreage and 21.3% to production of the crop during 2019-20. Gujarat (1945 kg), Rajasthan (1598 kg) and Telangana (1500 kg) had relatively high seed yield/ha. Production of 1.20 m t from 0.75 m ha of castor during 2018-19 was substantially lower than 1.96 m t obtained from 1.23 m ha during 2012-13 (Fig. 5).

In comparison to base year (2010-11), area, production and yield in 2019-20 increased by 21.6%, 37.0% and 15.1%, respectively. The acreage and production of castor has been continuously declining since 2011-12 and reduction was as high as 27.2% and 19.6% , respectively, during 2019-20 as compared to 2011-12. However, yield/ha increased by 24.0% in 2017-18 (1902 kg) in comparison to 2010-11 (1534 kg). Thereafter seed yield declined by 20.2% during 2018-19 and by 7.2% during 2019-20 in comparison to 2017-18 (Fig. 5).

Karnataka is the leading state for sunflower cultivation in India which covered more than half (54.2%) of the cropped area and production (61.5%) during 2019-20. Of the total sunflower area in the country (2.17 lakh ha), about 42.2% was planted during *kharif* and the rest during *rabi* season during 2019-20. Other states with a substantial acrage and production are Odisha, Bihar, Haryana, West Bengal and Maharashtra together accounting for 30.6% and 27.7% of the acreage and production, respectively, during 2019-20. Seed yield varied widely from 391 kg/ha in Maharashtra to 1950 kg/ha in Punjab whereas; the national average yield was 891 kg/ha (Table 1). However, in Punjab, sunflower occupies only 4000 ha area and grown as summer/spring crop. In major sunflower growing states, the yield/ha was 785 kg in Karnataka, 1068 kg in Odisha, 1427 kg in Bihar, 1743 kg in Haryana and 1221 kg in West Bengal. The area declined to 7.30 lakh ha during 2011-12 from 9.30 lakh ha during 2010-11 but rose to 8.31 lakh ha during 2012-13 and thereafter decreased consistently until 2019-20, leading to overall less production. Nevertheless, seed yield/ha in most of the years was always higher than that of the base year (699 kg) except 2012-13, 2015-16 and 2016-17 (Table 1). Thus there was reduction in area by 73.9%, in production by 66.6% and increase in yield by 27.5% of sunflower during 2019-20 as compared to 2010-11.

Niger had acreage of only 1.37 lakh ha in the country in 2019-20 with Odisha being the leading niger growing state with a contribution of 38.8% and 47.8% to total acreage and production, respectively. Other major states growing this crop during 2019-20 were Chhatisgarh, Maharashtra, Madhya Pradesh and Assam with a share of 37.3%, 5.1%, 4.4% and 4.4%, respectively. Major contributors to total production of 0.42 lakh tonnes of niger were Chhatisgarh (23.3%), Assam (7.9%) and Madhya Pradesh (4.8%) states. During the last 10 years, decline in area (63.1%) and production (61.1%) during 2019-20 was substantial in comparison to 3.71 lakh ha and 1.08 lakh t, respectively, during 2010-11 (Table 1). Seed yield/ha showed low improvement during this period varying from 269 kg (2011-12) to 332 kg (2016-17) and it was reduced by 8.1% in 2019-20 as compared to the highest ever yield (332 kg) recorded in 2016-17 but increased by 5.2% over that of the base year, 2010-11 (Table 1).

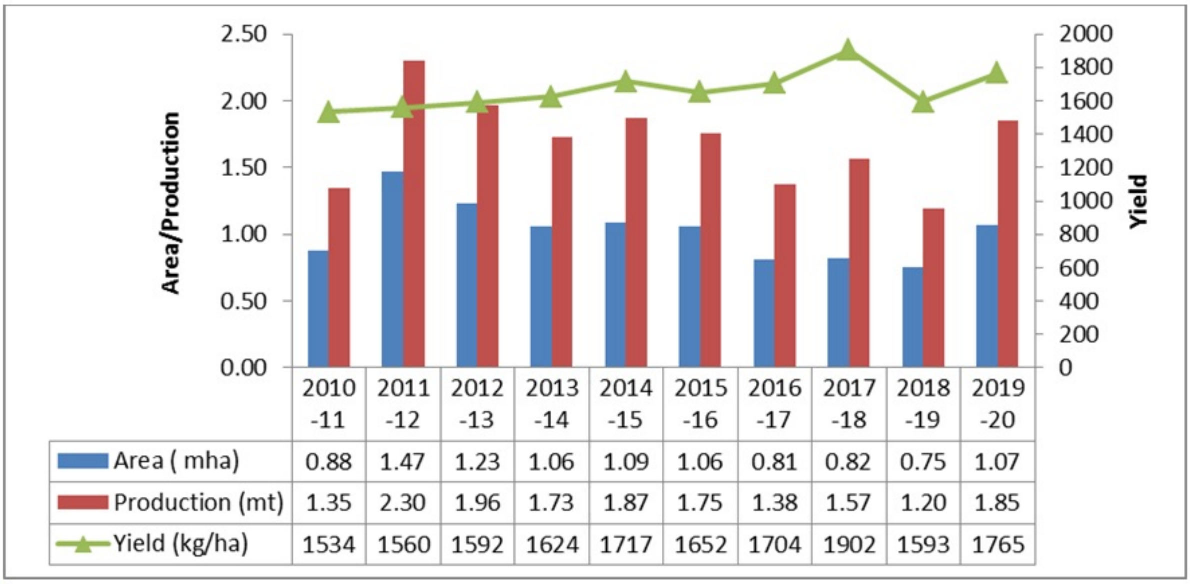


Fig. 5. Trends in area, production and yield of castor during the last decade

Table 1 Recent trends in area, production and yield of sunflower and niger crops in India during *kharif* season

Year	Sunflower			Niger		
	Area (lakh ha)	Production (lakh t)	Yield/ha (kg)	Area (lakh ha)	Production (lakh t)	Yield/ha (kg)
2010-11	9.30	6.50	699	3.71	1.08	290
2011-12	7.30	5.20	712	3.64	0.90	269
2012-13	8.31	5.44	655	3.10	1.01	329
2013-14	6.72	5.04	750	2.99	0.98	328
2014-15	5.90	4.34	736	2.32	0.71	328
2015-16	4.87	2.96	608	2.52	0.74	295
2016-17	3.81	2.51	660	2.56	0.85	332
2017-18	2.84	2.22	782	2.18	0.70	321
2018-19	2.62	2.26	826	1.56	0.45	290
2019-20	2.43	2.17	891	1.37	0.42	305

***Rabi* oilseeds**

Of the total 7.0 m ha area under *rabi* oilseeds in India, rapeseed-mustard, the principal crop, accounted for 96.7% and other two crops, linseed and safflower represented the rest during 2019-20. Rapeseed-mustard, contributed 27.3% and 25.1% to the total oilseeds production and acreage, respectively. Rajasthan was the major rapeseed-mustard growing state followed by Uttar Pradesh, Madhya Pradesh, Haryana and West Bengal with a contribution of 43.5%, 11.2%, 10.0%, 9.4% and 9.0%, respectively, to the acreage. Together these states contributed 87.7% to the rapeseed-mustard production in the country. Among the states having at least 1.5 lakh ha area, seed yield/ha varied from 642 kg in Assam to 2001 kg in Gujarat. Only Gujarat, Haryana, Rajasthan and Madhya Pradesh registered higher seed yield/ha than the national average (1345 kg). Rapeseed-mustard production in India, during 2010-11 to 2019-20, increased by 11.5% (from 8.18 m t to 9.12 m t) in spite of reduction in area by 1.7% (from 6.90 m ha to 6.12 m ha) during the same period (Anonymous, 2020a). Production declined from 2010-11 to 2016-17 and thereafter increased during the next two years to reach the highest level of the decade (9.26 m t in 2018-19) but declined to 9.12 mt during 2019-20 (Fig. 6). The highest yield increase of 13.2% over the base year 2010-11was achieved during 2018-19. Yield levels consistently increased from 1083 kg/ha during 2014-15 to 1511 kg/ha during 2018-19 but dipped to 1345 kg/ha during 2019-20. Overall, during the decade, seed yield was enhanced from 1185 to 1345 kg/ha representing an increase of 13.5%. The irrigated area during this period increased from 69.8% in 2010-11 to 79.9 % in 2015-16 (Anonymous, 2020a).

Linseed accounted for only 0.7% and 0.03% of the oilseed acreage and production, respectively during 2019-20. Madhya Pradesh was the leading linseed growing state with 27.7% and 22.7% share in acrage and production. Other major states in descending order of their contribution to crop area were Jharkhand, Uttar Pradesh, Chhatisgarh and Bihar which together contributed 49.9% to acreage and 51.2% to production. Seed yield/ha showed substantial variation, ranging from 284 kg in Chhatisgarh to 964 kg in Rajasthan with an overall all India average of 581 kg/ha. The area consistently and gradually decreased up to 2015-16 thereafter increased by 23.6% and 24.0% during 2016-17 and 2017-18, respectively, over that of 2015-16. Nevertheless, it was still lower than that of the base year (Table 2). Area under linseed decreased by 51.8% during 2018-19 and by 47.9% during 2019-20 over the base year. Seed yield showed variable trend but remained higher (ranging from 473 kg/ha in 2011-12 to 581 kg/ha in 2019-20) in all the years than that of the base year (408 kg/ha). Thus yield enhanced by 42.4% in 2019-20 over the base year (Table 2).

Contribution of safflower to oilseed production (0.16%) and acreage (0.09%) was very low as of 2019-20. Karnataka and Maharashtra were the only two major safflower growing states with respective contribution of 48.3% and 43.5%, to acreage and 63.5% and 30.2% to production. Seed yield/ha was 917 kg in Karnataka and 482 kg in Maharashtra. The safflower acreage was 2.44 lakh ha in 2010-11 which increased marginally (2.50 lakh ha) in 2011-12. Since then the area and production consistently declined up to 2019-20 and registered a reduction of 82.0% in area and 79.3% in production over the base year (Table 2). The seed yield/ha varied between 416 kg (2015-16) and 694 (2019-20). Yield enhancement during 2019-20 was 12.5% over 2010-11 (Table 2).

Development of varieties

In India, vibrant crop improvement programme in oilseeds is being carried out under the aegis of six All India Coordinated Research Project (AICRPs) on Groundnut, Soybean, Rapeseed-Mustard, Linseed, Sesame & Niger and Safflower, Sunflower & Castor spreading all over crop specific agro-climatic zones of the country (Chauhan *et al.,* 2016a). The first set of varieties was notified through S.O. 4045 dated September 29, 1969 that came in to force on October 1, 1969. Of the 5582 varieties released during 1969-2021, qualifying for formal seed production system, 923 belonged to oilseeds, *viz.,* 209 of groundnut; 148 of soybean; 214 of rapeseed-mustard; 90 of sesame; 85 of linseed; 21 of niger; 65 of sunflower; 40 of safflower and 51 of castor. Further, of the 1974 varieties of field crops released during 2011-21, 299 were of oilseeds (Table 3). Of these, highest number of varieties was released in rapeseed-mustard and soybean followed by groundnut (Table 3). However, rapeseed-mustard is a group of crops comprising eight different cultivated *Oleifera Brassica* types.

Furthermore, during the last decade the emphasis has also been laid on developing bio-fortified varieties having nutritionally superior edible oil such as high oleic acid in groundnut and safflower, high linoleic acid in linseed, low erucic acid in oil and/or low glucosinolates in seed meal of rapeseed-mustard and KIT and lipoxigenase free soybean. Oil and seed meal quality improvement programme in rapeseed-mustard was initiated in early 90's and first low erucic acid Indian mustard variety, 'Pusa Karishma' was released as early as 2005 (Table 4) followed by seven more of rapeseed-mustard until 2010 (Chauhan *et al.,* 2011). Many such special varieties of other oilseeds have also been released recently (Chauhan *et al.,* 2016a; Yadava *et al.,* 2020). Recently, 17 bio-fortified crop varieties including three of oilseeds were dedicated to the nation by Hon'ble Prime Minister of India on the occasion of World Food Day (October 16) in 2020.

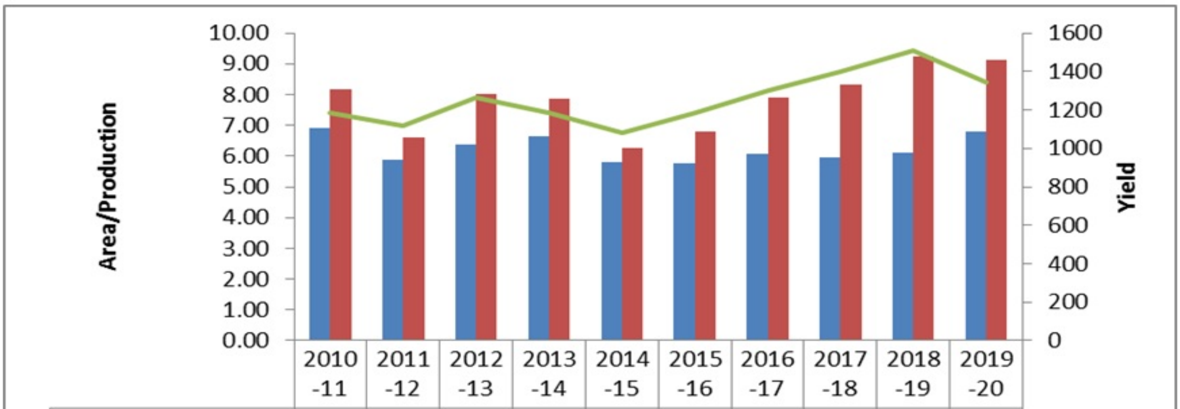
Table 2 Recent trends in area, production and yield of linseed and safflower in India

Year	Linseed			Safflower		
	Area (lakh ha)	Production (lakh t)	Yield/ha (kg)	Area (lakh ha)	Production (lakh t)	Yield/ha (kg)
2010-11	3.59	1.47	408	2.44	1.50	617
2011-12	3.23	1.52	473	2.50	1.45	580
2012-13	2.86	1.49	503	1.84	1.09	594
2013-14	2.93	1.42	482	1.78	1.13	638
2014-15	2.85	1.55	541	1.75	0.90	515
2015-16	2.63	1.26	477	1.28	0.53	416
2016-17	3.25	1.84	567	1.44	0.94	651
2017-18	3.26	1.74	533	0.82	0.55	673
2018-19	1.73	0.99	574	0.46	0.25	537
2019-20	1.87	1.09	581	0.44	0.31	694

Table 3 Varieties/hybrids of oilseeds released during 2011-21*

Crop	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
Groundnut	4	5	1	0	5	6	4	11	7	10	0	53
Soybean	1	0	3	6	3	5	5	10	11	17	10	71
Rapeseed-mustard	1	5	8	0	7	13	8	7	9	8	5	71
Sesame	0	3	1	0	3	3	0	4	0	2	1	17
Linseed	2	0	0	0	4	5	4	7	4	9	0	35
Niger	1	0	0	1	0	2	2	0	0	0	0	6
Sunflower	0	3	1	0	1	4	3	3	0	1	0	16
Safflower	0	1	1	1	1	0	0	3	3	3	0	13
Castor	1	2	0	0	0	3	2	4	3	2	0	17
Total	10	19	15	8	24	41	28	49	37	52	16	299

*Until 86th meeting of Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops held on March 15, 2021.



	2010 -11	2011 -12	2012 -13	2013 -14	2014 -15	2015 -16	2016 -17	2017 -18	2018 -19	2019 -20
Area (mha)	6.90	5.89	6.36	6.65	5.80	5.75	6.07	5.96	6.12	6.78
Production (mt)	8.18	6.60	8.03	7.88	6.28	6.80	7.92	8.32	9.26	9.12
Yield (kg/ha)	1185	1121	1262	1185	1083	1183	1304	1397	1511	1345

Fig. 6. Trends in area, production and yield of rapeseed-mustard during the last decade

Seed production

Indian seed sector, seed systems, supply chain and quality assurance mechanisms were discussed in details in our earlier publications (Chauhan *et al.,* 2016b; 2020). In the present paper, seed chain for the year 2020-21 has been analysed to assess the contribution of varieties released during the last 10 years (2011-2020), as per the guidelines of National Food Security Mission (NFSM), DAC&FW, to promote recently released high yielding varieties. In exceptional cases, on the insistence of State Department of Agriculture for any outstanding variety, a relaxation of 5 years is provided especially for oilseeds and pulses. Therefore, the share of such varieties developed during 2006-10 was also assessed.

Seed chain of oilseeds

Seed chain of oilseeds during 2020-21 had 261 varieties/hybrids comprising 62 of groundnut, 48 of soybean, 64 of rapeseed-mustard, 29 of sesame, 26 of linseed, 9 of niger, 7 of sunflower, 12 of safflower and 4 of castor. Of the 62 varieties of groundnut indented for production of breeder seed, 34 varieties were developed during the last 10 years and contributed 32.7% whereas; those beyond 10 years had a share of about 8%. The contribution of top 5 varieties to the total indent for the crop was 71.4% (Table 6). Of these, Dharani (2013), G 2-52 (2015) and Gujarat Junagadh Groundnut 32 (2018) were released within the last 10 years. The remaining two were developed even before 15 years and Kadiri-6 was the leading variety with a share of 47.8%. Of the 38 varieties released during 2016-20, 21 were in the seed chain. In soybean, of the 48 varieties indented, 32 were developed within the last 10 years and accounted for 69.7% of the breeder seed indent. Contribution of top five varieties was 64.8%. Except JS 335 and JS 95-60 which were released during 1994 and 2007 and had substantial share of 15.5% and 5.2%, respectively, the rest were developed within the last 10 years (Table 5). Of the 48 soybean varieties released during the last five years (2016-20) only 21 were in the seed chain during 2020-21.

The number of indented varieties/hybrids of rapeseed-mustard was 64. Twenty-one varieties released during 2011-15, in general, had a major share (41.9%) in seed indent followed by 15 that were released during 2016-20 (23.5%) with an overall share of 65.4% by the varieties developed during the last 10 years. Varieties developed earlier (2006-10) also had appreciable share (Table 6). The share of top 5 leading varieties was only 34.9%. The leading varieties in the seed chain were Pusa Mustard 26 (2011), Rohini (1986), Raj Vijay Mustard 2 (2013), Pusa Double Low Mustard 31 (2016) and RH 725 (2018), all of which were developed during the last 10 years except for Rohini which is very old and should have been replaced in the seed chain by now. Of the 45 varieties released during 2016-20, only 21 were in the recent seed chain.

Contribution of top five sesame varieties was 54.1%. Among the leading varieties, Swetha Til released about 22 years ago (1999) had the highest contribution to the seed indent. The rest were released within the last 10-15 years. Nevertheless, four varieties (CUMS-17 Suprava, Gujarat Til 6, TRC Til 1-8-1-1 Tripura Siping and Gujarat Junagadh Til 5) developed during 2016-18 occupied 15.2 % of the total breeder seed indent (Table 5) for sesame. Eleven varieties released during the last 10 years contributed 39.8% to the seed indent. Of the nine varieties released during the last 5 years, four were in the seed chain during 2020-21. In linseed, of the 26 varieties indented for breeder seed production, 16 were developed during 2016-20 and 6 during 2011-15 and contributed 66.7% and 25.9%, respectively. Contribution of five topmost varieties was only 41.6%. With 12.8% share, *Utera Alsi* released during 2018 was the major contributor to the seed indent. JLS 66 released during 2018, JLS 79 in 2016, Kota *Barani Alsi* in 2016 and Jawahar Linseed 11 in 2011 all were released within the last 10 years. Twenty-three varieties were released during 2016-2020 and only 16 were in the seed chain. Eight varieties were indented for breeder seed production (13.11 q) of niger during 2020-21 and five leading varieties contributed about 95.0%. The predominant high yielding varieties in the seed chain were Birsa Niger 3 (released in 2010), Utakal Niger 150 (released in 2002), JNS 9 (released in 2006), JNS 28 (released in 2017) and Birsa Niger (released in 1996) with a share of 44.6%, 22.9%, 15.0%, 6.9% and 5.7%, respectively. Of the six varieties released during the last 10 years, all were inducted in the seed chain.

In sunflower, six hybrids and a variety were indented for breeder seed production (1.63 q) in 2020-21. DSRF 108 (released in 2005) contributed the highest (61.3%) and other prominent hybrids were KBSH 44 (released in 2003), KBSH 53 (released in 2009), LFSH 17 (released in 2018) and Phule Bhasker (released in 2016) together contributed 33.8% to the total indent of 2020-21. In safflower, only 18.95 q breeder seed of its 12 varieties was indented for during 2020-21. Five top varieties, *viz.,* ISF 764 (released in 2019), PBNS 86 (released in 2018), NARI 96 (released in 2018), PBNS 40 (released in 2007) and AKS 207 (released in 2007) contributed 24.0%, 12.1%, 11.1%, 10.6% and 10.6%, respectively, and collectively accounted for 68.3% of the total indent. In castor, only four hybrids GCH 8, GCH 9, ICH 66 and DCH 107 were indented for breeder seed production (2.05q) during 2020-21. DCH 107 (released in 2011) and GCH 8 (released in 2018) were the major contributors with the share of 48.8% and 36.6%, respectively.

Table 4 Bio-fortified varieties of oilseeds

Crop	Trait	Variety/ies
Indian Mustard	Low erucic acid (< 2% erucic acid in oil)	Pusa Karishma (2005)*, Pusa Mustard 21 (2007), Pusa Mustard 22 (2008), Pusa Mustard 24 (2009), Pusa Mustard 29 (2013), Pusa Mustard 30 (2013), Pusa Mustard 32 (2020), RLC 1(2007), RLC 2 (2016)
	Low erucic acid content (< 2% erucic acid in oil) and low glucosinolates (< 30 micromoles / g defatted seed meal)	Pusa Mustard 31 (2016), RLC 3 (2016)
Gobhi sarson	Low erucic acid content (< 2% erucic acid in oil) and low glucosinolates (< 30 micromoles / g defatted seed meal)	GSC 5 (2005), GSC 6 (2008), GSC 7 (2015), NUDB 26-11(2008), TERI-Uttam –Jawahar (2008)
Soybean	Kunitz trypsin inhibitor free	NRC 127 (2018)
	Lipoxigenase 2 free	NRC 132 (2020)
	High oleic acid (42.0%)	NRC 147 (2020)
Linseed	High linoleic acid (58.9%)	TL 99 (2019)
Groundnut	High oleic acid (78.4%),	Girnar 4 (2020), Girnar 5 (2020)
Safflower	High oleic acid (76%)	ISF 1(Pride) (2019)

*Figures in parenthesis indicate year of release.

Table 5 Contribution of recently released varieties (up to fifteen years old) of oilseeds in the seed chain to breeder seed indent of the crop during 2020-21

Crop	Indent (q)	Varieties (No.)	2006-10	2011-15	2016-20	Top five leading varieties with contribution to seed indent in descending order
Groundnut	13299.6	62	14 (7.8%)	13 (25.7%)	21 (7.0%)	Kadiri 6 (47.8%), Dharani (13.4%), G 2-52 (4.1%), Vikas (3.4%), Gujarat Junagadh groundnut 32 (2.7%)
Soybean	13107.3	48	8 (9.5%)	11 (42.1%)	21 (27.6%)	JS 20-34 (22.6%), JS 335 (15.5%), JS 20-98 (12.2%), JS 20-29 (9.2%), JS 95-60 (5.2%)
Rapeseed-mustard	82.9	64	13(17.5%)	15(41.9%)	21 (23.5%)	Pusa Mustard 26 (10.5%), Rohini (6.5%), RajVijay Mustard 2 (6.1%), Pusa Double low Mmustard 31 (6.0%), RH 725 (5.8%)
Sesame	29.4	29	8 (30.9%)	7 (24.6%)	4 (15.2%)	Swetha Til (17.1%), TKG 306 (10.0%), TKG 308 (9.9%), Rajasthan Til 351 (9.8%), Smarak (7.3%),
Linseed	87.5	26	2 (6.8%)	6 (25.9%)	16 (66.7%)	Utera Alsi (12.8%), Jawahar Linseed 11 (8.9%), JLS 66 (7.5%), JLS 79 (6.3%), Kota Barani Alsi (6.0%)

*Source: https://seednet.gov.in/readyrecknor/Seed_III_VI.aspx visited on 1.12.2020 **: Within parenthesis is the contribution to the crop indent.

Table 6 Breeder seed indent and production (q) of nine annual oilseed crops during the last decade (2010-11 to 2019-20)*

Year	Indent/ Production	Crop								
		Groundnut	Soybean	Rapeseed-mustard	Sesame	Linseed	Niger	Sunflower	Safflower	Castor
2010-11	Indent	11423	22293	75	28	49	16	9	20	24
	Production	15092	18327	152	49	97	10	36	51	202
2011-12	Indent	18115	22973	49	42	145	11	32	27	11
	Production	20076	20853	124	67	157	15	48	53	28
2012-13	Indent	13075	24688	110	32	96	10	5	28	9
	Production	12014	20718	211	41	139	15	16	65	15
2013-14	Indent	11027	19509	95	26	41	8	3	21	4
	Production	12996	8660	213	59	99	10	15	331	15
2014-15	Indent	10546	14919	127	23	61	9	2	28	5
	Production	10459	8960	290	23	116	5	11	33	9
2015-16	Indent	7129	16614	107	26	46	13	1	14	3
	Production	9823	8901	304	45	144	20	11	65	9
2016-17	Indent	11318	17767	101	29	49	14	2	12	2
	Production	13953	14383	249	28	339	23	23	44	3
2017-18	Indent	10168	21951	82	18	73	18	3	14	14
	Production	12513	11051	303	20	110	15	14	57	37
2018-19	Indent	10167	14740	85	45	75	20	1	14	2
	Production	9328	15307	256	53	493	11	4	43	4
2019-20	Indent	9595	16881	76	29	72	14	2	16	2
	Production	8658	13783	259	40	220	12	44	41	20

*Source: Chauhan *et al.* , 2020 and Anonymous, 2021)

Seed requirement and availability

Breeder seed: Seed chain commences with the production of breeder seed. Breeder seed is the key to the successful quality seed production. The planning and execution of breeder seed production programme have been discussed elsewhere (Chauhan *et al.,* 2016 b). During the decade, contribution of oilseeds to total breeder seed indent of field crops varied from 38.7% (2015-16) to 46.8% (2012-13). Analysis of indent and production of breeder seed during the decade showed inconsistent trend. Breeder seed indent was the highest during 2011-12 registering an increase of 22.5% over the base year and thereafter was always lower than that of the base year by 9.4% (2013-14) to 41.2% (2015-16) except for 2012-13 when it showed an increase of 12.1% (Fig. 7). During the last 10 years, breeder seed production was always lower than the indents except 2010-11, 2011-12 and 2018-19. Trends of the breeder seed production in nine annual oilseed crops are discussed here. Soybean contributed the highest (55.5%-69.4%) followed by groundnut (29.8%-43.8%) to the total indent during the last 10 years (Anonymous, 2017; 2018; 2019b; 2020d). Rapeseed-mustard with a share of 0.22% (2010-11) to 0.49% (2014-15) is the 3rd major contributor to the breeder seed indent of oilseeds. Other six crops *viz.,* sesame, linseed, niger, sunflower, safflower and castor together contributed only up to a maximum of about 0.8% during the last 10 years. Breeder seed indent of groundnut increased by 58.6% during 2011-12 and by 14.5% in 2012-13 over the base year. Thereafter, it continuously declined and was always lower than that of the base year and reduced by 16.0% during 2019-20 (Table 6). Soybean breeder seed indent increased during 2011-12 and reached the highest of the decade during 2012-13, registering an increase of 10.7%. Since then it showed inconsistent trend of increase or decrease in different years but always remained less than that of the base year and reduced by 24.3% during 2019-20. Except for 2011-12, the rapeseed-mustard breeder seed indent showed an increasing trend until 2019-20. The highest increase in breeder seed indent was recorded during 2012-13 (110 q) which was higher by 46.7% over that of the base year. Indent for sesame breeder seed showed an increasing trend up to 2012-13 and then declined until 2017-18 except during 2016-17. During 2018-19 and 2019-20, the indents increased by 60.7% and 3.4%, respectively, as compared to 2010-11. Except in 2015-16 and 2016-17, the linseed breeder seed indent was higher in other years over the base year and highest increase of 195.9% was recorded during 2011-12 (Table 6). Sunflower seed indent increased by 255.6% during 2011-12 over that of 2010-11 and gradually declined in succeeding years recording a reduction of 77.8% during 2019-20. Variable trend in seed indent was exhibited by safflower. It increased up to four years from the base year and decreased by rest of the years till 2019-20. Overall, the increase in safflower indent was highest (40.0%) during 2012-13 and 2014-15 whereas reduction was highest (40.0%) during 2016-17. The decrease in seed indent during 2019-20 was 25.0% in comparison to the base year. Breeder seed indent for castor showed consistent and gradual decline from 2010-11 until 2019-20 with an overall reduction of 91.7% (Table 6).

During the last 10 years, breeder seed production was always higher than the indents for rapeseed-mustard, linseed, sunflower, safflower and castor (Table 6). It was also higher for groundnut except for three years, 2012-13, 2018-19 and 2019-20; sesame except for the year 2016-17 and niger except for four years, 2010-11, 2017-18, 2018-19 and 2019-20. However, for soybean, there was always a shortfall in breeder seed production except in 2018-19. Nevertheless, varietal mismatches, though low, yet reported in all the crops in breeder seed production. Groundnut and soybean with a share of 49.9% and 49.2%, respectively, were the main contributors to the oilseeds indent during 2020-21 (26,642q).

Foundation seed: In seed production chain, there are two distinct activities, *viz.*, production of breeder seed and it's downstream conversion to foundation and certified class of seed. In the first stage, breeder seed is converted to foundation seed. During 2019-20, foundation seed availability was lower than the requirements by 5.7 %. The increase in foundation seed availability was higher by 2.5% (sesame) - 893.0% (linseed). In groundnut and sunflower, a shortage of 20.6% and 7.5%, respectively, was recorded in foundation seed availability in relation to requirement (Table 7).

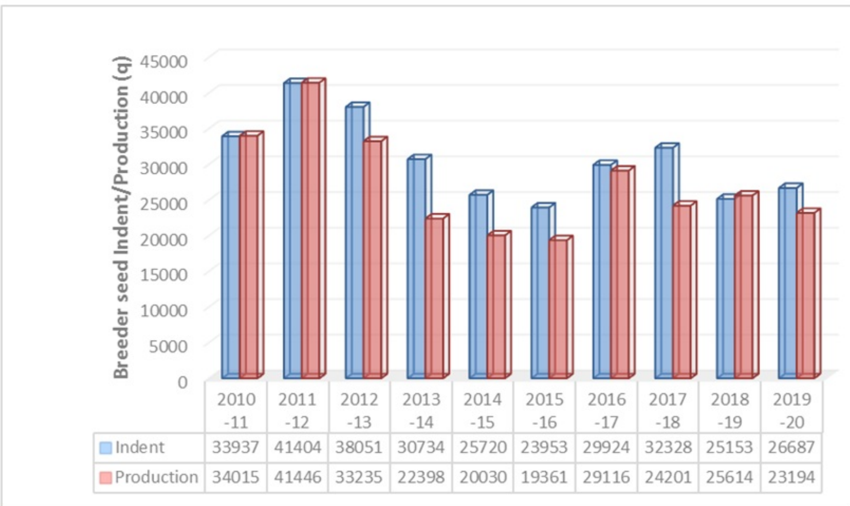


Fig.7. Trends in indents and production of annual oilseeds during the last decade

Table 7 Requirement, availability of foundation seed of oilseeds during 2019-20

Crop	Foundation seed		
	Requirement (q)	Availability (q)	Change over requirement (%)
Groundnut	1,93,480	1,53,568	-20.6
Soybean	2,36,292	2,59,492	9.8
Rapeseed-mustard	2,036	10000	391.2
Sesame	800	2,668	233.5
Linseed	455	4,518	893.0
Niger	207	380	83.6
Sunflower	117	109	-7.5
Safflower	247	315	27.5
Castor	655	715	9.2
Total	4,34,289	4,31,764	-5.7

Table 8 Requirement and availability of quality seed of oilseeds in India and share of public and private sector in seed production from 2010-11 to 2019-20

Year	Seed (lakh q)		[A-R]/R (%)	Production/ availability (lakh q)		Share (%)	
	Availability [A]	Requirement [R]		Public	Private	Public	Private
2010-11	69.16	57.88	19.5	42.87	26.29	62.0	38.0
2011-12	72.84	63.41	14.9	44.37	28.47	60.9	39.1
2012-13	68.51	58.92	16.3	39.09	29.42	57.1	42.9
2013-14	71.73	66.88	7.3	39.90	31.83	55.6	44.4
2014-15	61.93	67.13	-7.7	30.91	31.02	49.9	50.1
2015-16	51.39	59.45	-13.6	24.90	26.49	47.7	52.3
2016-17	59.16	56.48	4.7	30.08	29.08	50.8	49.2
2017-18	69.36	63.74	8.8	32.79	36.57	47.3	52.7
2018-19	62.28	58.56	6.4	28.91	33.36	46.4	53.6
2019-20	55.61	63.60	14.4	27.33	36.27	43.0	57.0

Certified / quality seed: Analysis of data of certified/quality seed requirement and availability during the last decade (2010-11 to 2019-20) revealed that there had been a continuous surge in the requirement for seed of oilseeds from 2010-11 (57.88 lakh q) until 2018-19 (58.56 lakh q) but declined by 3.9% to 55.61 lakh q during 2019-20 (Anonymous, 2020a). The highest requirement (67.13 lakh q) was recorded for the year 2014-15, an increase of about 16.0% (Table 8). However, no consistent trend of seed requirement and availability was discernible from the data due to increase/decrease in different years within the decade. Similar was the trend for individual oilseed crops. Seed availability during the decade was higher by 4.7% during 2016-17 to 19.5% during 2010-11. However, during 2014-15 and 2015-16, shortage in seed availability by 7.7% and 13.6 %, respectively, was recorded. Seed availability during 2019-20 was more by 14.4% than requirement. Of the total seed availability during 2019-20, the share of public and private sector was 43.0% and 57.0%, respectively.

Seed requirement for groundnut during the period under study showed inconsistent trend and varied from 23.48 lakh q during 2016-17 to 29.62 lakh q during 2013-14 (Table 9). It was 23.76 lakh q during 2010-11. Thus the requirement increased by 22.9% during 2011-12, 24.7% during 2013-14, 19.8% during 2014-15, 2.3% during 2015-16, 2.2% during 2017-18 and 7.5% during 2018-19 and decreased by 0.4% during 2012-13 and 10.2% during 2019-20 over the base year (Table 9). Soybean seed requirement increased from 29.68 lakh q (2010-11) to 34.29 lakh q (2014-15). It showed a declining trend up to 2016-17 and again peaked with an increase of 20.3% to 35.65 lakh q during 2017-18 and this increase was only 3.0% during 2019-20 over that of base year (2010-11). Seed requirement of rapeseed-mustard increased by 7.8% to 2.64 lakh q during 2014-15 in comparison to 2010-11 (2.45 lakh q). Seed requirement during 2019-20 was 2.47 lakh q. For all other years, seed requirement was lower than the base year.

Sesame seed requirement was always higher than that of the base year (0.22 lakh q) ranging from 0.26 lakh q (2011-12) to 0.49 lakh q (2017-18 and 2018-19) indicating an increase of 122.7% during 2017-18 and 2018-19. But this increase was only 77.3% during 2019-20 (Table 9). Linseed

seed requirement more than doubled during the last 10 years under investigation from 0.08 lakh q (2010-11) to 0.19 lakh q (2019-20). During 2019-20, it was higher by 46.2% over that of 2018-19 (0.14 lakh q) and 137.5% higher over that of the base year (Table 9). Except for 2011-12, seed requirement was always higher than that of the base year.

Niger seed requirement during the last 10 years did not follow any pattern and overall, increased by 33.3% in 2018-19 (0.04 lakh q) in comparison to that of base year (0.03 lakh q). In fact, seed requirement was either reduced or remained stagnant during the decade except for the year 2018-19 (Table 9). Sunflower seed requirement registered a declining trend since the base year and gradually reduced up to 0.17 lakh q (2019-20), a reduction of 85.7% over the base year (Table 9). Except for 2015-16 and 2018-19 when the requirement marginally increased over the immediate preceding years, the declining trend was consistent (Anonymous, 2020a). The seed requirement for safflower surged by 42.9% from 2010-11 to 2011-12. It was higher by 71.4% during 2012-13 but reduced by 14.3% during 2018-19 over that of the base year (Table 9). The seed requirement for castor during this period rose by 63.6%, from 0.44 lakh q in the year 2010-11 to 0.72 lakh q during 2014-15. But during 2018-19, it was only higher by 27.3% (0.56 lakh q). Nevertheless, seed requirement was always higher in all the years than that of the base year except in 2019-20 (Table 9). The contribution of groundnut (38.1%-46.0%), soybean (47.3% - 55.9%) and rapeseed-mustard (2.3%-3.5%) to total seed requirement ranged between 96.5% (2010-11)-97.6% (2016-17). Conversely, sesame, linseed, niger, sunflower, safflower and castor together accounted only for 2.4%-3.5% of the total seed requirement during the last 10 years.

Availability of quality seed of groundnut during the last 10 years varied from 28.03 lakh q (2010-11) to 29.27 lakh q (2018-19), an increase of 4.4%. But availability was decreased by 9.3% during 2019-20 in comparison to 2010-11 (Table 9). Nevertheless, it was always higher than the requirement except for the year 2015-16. The seed availability was higher by 20.2% over that of 2010-11, during 2011-12, when highest ever availability of seed was recorded. The seed availability for soybean was more than the requirement except for the years 2014-15, 2015-16 and 2018-19. Availability of quality seed was, in general, at par or higher than requirement for rapeseed-mustard (except in 2016-17), sesame, sunflower, safflower (except in 2019-20) and castor (except in 2015-16). The corresponding change in seed availability in 2019-20 over the base year was 1.4%, 41.4%, -86.4%, -25.0% and -19.7%, respectively, for these above mentioned crops. The highest seed availability was recorded during 2018-19 (2.99 lakh q) for rapeseed-mustard, an increase of 6.8%; during 2018-19 (0.56 lakh q) for sesame, an increase of 93.1%; during 2011-12(0.98 q) for sunflower, a decrease of 30.0%; during 2016-17 and 2012-13 (0.13 lakh q) for safflower, an increase of 62.5% and during 2014-15 (0.85 lakh q) and for castor, an increase of 28.8% over the base year (Table 9). The highest recorded seed availability of linseed during 2016-17 and 2018-19 was higher by 83.3% than that of the base year. However, seed requirement of linseed was always more than the availability except for the years 2011-12 and 2018-19. The seed availability was at par or higher than the requirement for niger except for the years 2011-12 and 2018-19 (Table 9). The highest seed availability was observed during 2019-20 (0.04 lakh q) for niger, an increase of 33.3% over the base year. Groundnut, soybean and rapeseed-mustard together accounted for 96.8% (2015-16) - 97.8% (2019-20) of the seed availability and the rest of the crops only contributed 2.2%-3.2%. The contribution of groundnut, soybean and rapeseed-mustard to total quality seed availability was 36.1% - 48.4%; 44.1% - 55.9% and 3.3% - 4.8%, respectively, during the period of study.

Certified/quality seed distributed

Farmers/growers use certified seed to grow crops that could raise crop yield by enhancing seed replacement rate. The quality seed of oilseeds, distributed to the stakeholders during the last 10 years showed quite variable, down ward trend and decreased from 61.49 lakh q (2011-12) to 48.26 lakh q registering a reduction of 21.5% during 2018-19 (Table 10). Despite the higher requirement (55.61 lakh q) and availability (63.01 lakh q) of quality seed of oilseeds during 2019-20, only 53.08 lakh q was distributed to the stakeholders (Table 10). The highest decrease of 30.0% in seed supply was recorded during 2014-15. However, seed supply increased by 10.2%, 16.1%, 33.0%. 12.2% and 23.4%, respectively, during 2015-16, 2016-17, 2017-18, 2018-19 and 2019-20. Quality seed distribution of groundnut was the highest during 2017-18 with an increase of 18.6% over the highest ever achieved earlier during 2012-13. The lowest seed distribution was during 2018-19 with a reduction of 43.2% over that of 2017-18. In soybean, maximum dissemination of quality seeds was during 2013-14 showing an increase of 52.4% over that of the base year, 2010-11. The lowest seed distribution in soybean was during 2014-15 which increased consistently thereafter by 16.5%, 13.4%, 11.2%, 28.6% and 32.7% during 2015-16, 2016-17, 2017-18, 2018-19 and 2019-20, respectively.

Rapeseed-mustard quality seed distribution decreased consistently from 2011-12 to 2015-16. The reduction in seed distribution as compared to the base year, 2010-11 (2.07 lakh q) was 9.2%%; 21.3% and 44.4%, respectively, during 2012-13; 2013-14; and 2015-16 but higher by 2.9% during 2014-15 (Table 10). However, the seed distribution was higher by 15.9% in 2016-17 and 10.9% in 2017-18 as compared to that of 2011-12 (Anonnymous 2019b;2020b) but it declined by 26.6% and 27.3% during 2018-19 and 2019-20, respectively (Table 10). But no consistency was observed in the pattern of quality seed distribution for sesame whereas, the highest reduction of 10.0% and increase of 35.0% was observed during 2013-14 and 2016-17, respectively, as compared to that of 2010-11 (Table 10). There was reduction in seed distribution of sesame during 2017-18 and 2018-19 by 25.9% and 29.6%, respectively in comparison to that of 2016-17. The highest increase in quality seed distribution over the base year was 300.0% for niger (2014-15 and 2018-19), 219.4% for castor (2012-13), 20.7% for sunflower (2012-13), 10.0% for linseed (2019-20) and 1.3% for safflower (2011-12, 2015-16, 2016-17). Nevertheless, for sunflower the seed distribution was reduced by 80.0% (2019-20) over that of 2010-11. Overall changes in the distribution of quality seed during 2019-20 over the base year were 70.0% for sesame; 61.3% for castor; 50.0% for linseed; 0% for niger; -80.0% for sunflower and -75.0% for safflower. Soybean (45.3.0% - 63.7%) followed by groundnut (31.7% - 47.8%) and rapeseed-mustard (2.4% - 5.0%) were the main contributors to the total certified /quality seed distributed and together contributed 97.0% (2018-19) - 98.3% (2013-14). Barring rapeseed-mustard, niger and safflower, the other crops had increased distribution of seed during 2019-20 than that of 2018-19. The increase was the highest for sesame (78.9%) and the lowest for soybean (3.2%). Groundnut and soybean together accounted for 94.5% of the total quality seed distributed to the stake holders during 2019-20.

Table 9 Requirement and availability of seeds of nine annual oilseed crops (lakh quintals) during the last decade

Year	Requirement / Availability	Crop								
		Groundnut	Soybean	Rapeseed-mustard	Sesame	Linseed	Niger	Sunflower	Safflower	Castor
2010-11	Requirement	23.76	29.63	2.45	0.22	0.08	0.03	1.19	0.07	0.44
	Availability	28.03	35.81	2.80	0.29	0.06	0.03	1.40	0.08	0.66
2011-12	Requirement	29.20	30.02	2.37	0.26	0.04	0.03	0.72	0.10	0.50
	Availability	33.69	34.44	2.66	0.26	0.04	0.02	0.98	0.10	0.65
2012-13	Requirement	23.66	31.00	2.44	0.29	0.09	0.02	0.67	0.12	0.63
	Availability	25.73	38.28	2.65	0.30	0.02	0.02	0.68	0.13	0.70
2013-14	Requirement	29.62	33.00	2.21	0.28	0.06	0.03	0.54	0.12	0.63
	Availability	30.22	36.95	2.34	0.31	0.03	0.03	0.60	0.12	0.73
2014-15	Requirement	28.47	34.29	2.64	0.31	0.12	0.02	0.45	0.12	0.72
	Availability	29.99	27.33	2.70	0.37	0.08	0.02	0.46	0.12	0.85
2015-16	Requirement	24.30	31.02	2.52	0.32	0.08	0.01	0.48	0.10	0.61
	Availability	23.64	23.45	2.65	0.36	0.04	0.01	0.51	0.11	0.47
2016-17	Requirement	23.48	29.00	2.49	0.28	0.13	0.01	0.39	0.12	0.58
	Availability	25.16	29.64	2.47	0.40	0.11	0.01	0.40	0.13	0.84
2017-18	Requirement	24.28	35.65	2.31	0.49	0.08	0.01	0.20	0.11	0.60
	Availability	25.01	40.25	2.55	0.51	0.05	0.02	0.21	0.12	0.63
2018-19	Requirement	25.54	29.11	2.34	0.49	0.14	0.04	0.28	0.06	0.56
	Availability	29.27	28.17	2.99	0.56	0.11	0.03	0.43	0.10	0.62
2019-20	Requirement	21.33	30.52	2.47	0.39	0.19	0.03	0.17	0.07	0.44
	Availability	25.42	33.88	2.84	0.41	0.13	0.04	0.19	0.06	0.53

Table 10 Distribution of certified/quality seeds (lakh quintals) of oilseeds during the last decade

Crop	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20
Groundnut	21.79	20.02	23.16	19.39	16.56	17.95	19.89	27.37	15.55	19.21
Soybean	25.55	37.60	32.08	38.94	23.34	27.19	26.46	25.95	30.01	30.97
Rapeseed-mustard	2.07	2.56	1.88	1.63	2.13	1.15	2.40	2.84	1.88	1.86
Sesame	0.20	0.23	0.20	0.18	0.22	0.21	0.27	0.20	0.19	0.34
Linseed	0.04	0.02	0.02	0.05	0.04	0.04	0.05	0.05	0.05	0.06
Niger/others	0.01	0.01	-	0.01	0.04	0.01	0.01	0.005	0.04	0.01
Sunflower	0.55	0.29	0.35	0.32	0.28	0.22	0.19	0.29	0.10	0.11
Safflower	0.08	0.09	0.04	0.06	0.03	0.09	0.09	0.02	0.02	0.02
Castor	0.31	0.67	0.68	0.51	0.55	0.58	0.62	0.51	0.42	0.50
Total	50.61	61.49	58.44	61.09	43.03	47.44	49.97	57.23	48.26	53.08

Table 11 Growth in oilseeds during the decade 2010-11 to 2019-20

Crop	Increase (+)/decrease (-) during 2019-20 over 2010-11 (%)			Increase (+)/ decrease (-) during 2019-20 over the highest achieved during the decade (%)		
	Area	Production	Yield	Area	Production	Yield
Groundnut	-16.6	+22.3	+46.4	-16.6	+4.0	+9.1
Soybean	+25.9	-11.9	-30.1	+3.2	-23.5	-31.4
Rapeseed-mustard	-1.7	+11.5	+13.5	-1.7	-1.5	-11.0
Sesame	-22.1	-15.7	+7.9	-22.1	-15.7	-2.3
Linseed	-47.9	-25.9	+42.4	-47.9	-40.8	1.2
Niger	-63.1	-61.1	+5.2	-63.1	-61.1	-8.1
Sunflower	-73.9	-66.6	+27.5	-73.9	-66.6	+7.9
Safflower	-82.0	-79.3	+12.5	-82.4	-79.3	+3.1
Castor	+21.6	+37.0	+15.1	-27.2	-19.6	-7.2

Table 12 Seed replacement rate (%) of oilseeds during the last 10 years

Year	Groundnut	Soybean	Rapeseed-mustard	Sesame	Sunflower	Safflower	Castor
2010-11	24.5	35.9	63.6	20.1	61.2	28.6	28.3
2011-12	22.1	52.8	78.9	22.8	32.5	32.9	60.6
2012-13	24.9	51.6	57.3	19.8	35.8	14.6	61.5
2013-14	25.4	37.5	51.3	23,6	86.3	32.9	41.1
2014-15	23.7	30.5	54.6	19.5	96.3	29.1	42.9
2015-16	23.6	37.4	62.2	30.9	86.2	29.5	54.1
2016-17	25.2	38.2	68.0	42.4	30.7	29.3	80.8
2017-18	23.5	39.9	54.9	37.4	32.2	26.6	95.4
2018-19	22.4	37.5	52.4	39.5	30.3	36.7	54.0
2019-20	26.7	41.0	60.6	43.6	43.1	33.8	61.3

Table 13 Projected demand for breeder seed for major oilseeds in the next five years

Crop	Cropped area (m ha)		SMR*	Seed rate (kg/ha)	SRR 2019-20 (%)	Breeder seed (2019-20)		Future requirement	
	Highest ever since 2005-06	Actual (2018-19)				Indent (q)	Production (q)	Targeted SRR (%)	Requirement of breeder seed (q) to achieve the target SRR by 2025-26
Groundnut	6.7	4.9	10	100	26.7	9595	8658	36.0	24120.0
Soybean	12.0	11.3	15	75	41.0	16881	13783	50.0	20000.0
Rapeseed -mustard	7.3	6.1	200	5	60.6	76	259	61.0	5.5
Sunflower	2.3	0.3	50	10	43.1	2	44	95.0	87.4
Sesame	2.1	1.6	200	5	43.6	29	40	50.0	1.3
Linseed	0.47	0.17	50	45	-	72	220	50.0	42.3
Niger	0.37	0.14	200	10	-	14	12	50.0	0.5
Safflower	0.38	0.05	60	7	33.8	16	41	50.0	3.7
Castor	1.47	0.75	60	5	61.3	2	20	95.0	19.4

**Seed multiplication ratio

Conclusions and future prospects

The growth rate for area and production of sesame, linseed, niger, sunflower and safflower during this decade was negative. It was also negative for area of groundnut and rapeseed-mustard. Castor showed a higher growth rate for area, production and yield. Rapeseed-mustard registered positive, while, soybean registered negative growth for production (Table 12). Higher productivity resulting in to high production and area expansion as in castor would be an ideal situation for motivating the farmers to grow oilseeds. Even rapeseed-mustard and groundnut also present an encouraging scenario for area expansion with their high growth rate for yield. As a matter of fact, all the oilseed crops except soybean showed positive growth for yield per unit area, a better parameter to evaluate the technology driven growth in oilseeds. Therefore, a detailed analysis for negative growth in area and production of majority of the oilseeds despite high productivity should be carried out. The plausible reasons may be substitution of oilseed crops with crops of high economic returns or lack of timely availability of inputs or emergence of new biotic stress/es. Development of value added varieties is another option for area expansion. In this context, 23 bio-fortified varieties would prove assets in alleviating malnutrition as well as increasing farmers income if a premium price is fixed for such varieties. But well crafted market approach is required including creating awareness among consumers through print and electronic media for using healthy oil. Special niche areas need to be identified for their seed- as well as commercial production to maintain the high expression of the target trait. And above all, there is need to ensure premium price for growing such varieties and a clear cut market assessment about their domestic and export needs. Tying up the production with appropriate marketing agencies both in public and private sector through contract farming are important for the success of these specialty groups of varieties. In rapeseed-mustard, several varieties with nutritionally superior oil and/or seed meal have been released about a decade ago, but due to lack of any incentive, the farmers have continued to grow them with other normal varieties despite the fact that they need special growing conditions like proper isolation distance. Therefore the release of such varieties has not made much impact.

Two hundred and ninety nine varieties were developed during the last 11 years (2011-21). Of these, 76 were developed during the first phase (2011-15) and 207 during the second phase (2016-20) and 16 in 2021. Of these, only 56 from first and 96 from second phase were inducted in the seed chain during 2020-21 leaving still 147 varieties for formal seed production. It takes at least 2-3 years after release and notification of any variety, depending upon the efficiency, to occupy a sizable area in farmers' field. However, it is a matter of concern that 20 cultivars released during 2011-15 have not found a place even in the recent seed chain. Therefore, there is a need to review the testing procedure under AICRPs, identification and release of varieties. It has been observed that in many oilseeds, the testing locations are very few to evaluate potential of the candidate variety. Mini-kit testing and adaptive state trials in respective states must be carried out simultaneously with AVT II testing under AICRPs. Genetic resource management should be the top priority of research institutions with an objective of developing national catalogue of available germplasm for both agronomic and molecular diversity. Accordingly, diverse gene pools must be established in each crop to facilitate selection of parents for national hybridization programmes. In each crop, there is a need to analyse the diversity using molecular markers as well as genetic gain in yield of the varieties released during the last 20 years to decide even the appropriate breeding method/s. Except soybean (Karmakar and Bhatnagar 1996; Bharadwaj *et al.,* 2002) no such study has been carried out in any of the oilseed crops. In rapeseed-mustard, repeated utilization of a few donors without knowledge of their pedigree has resulted in a low genetic diversity and pure line selection has been emphasized (Chauhan *et al.,* 2011) in breeding schemes. Many leading varieties were either the product of pure line selections or derivative of the *inter se* hybridization of the same variety unintentionally.

Seed played an important role in green revolution (mainly in rice and wheat) and also in enhancing production of oilseeds and would continue to remain the major factor in any crop for increasing yield. Since it is a low cost input and enables the variety(ies) to realize the genetic potential, seed production needs immediate attention and strengthening. Despite production of enough or even more than enough breeder seed, the requisite seed replacement rate (SRR) could not be achieved due to lack of its proper downstream conversion. In most of the years during this decade, though, the breeder seed availability was higher than the requirement, the SRR could not reach the ideal level of, 33% for self-; 50% for cross pollinated crops and 100% for hybrids, as in case of groundnut; sunflower and castor, respectively. Secondly, very high SRR was achieved in most of the oilseeds but could not be sustained (Table 12). In sunflower and castor, where, hybrids are largely grown, the SRR declined to 43.1% in 2019-20 as compared to 96.3% in 2014-15 in case of sunflower and 61.3% in 2019-20 from 95.4% in 2017-18 in case of castor (Table 12). But indent of breeder seed was very well above the requisite quantity in most of the oilseed crops for meeting the standard seed replacement rate considering the highest area planted to the crop till date. Actually, this is an issue of irrational indenting in many oilseeds crops. Such high indents for all the crops are unwarranted and sheer wastage of scarce resources. So such shortfall is not of much consequence in most of the crops but issue of varietal mis-matches should be adequately addressed. Timely and careful planning for seed production with varieties/hybrids having wider acceptance among the farmers be pursued. There is a need for region wise, preferably, district wise mapping of the varieties for seed production at micro-level, viz., blocks and panchayat in collaboration with Farmer Producing Organizations (FPOs) or any appropriate farmers' organizations/societies for speedy and cost effective seed production and distribution.

Enabling the stakeholders including youth and farm women by proper skill development and continuous technical backstopping is of paramount importance. Soybean and groundnut are large volume crops, thus, deserve special attention in seed production. In this decade, except 2018-19, breeder seed production of soybean was adversely affected by unusal heavy rains especially during seed formation stage and indequate rains during early developmental stage. This crop is exclusively rainfed. Therefore, efforts should be made to identify alternate areas for seed production in *rabi* season and associated technologies should be developed. Indian Institute of Seed Science, Mau initiated such a programme during this decade, but cost of production was prohibitive, but, this can be augmented with development of proper technologies and government support. Other oilseeds are small seeded with high seed multiplication ratio, requiring very small quantity of breeder seed (Table 13), even two stage multiplication of seed would be satisfactory for rapid dissemination of newly released varieties.

Seed research for proper breeder seed storage be undertaken and their regular production may be avoided to save the resources and utilize them for seed production of soybean and groundnut. Presently, large quantity of breeder seed is produced in all oilseeds including soybean and groundnut. In the present paper, we have assessed the breeder seed requirement for oilseed crops considering the highest ever cropped area since 2005-06 and target SRR for 2025-26 (Table 13). The National Mission on Oilseeds and Oil palm, NMOOP (2018) envisioned to bring additional 4.5 m ha area under oilseeds from 26.67 m ha during 2016-17 to 31.20 m ha with anticipated production of 45.64 m t with yield of 1.46 t/ha during 2022. The strategy has major focus on increasing seed production and distribution of newly released varieties and bridging the yield gaps. Rice fallows amounting to 11.65 m ha in India, offers good opportunity for area expansion in non-traditional as well as in traditional areas. The NEH plains and hills are suitable for rapeseed-mustard and groundnut crops. NAAS (2013) organized a brain storming session to discuss strategy for their utilization with short duration pulses and oilseeds. Sporadic efforts were made by some institutes but no proper systematic programme was initiated to specifically identify suitable crops/varieties and develop matching technology for such areas. This needs proper survey and analysis of growing environment to introduce the crop. The frontline demonstrations in various oilseeds during 2018-19 have shown very high exploitable yield reservoir of 48.9%. Efforts should be made to bring this yield gap down to 20% in the next 3-4 years through ensuring the timely availability of various inputs (seed, fertilizers, pesticides, bio-agent for seed quality enhancement, micro irrigation facilities for life saving irrigation/proper water management through agronomic interventions in case of excess rains) including credit to the farmers, regular and timely technical backstopping and attractive remunerative price to the crop produce. Through these efforts, up to 9.0 m t can possibly be added to the oilseeds pool with the existing technology in the near future.

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Research News

Attack the enemy silently in its own den: SIGS - Spray-induced gene silencing, a novel approach to contain pathogens

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ABSTRACT

RNA interference (RNAi) technology is considered an alternative tool to develop more environmentally friendly broad-spectrum pesticides in agriculture. In this approach, sequence-specific knockdown of gene targets in pests and pathogens using double-stranded RNA (dsRNA) is utilized. Two different dsRNA application methods, host induced gene silencing (HIGS) and spray induced gene silencing (SIGS) are being followed. HIGS involves developing transgenic plants that produce the intended dsRNA which will be delivered into the pests when they feed or grow on the transgenic plants, while in SIGS the dsRNAs applied topically on the plants will be taken up by the target organisms. Once the dsRNA is in the target organism, the host RNAi cellular machinery will be used to silence the target genes. SIGS has been applied now against many pests and diseases in different crops and has given promising results. With the development of tools that facilitate economic production of large scale dsRNA and improve the stability and longevity of the sprayed dsRNAs on the plant surface, SIGS is a promising technology that could be adopted across crops and against different pests and pathogens. In this research update, we provide a summary of the recent developments in the area of SIGS with an emphasis on the examples of fungal pathogen control.

Keywords: dsRNA, Gene silencing, HIGS, RNA interference, SIGS

The most widely adopted method to manage pathogens is the use of chemicals. But, continuous use of chemicals has not only impacted the environment and human health but also has led to resurgence of resistance among pests against chemicals. Therefore, development of new sustainable eco-friendly alternatives to restraint the disease-causative agents for crop protection is a continuous endeavor. Of late, the RNA interference (RNAi) pathway has emerged as a powerful tool to contain plant pests including insects, virus, parasites and fungal pathogens. Briefly, RNAi is a conserved natural regulatory gene silencing mechanism and is set off by processing the dsRNA into small-interfering RNA (~20-25 bases) by the activity of a ribonuclease III enzyme called Dicer-like (DCL) enzymes (Guo *et al*., 2016). The siRNAs are embodied into a RNA-induced silencing complex (RISC) which then binds to target mRNA through base pairing and facilitates degradation of the target RNA.

Environmental RNAi (eRNAi), a phenomenon of gene silencing induced by the RNAs taken from the environment, was first observed in worms and later in other organisms including fungi. In eRNAi, externally supplied dsRNAs could be taken up by the hosts and processed into small interfering RNAs (siRNAs) that in turn degrade the host transcripts in sequence specific manner. A study by Weiberg *et al*. (2013), had shown that small RNAs (sRNAs) of *B. cinerea* can silence Arabidopsis and tomato genes involved in immunity. The sRNAs of Bc-DCL1 and Bc-DCL2 (Dicer-like protein) were delivered into host plant cells where they hijacked the host RNA interference (RNAi) machinery by binding to Argonaute 1 (AGO1), a protein of RNA induced silencing complex (RISC), and selectively silenced the host immunity genes. This transfer of "virulent" sRNA effectors into host plant cells demonstrated a naturally occurring cross-kingdom RNAi virulence mechanism. This type of communication among different organisms through sRNA signals is termed 'cross-kingdom RNAi' (Knip *et al*., 2014). The seminal work carried out by Wang *et al.* (2016) clearly established that RNAi occurs naturally in a bi-directional way during the initial phase of *B. cinerea* and Arabidopis interaction - fungal produced sRNAs trying to silence the host mediated resistance reaction and the sRNA produced by the host suppressing the pathogenicity and/or proliferation of the pathogen. Their experiments also established that this phenomenon could be exploited to suppress *B. cinerea* infection in different host plants. In principle, the transcripts of important genes of pathogen(s) could be degraded in a targeted manner by the dsRNA molecules supplied from outside so that the infection and/or proliferation of the pathogen could be contained. Recent studies on cross-kingdom sRNA communication have led to an understanding that there is horizontal transfer of sRNAs among animals, plants and microbes, and the mechanism of RNA interference (RNAi) signal transmission via cross-kingdom sRNAs is beginning to unravel (Zeng *et al*., 2019). Plant biologists have exploited the phenomena of eRNAi as well as the sRNA mediated communication channels to deliver lethal siRNAs that can silence the vital genes of pathogens.

Two approaches are followed to deliver the lethal siRNAs signals to the pathogens. In the first approach called host-induced gene silencing (HIGS), the signals are generated *in planta,* and involves development of transgenic

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plants producing the siRNAs against the selected genes of the pests (Qi *et al*., 2019). However, the limitations associated with HIGS are the requirement for the generation of transgenic lines which is time consuming and restricted to crops with transformation protocols, genetic instability associated with transgenic trait, and less public acceptance of transgenic crops in many countries. Besides, this strategy cannot be easily adopted to test many target genes in a short time, therefore newer methods are favorable (Song *et al.*, 2018). The second approach, a more recent one, tries to overcome the limitations of HIGS and it involves the exogenous application of double-stranded RNA (dsRNA), small-interfering RNA (siRNA), and hairpin RNAs (hpRNAs), which upon entry into the pathogen results in post-transcriptional gene silencing of the target genes of the pathogen. This latter strategy is known as spray-induced gene silencing (SIGS) and has emerged as a promising tool to control the crop diseases caused by parasitic pests, nematodes, viruses, and fungi (Das and Sherif, 2020). SIGS strategy to control pests is more environmentally friendly as it leaves no chemical residues in crops and inhibits only the target organisms due to sequence specificity. Fig 1 depicts the two strategies. In this article we try to summarize the recent developments in the field of SIGS and the potential use of SIGS to contain diseases.

Spray induced gene silencing - a new way to silence pest specific genes

In this strategy, as outlined in Fig.1, the dsRNA targeting one or a few pathogen specific genes is exogenously sprayed onto plant surface. There are two pathways proposed for the dsRNAs or siRNAs applied onto the plant surface to enter fungal cells: (i) the foliar-applied RNAs enter fungal cells directly and induce the fungal RNAi machinery and/or (ii) the RNAs are taken up by host plant first, induces the plant RNAi machinery, and then siRNAs are translocated into the fungal cells. Once inside the pathogen, the sRNA signals are expected to bind to the target transcript(s) due to complementarity and then facilitate degradation of the transcript(s) using RNAi machinery of the pathogen. This provides a new era of RNAi-based strategies which are sustainable and effective for control of fungal as well as other pathogenic diseases. As SIGS strategy does not depend on plant transformation, it is expected to be adopted across all the crops. Thus, this approach silences pathogen's gene(s) without introducing heritable modifications into the plant genome and is more environmentally friendly as it leaves no chemical residues in crops and inhibits only the target organisms due to sequence specificity. SIGS shows many advantages: (i) specificity can be managed by choosing a more or a less conserved nucleotide sequence; (ii) it is possible to develop specific sequences for an unlimited range of pathogens having an active RNAi machinery; (iii) multiple essential genes can be targeted at once; and (iv) scalable, cost-effective and eco-friendly. Thus, SIGS is a new innovative strategy for protecting crops from pathogen infection (Nerva *et al*., 2020).

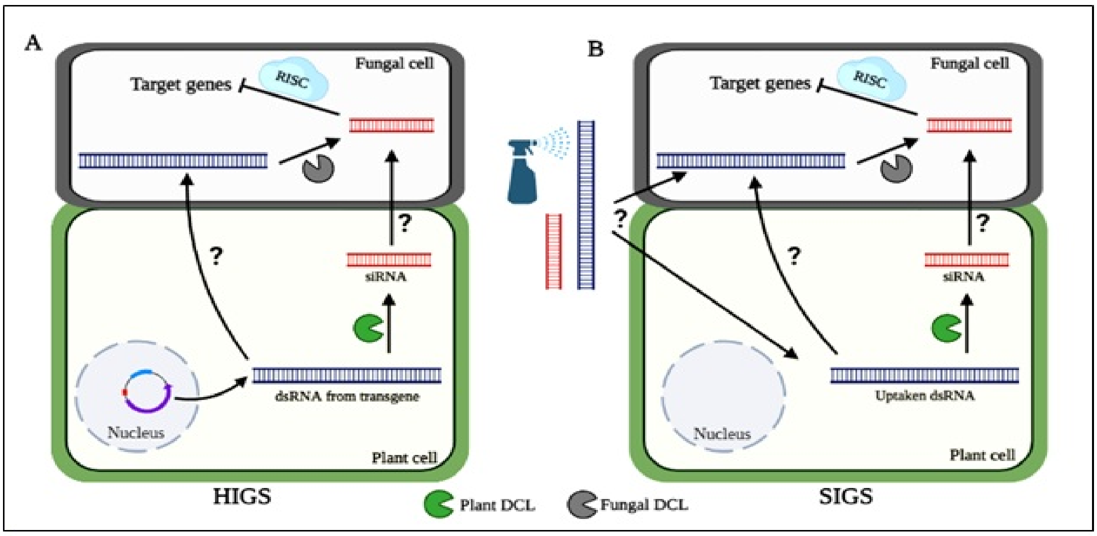

Figure 1. RNAi process could be exploited to silence the pathogen specific genes. There are two main approaches to achieve this. A) Host Induced Gene Silencing (HIGS) and B) Spray Induced Gene Silencing (SIGS). In HIGS, the signaling molecule (dsRNA) is produced inside the plant cell and exported into the pathogen whereas in SIGS, the dsRNA is sprayed on plant surface and then taken up by the pathogen either directly or through plant cell. Once inside the pathogen, the siRNA will bind to target transcript and directs degradation of the transcript. '?' indicates that the molecular mechanisms involved these steps are not completely understood but it is beginning to be unraveled using different experimental systems. DCL- dicer-like protein; RISC - RNA induced silencing complex; lines with blunted ends indicate inhibition; arrows indicate the direction of reaction/transport

Requirements for SIGS

Even though SIGS is a strategy that could be adopted across crops, there are a few critical requirements to be met. With respect to the chosen target genes of the pathogen: (i) the functionality and sequence information must be available, (ii) must be unique to the intended pathogen with no homologues in the plant genome or any other beneficial organisms to avoid unintended off-target effects, (iii) preferably be actively involved in the early events of interaction between pathogen and host plant so that the pathogen could be controlled early or the gene should be important in a critical phase of life cycle of the pathogen, (iv) preferably it could be a regulatory gene with an effect on many downstream genes so that the effect on pathogen is expected to be prominent, and (v) as the predominant effect of the siRNA is expected to be post-transcriptional, the target genes in the pathogen must be expressed. The pathogen should have an active RNAi pathway machinery so that the introduced sRNA signal could become instrumental and effective in degradation of the targeted transcripts. Recently, it has been demonstrated that for effectivity of SIGS for a longer duration there must be amplification of the introduced sRNAs in the pathogen brought about by RNA dependent DNA polymerase (RdDP) pathway (Song *et al*., 2018).

Tools for SIGS

As SIGS involves spraying of dsRNA, there must be systems for production of dsRNA. Predominantly there are two production systems - *in vitro* and *in vivo.* The *in vitro* dsRNA production involves (a) the cloning of the target sequence into an inducible cassette with the double and convergent T7 polymerase promoter on either side or the intended sequence of the target gene/combination of genes would be amplified along with the T7 promoter sequence on both the ends and (b) the resultant clone or fragment would be subjected to in vitro transcription using the T7 primers and T7 DNA dependent RNA polymerase (DdRP). This *in vitro* transcription is usually carried out using commercial systems (kit) such as MEGAscript RNAi Kit (Life Technologies). In this strategy, the synthesized dsRNA could be fragmented into siRNAs by digesting it with ShortCut RNase III (NEB), and subsequently purified with siRNA purification kit (Wang *et al.,* 2016). The efficiency of produced dsRNAs on the growth and virulence of pathogens and pests could first be tested through *in vitro* experiments and subsequently *in vivo* effects are evaluated by means of assessing disease progression on the host plant after spraying the plant/excised plant parts with dsRNAs (Nerva *et al.,* 2020).

For *in vivo* dsRNA production, *Escherichia coli* or *Pseudomonas syringae* or yeast (*Saccharomyces cerevisiae* and *Yarrowia lipolytica*) harboring the phage T7 DdRP for transcription are the commonly used hosts (Voloudakis *et al*., 2015; Alvarez-Sanchez *et al.,* 2018). The transformed host cells contain the target specific DNA under the control of T7 polymerase promoter. The sequences are either transcribed to produce complementary ssRNA molecules and anneal inside the host cells upon induction or are amplified by phage phi6 polymerase complex in a phi6 carrier state Pseudomonas cell line. Alternatively, the dsRNA are expressed in the RNase III-deficient *Escherichia coli* strains such as HT115, M-JM109, or M-JM109lacY for efficient and stable *in vivo* production of large amounts of dsRNA. In most cases, the crude bacterial extracts are treated with DNAse and RNAse before application (Fig. 2). A microbial fermentation technology has also been developed for large-scale production of dsRNAs by "RNAgri" an agricultural industry and in comparison to *in vitro* production system, this technology is considered as a sustainable one for providing large quantities of dsRNAs (Das and Sherif, 2020). It is assumed that 2 to 10 g of dsRNA would be required to spray on one hectare crop and the cost of production of each gram of dsRNA has come down from 12500 USD during 2008 to nearly 2 USD at present (Dalakouras *et al.,* 2020). This might promote application of SIGS in many crops once the effectiveness of SIGS in controlling the particular pest is proven in the crop through experimentation.

Limitations of SIGS and strategies to overcome them

SIGS has emerged as a potential tool for improving various agronomically important plants. However, several factors need to be considered to use this technology at a wider scale. In spite of having technologies to produce dsRNAs in large scale (as stated earlier), the major challenge facing the practical agricultural utilization of this technology is the identification of suitable target genes to be silenced in the pest. The target genes for RNAi-based pesticides are still limited and a complete transcriptomic data set needs to be available to identify target genes involved in virulence and pathogenicity. The other major concern for wider application of SIGS is the short-term stability of naked-dsRNAs sprayed on the plant surface which usually offers only a protection window of 5-7 days post spray. To overcome this, the desired RNAs are bound to protein to protect them against degradation and the protected dsRNAs are stable and safe to use compared to naked dsRNAs (http://www.rnagri.com/). Recently, nanotechnology-based and surfactants-based delivery methods are extensively used along with naked-dsRNAs application in plants. Some studies reported that nanoparticle based delivery could enhance the stability and efficacy of exogenously applied dsRNAs when compared to naked-dsRNA delivery (Numata *et al*., 2014; Mitter *et al.,* 2017). When combined with cationic fluorescent nanoparticles dsRNAs also exhibited more dramatic suppression of target genes than naked-dsRNAs.

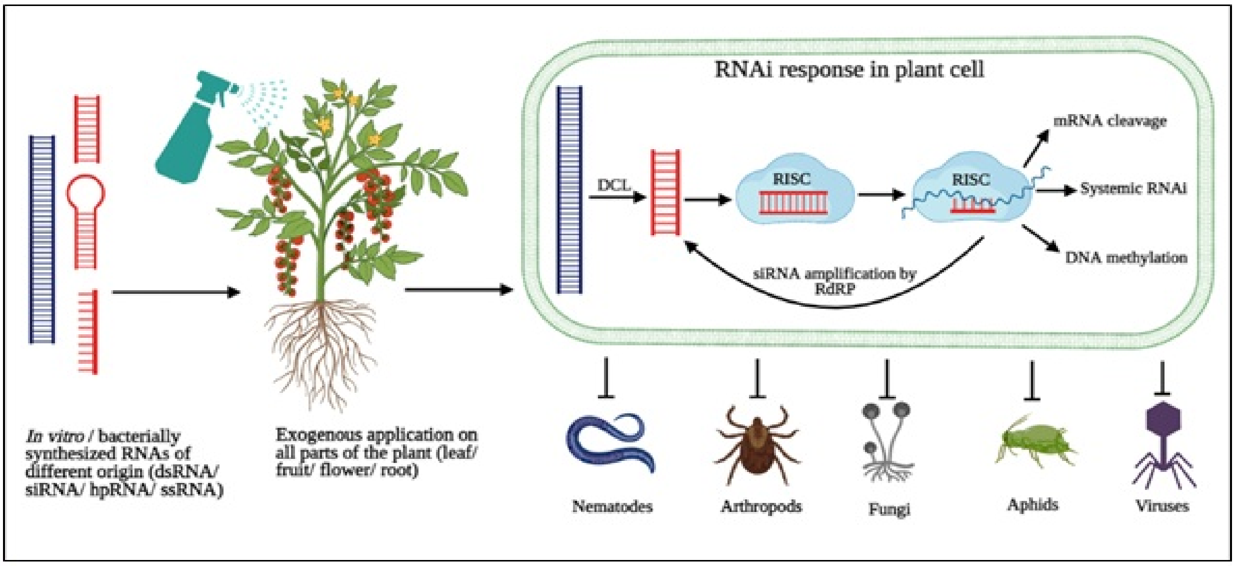

Fig. 2: Schematic representation of the types of exogenously applied RNAs on different crop plants and the subsequent RNAi mechanism in plant cells (Dubrovina and Kiselev 2019; Das and Sherif 2020; Sang and Kim 2020).

Successful examples of application of SIGS in crops

SIGS is shown to be effective in targeting many plant pathogens, including various plant viruses and viroids (Morozov *et al.,* 2019; Dubrovina and Kiselev, 2019), fungal pathogens and insect pests (Li *et al.,* 2015; Kuo and Falk 2020). The SIGS strategy for disease control have been reported to protect several plant species including barley, tomato, strawberry, grape, oilseed rape, wheat, onion, rose, lettuce, cucumber, soybean, and *Arabidopsis* against several fungi such as *Fusarium graminearum, Botrytis cinerea, Sclerotinia sclerotiorum,* and *Fusarium asiaticum* (Koch *et al.,* 2016; Wang *et al.,* 2016; McLoughlin *et al.,* 2018; Song *et al.,* 2018; Zeng *et al.,* 2019). In several studies, dsRNAs targeting multiple genes were shown to be effective as a foliar treatment, thus providing insurance and allowing for alteration of targets between growing seasons. Several factors such as the concentration, length, stability, etc are known to influence the efficiency of SIGS (Das and Sherif, 2020).

It has been demonstrated that SIGS confers resistance against viruses in various host species, such as tobacco, tomato, maize, papayas, watermelon, and squash against different viruses such as tobacco etch virus (TEV), tobacco mosaic virus (TMV), alfalfa mosaic virus (AMV), pepper mild mottle virus (PMMoV), potyvirus, bean common mosaic virus (BCMV), papaya ringspot virus (PRSV), and zucchini yellow mosaic virus (ZYMV) (Dubrovina and Kiselev, 2019). The viral genes such as replicase (RP) or coat protein (CP) genes have been targeted and the dsRNAs or hpRNAs which when exogenously applied has shown to delay the onset of viral infection symptoms, reduce the infection symptoms, and lower viral titer. Similarly, studies have shown that foliar application of dsRNA to insect pests and their larvae mediates silencing of the targeted genes through penetration into insect cuticle. The effects of silencing has been shown in plant hosts such as rice, maize, potato tomato, beans and citrange against different agricultural pests, including aphids, whiteflies, and mites. The first study to control the insect pests by spraying RNA molecules was conducted using siRNA molecules against the diamondback moth, *Plutella xylostella*. Mortality rates of ?80% of the cabbage moth were observed when larvae were fed with *Brassica* spp. leaves sprayed with synthesized dsRNAs targeting the acetylcholine esterase genes, AChE1 and AChE2 (Gong *et al.*, 2013). More extensive attempts on insect RNAi have been reviewed elsewhere (Wang and Jin, 2017).

Utility of SIGS against diseases caused by fungal pathogens has also been demonstrated in many crops and against different pathogens. The grey mold, caused by Botrytis spp. is the second most important necrotrophic fungus impacting agricultural production worldwide (Dean *et al.,* 2012). Studies have been carried out to see the effect of SIGS in controlling this disease. The topical application of either dsRNAs and small RNAs targeting the components of the RNAi machinery, Dicer-like (DCL)1 and DCL2 genes of the fungal pathogen *Botrytis cinerea*, inhibits grey mold disease on fruits, vegetables, and flowers (Wang *et al.,* 2016). SIGS is reported to have reduced *B. cinerea* infections in detached strawberry and tomato fruits as well as in detached leaves of oilseed rape (McLoughlin *et al.,* 2018). Double stranded RNA corresponding to parts of the three essential genes of *B. cinerea* (lanosterol 14α-demethylase, chitin synthase 1 and elongation factor 2), selected on the basis of fungicide site of action, conferred protection against *B. cinerea* in both pre- and post-harvest conditions (Nerva *et al.,* 2020).

Late blight of potato caused by *Phytopthora infestans* is a destructive plant pathogen that triggered the Irish potato famine and remains the most costly potato pathogen to manage worldwide (Goss *et al.,* 2014). Recently SIGS strategy has been applied to control this disease. Partial sequences of Sorbitol dehydrogenase (SDH), Translation elongation factor 1-α (EF-1α), Phospholipase-D like 3 (PLD3), Glycosylphosphatidylinositol-anchored acidic serine-threonine rich HAM34-like protein (GPI HAM34) and Heat shock protein-90 (Hsp90) of the pathogen were targeted to develop dsRNA spray formulations. These enzymes were chosen as they were associated with the establishment of infection by the pathogen on the host (potato) (Siddappa *et al.,* 2021). In another study, SIGS has been demonstrated to control this disease by targeting genes using an array of *P. infestans* genes, guanine-nucleotide binding (G) protein β-subunit, oxysterol binding protein, haustorial membrane protein, cutinase and endo-1,3(4)-β-glucanase, all of them known to be essential for pathogenesis, expressed at different stages of the infection cycle and an agrochemical target (Kalyandurg *et al*., 2021). The degree of disease control was dependent on the selection of the target genes.

The effectiveness of spray applications of dsRNAs and siRNAs onto detached leaves was demonstrated in an agronomically important barley - *Fusarium graminearum* pathosystem. The spray formulation of long dsRNA targeting the three fungal cytochrome P450 genes - CYP51A, CYP51B and CYP51C of *F. graminearum,* required for biosynthesis of fungal ergosterol attenuated fungal growth in the local as well as the non-sprayed (distal) parts of detached leaves. It was also shown that the dsRNA traversed the plant vascular system in distal parts and was processed into small interfering (si)RNAs by fungal DICER-LIKE 1 (FgDCL-1) after uptake by the pathogen and exhibited efficient spray-induced control of fungal infections (Koch *et al.,* 2016). When myosin5 gene (Myo5) was chosen as the target of SIGS in wheat - *Fusarium asiaticum* system, it reduced fungal virulence and led to weaker disease symptoms. It was shown that a region of the Myo5 gene induced sequence-specific RNA interference (RNAi) activity in *F. asiaticum, F. graminearum, F. tricinctum* and *F. oxysporum* (Song *et al.,* 2018). Many of the examples of application of SIGS in controlling plant pathogens has been provided by Zeng *et al.* (2019).

Cultivation of oilseed crops is beset with problems of pathogens such as grey mold, wilt, rot, leaf spots and viral diseases. Successful application of SIGS to reduce the severity of diseases has been reported in oilseed rape, soybean and of course in the model oilseed crop *Arabidopsis*. Also, it has been demonstrated that SIGS are effective against fungal pathogens such as *Fusarium* spp, *Botrytis cinerea, Sclerotinium* spp. which are common pathogens in oilseed crops and thus offers scope to contain these diseases. Thus, there is enough scope to try SIGS strategy to control diseases in oilseed crops. At IIOR we are trying to adopt this tool to manage grey mold disease in castor.

Future Prospects

With the rapid progress made in cost-effective production of dsRNAs and with the attempts made to increase the stability of these molecules on plant surface, it is conceivable that in near future SIGS could be used for commercial applications in agriculture. Still specific application tools need to be developed and the stabilizing agents useful for field conditions need to be identified. Understanding the exact mechanism of recognition, uptake, and transport of externally sprayed RNA into pathogens either by direct uptake or through plant cells is another potential area of research that advance the efforts to design new generation bio-pesticides. Compared with HIGS, the knowledge of SIGS is still limited, and more exploration is needed. Cross-kingdom sRNAs hold a big promise for pest and disease control, but it is still part of the process to find lethal genes suitable for the RNAi-based technologies in microbial pathogens or pests, as well as effective delivery strategies for sRNA direct application in the natural environments. For effective induction of the silencing of target genes, the length of the dsRNA fragment, concentration, and frequency of application must be optimized. The uptake mechanisms of exogenous dsRNA by plants or pathogen cells remain inexplicable and more research on the roles of membrane-bound proteins and receptors of plant and pathogen cells may improve our understanding of the underlying small RNA uptake mechanisms (Wytinck *et al.,* 2020; Islam and Sherif, 2020).

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Generation mean analysis for seed yield and its component traits in five crosses of castor (*Ricinus communis* L.)

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ABSTRACT

The present study was carried out to estimate gene effect, heterosis, inbreeding depression, heritability and expected genetic advance for seed yield and its component characters in five crosses of castor (*Ricinus communis* L.). The analysis of variance revealed significant differences among different crosses and among different generations within cross for all the characters studied. In the present study, both additive and non-additive gene actions were found to be important for the expression of seed yield and most of its component traits indicating that intermating among the selected segregants to break the undesirable linkage followed by one or two generations of selfing could facilitate the accumulation of favorable alleles for the improvement of these traits. However, some of the characters in various crosses were governed by fixable (additive and additive x additive) gene effects and hence, these characters could be improved through pedigree method of selection. Significant heterosis and heterobeltiosis in desired direction observed for seed yield and its majority of the components *viz.,* number of total and effective branches/plant, number of capsules on primary raceme, shelling out turn and 100-seed weight suggested the possibility of utilizing hybrid vigour on commercial scale. High estimates of broad as well as narrow sense heritability along with high genetic advance observed for seed yield/plant in cross I (SKI 324 x PCS 124), cross II (ANDCI 10-7 x JH 109) and cross V (ANDCI 10-7 x SKI 324) suggested the preponderance of additive/fixable gene effect and hence this character could be further improved by adopting selections in succeeding segregating generations. The combination of low narrow sense heritability along with low genetic advance detected for few characters indicated the major role of non-additive gene action and therefore, heterosis breeding or population improvement approach would be more effective for the improvement of these traits. It is being suggested that the parental genotypes SKI 324, ANDCI 10-7 and ANDCI 8 due to their presence in high heterotic combinations *viz.,* ANDCI 10-7 x JH 109 and ANDCI 8 x SKI 324 need to be further exploited in future castor breeding programme.

Keywords: Castor, Gene action, Genetic advance, Heritability, Heterosis, Inbreeding depression

Castor (*Ricinus communis* L.) with 2n = 20, belongs to the family Euphorbiaceae and it is indigenous to eastern Africa and most probably originated in Ethiopia. India is the world's principal producer of castor and ranks first both in area and production. Castor productivity in India is more than world's average and it ranks first among the major castor producing countries *viz*., India, China, Brazil and Thailand. Castor is a non-edible oilseed crop cultivated around the world because of commercial importance of its oil. The oil is mainly used as lubricant because of its property to remain liquid at very low temperatures (-32°C), high density and viscosity (18 times higher than that of any other vegetable oil). Castor oil and its derivatives have wide range of uses in the manufacture of lubricants, plastics, adhesives, waxes, polishes, coating applications, inks, paints etc. Though, castor oil is a chief commercial commodity, castor cake is also a good source of nitrogen (4.5-6.6 %) and is widely used as manure. However, because of presence of toxic substance, ricin, it is unfit for human consumption and cattle feed.

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Seed yield of a crop is due to interaction of many genes with environment, thus, direct selection for it will not be successful. Selection for yield components has been suggested as a solution for further advance in increasing the yield. For increasing inherent yielding potential of a crop plant, the selection criterion may be yield or some of the yield related components. An understanding of the mode of inheritance of the yield components, the correlations among them and the association between each component with yield is necessary for the intelligent choice of breeding procedures for developing high yielding varieties.

Exploitation of hybrid vigour has long been recognized as a practical tool in improving yield and other economic traits. Most of the area under castor crop is covered by hybrids. Therefore, estimation of heterosis and inbreeding depression is of immense importance for the development of hybrids in castor. Heritability is a good index of the transmission of characters from parents to their offspring. Since, narrow sense heritability is estimated from additive genetic variance, estimation of heritability and genetic advance is necessary for selection of elite genotypes from segregating populations of castor. Various biometrical techniques are extensively used for estimation of relative magnitude of different components of genetic variation. Out of which, techniques developed by Hayman and Mather (1955), Hayman (1958), Jinks and Jones (1958), Mather (1949) and Gamble (1962) require less number of crosses and are comprehensive, easy and equally informative. One of the best methods for estimation of genetic parameters is generation mean analysis, in which epistatic effects could also be estimated. Six basic generations can give accurate information about average dominance ratio and its inheritance. Hence, these components can give complete derived information from mean (Mather and Jinks, 1982; Kearsey and Pooni, 1996). Keeping this in view, an experiment was laid out to estimate the nature and magnitude of gene effects, heterosis and inbreeding depression, heritability and genetic advance for seed yield and its component characters using six basic generations of five cross combinations in castor.

MATERIALS AND METHODS

Experimental material: The experimental material comprised of seven diverse inbred lines of castor *viz.,* ANDCI 10-7, ANDCI 8, JI 358, SH 42, SKI 324, PCS 124 and JH 109, which were selected on the basis of their geographic origin and wide variation in morphological characters. The seeds of F_1 generation of SKI 324 x PCS 124 (cross I), ANDCI 10-7 x JH 109 (cross II), ANDCI 8 x SKI 324 (cross III), JI358 x SH 42 (cross IV) and ANDCI 10-7 x SKI 324 (cross V) were obtained from the Department of Genetics and Plant breeding, B. A. College of Agriculture, Anand Agricultural University, Anand. These F_1s along with their parents were grown during *kharif* 2015-16, where fresh F_1s and back crosses (B_1 and B_2) were developed. Parents and F_1 plants were selfed during the same season to obtain seeds of parents and F_2 generations, respectively.

Crossing and selfing technique: Seven inbred lines and their five F_1 hybrids were sown during *kharif* 2015-16 and crossing was carried out. At the same time parents and F_1 hybrids were selfed to get pure seeds of parents and F_2 generations, respectively. At the initial stage of emergence of raceme on female parents, all the male flowers as well as opened female flowers were clipped off and raceme having only unopened female buds were covered with suitable butter paper bags. To obtain uncontaminated pollen grains from male parents, all opened male flowers in the raceme were removed prior to bagging. On the emergence of stigma (next day), pollen grains collected from racemes of desired male parents were dusted over the stigma of the flowers of female parents. The dusting of pollen was repeated three to four times to ensure sufficient seed setting on spike of female parents. The pollinated racemes of female parents were thoroughly checked at periodical interval and newly emerged male flower buds were clipped off to avoid selfing. The raceme of female parent was bagged and labeled properly. On selected plants of the female and male parents, selfing was also done to obtain genetically pure seeds of parents. At the same time the selected plants from F_1s were crossed as female with P_1 and P_2 parent to obtain seeds of back cross generation (B_1 and B_2), respectively. Capsules from selfed and crossed plants of different crosses were harvested separately, manually threshed, dried and labeled properly.

Experimental design: The experimental material consisting of five crosses, each having six generations (P_1, P_2, F_1, F_2, B_1 and B_2) were evaluated during *kharif* 2016-17 in compact family block design with three replications. The five crosses formed the family blocks, whereas, different generations *viz.,* P_1, P_2, F_1, F_2, B_1 and B_2 of each cross represented individual experimental units within a cross. Individual replication was represented by five family blocks, one row each for P_1, P_2 and F_1, two rows each for B_1 and B_2 and four rows for F_2 generation. Total 10 plants were accommodated in each row. The inter and intra row spacing was 120 cm and 60 cm, respectively. All the recommended agronomical practices and plant protection measures were followed as and when required for raising healthy crop.

Characters studied: The observations for all the metric characters under study were recorded in each experimental unit i.e., generation from five plants each in P_1, P_2 and F_1, ten plants each in each B_1 and B_2 and twenty plants each in F_2. The plants for recording observations were selected randomly from the competitive plants excluding border plants. The selected plants were tagged and numbered for recording observations on seed yield//plant (g) and other component traits *viz.,* days to flowering of primary raceme, days to maturity of primary raceme raceme, plant height up to primary raceme (cm), number of nodes up to primary raceme, number of total branches/plant, number of effective branches/plant, total length of primary raceme (cm), effective length of primary raceme (cm), number of capsules on primary raceme, shelling out turn (%), 100 seed weight (g) and oil content (%). Per cent oil content in castor seed was determined by using Nuclear Magnetic Resonance (NMR) technique (Tiwari *et al*., 1974).

Statistical analysis: The mean values, standard errors and variances of the different generations were subjected to weighed least-square analysis using the scaling test (Mather 1949) to estimate the gene effects. The genetic effects were estimated using the models suggested by Jinks and Jones (1958) and Mather and Jinks (1982). The significance of the scaling test and gene effects were tested by using the t-test (Singh and Chaudhary, 2004). The type of epistasis was determined only when dominance (h) and dominance x dominance (l) effects were significant; when these effects had the same sign the effects were complementary, while different signs indicated duplicate epistasis. The heterotic effects in term of superiority of F_1 over better parent (heterobeltiosis) was worked out as per Fonseca and Patterson (1968); over mid parent value (relative heterosis) as per Turner (1953) and inbreeding depression as loss in vigour due to inbreeding. The broad sense heritability in per cent was calculated by using the formula suggested by Burton (1951) and Heritability in narrow sense was estimated as per the method of Warner (1952). The expected genetic advance at 5% selection intensity was estimated by using formula suggested by Allard (1960).

RESULTS AND DISCUSSION

Analysis of variance (ANOVA): Analysis of variance for generation means comprising six generations *i.e.*, P_1, P_2, F_1, F_2, B_1 and B_2 was computed for thirteen characters of each cross. The values of analysis of variance for crosses and generations within the cross for various characters are presented in Table 1. Analysis of variance between cross comparisons depicted significant differences for all the characters. Analysis of variance between progenies within cross comparisons also indicated significant differences for all the characters in five crosses. Significant differences suggested presence of sufficient variation for generation mean values of all the crosses for different traits, thereby revealing existence of sufficient variation to analyse and interpret the results in terms of objectives under investigation. The significant variation for all the characters under study might be due to more diversity between the parents which resulted in high variability among its generations.

Gene effects: The individual scaling test/s and/or χ^2 value of joint scaling tests (Table 2) were significant in all the crosses for various characters except plant height in cross III, number of nodes up to primary raceme in cross V, number of total branches/plant in cross I, number of effective branches/plant in cross III and cross IV, total and effective length of primary raceme in cross II, number of capsules on primary raceme in cross III and shelling out turn in cross I, cross IV and cross V indicating the inadequacy of additive-dominance model and presence of inter-allelic interactions in the inheritance of these characters.

The significance of 'm' value in all the crosses for various characters (Table 2) suggested that mean values of different generations in all the crosses for different characters statistically differed within respective cross and hence, information generated through first degree statistics would be unbiased.

The estimates of gene effects using different genetic parameter models are presented in Table 2. The perusal of data showed that in cross I (SKI 324 x PCS 124), only additive gene effect for number of effective branches/plant; dominance gene effect for seed yield/ plant and shelling out turn; additive and dominance gene effect for days to flowering of primary raceme, days to maturity of primary raceme and number of total branches/plant; additive and epistatic (additive x dominance) gene effects for plant height upto primary raceme, number of nodes/plant, total length of primary raceme, effective length of primary raceme and number of capsules on primary raceme; additive, additive x additive and dominance x dominance gene effects for 100-seed weight and additive gene effect along with all the types of digenic interactions for oil content were found to be significant.

The estimates of various components of gene effect in cross II (ANDCI 10-7 x JH 109) revealed that only additive gene effect for total length of primary raceme, effective length of primary raceme and 100-seed weight; only dominance gene effect for number of capsules on primary raceme and shelling out turn; additive x additive epistasis for number of total branches/plant; additive x additive and dominance x dominance epistatic gene effects for seed yield/plant; additive, dominance and additive x additive gene effects for days to flowering of primary raceme; dominance and additive x additive gene effects for plant height upto primary raceme; all the gene effects except dominance x dominance for days to maturity of primary raceme and additive, dominance and all types of digenic interactions for oil content were found significant. Presence of duplicate epistasis was also observed for oil content.

The magnitude of different gene effects varied with different characters in cross III (ANDCI 8 x SKI 324); as only dominance gene effect for number of nodes/plant; both additive and dominance gene effects for plant height upto primary raceme, number of effective branches/plant and number of capsules on primary raceme; only additive x additive for 100-seed weight; additive and additive x additive for effective length of primary raceme; dominance and additive x additive for total number of branches/plant and seed yield/plant; additive, dominance and additive epistasis for total length of primary raceme, dominance gene effect with additive x dominance and dominance x dominance for days to flowering of primary raceme and days to maturity of primary raceme and dominance gene effect with all the types of digenic interactions for oil content were found significant. However, non-additive gene effect was found preponderant for inheritance of most of the characters in cross III. Presence of duplicate epistasis was evidenced for oil content in this cross.

The estimates of various gene effects with three or six parameters model in cross IV (JI 358 x SH 42) revealed that only additive gene effect for days to flowering of primary raceme and shelling out turn; only dominance gene effect for seed yield/plant; both additive and dominance gene effect for number of effective branches/plant and 100-seed weight;

additive, dominance and additive x additive for days to maturity of primary raceme; dominance, additive x additive, dominance x dominance for oil content; dominance and dominance x dominance epistasis for number of nodes up to primary raceme; only dominance gene effect for total length of primary raceme and effective length of primary raceme and additive x dominance and dominance x dominance gene effects for number of capsules on primary raceme were found to be significant. The character oil content exhibited duplicate epistasis.

Table 1 Analysis of variance of five crosses and their six generations for different characters in castor

Source	d.f.	Mean sum of square												
		Days to flowering of primary raceme	Days to maturity of primary raceme	Plant height up to primary raceme	Number of nodes up to primary raceme	Number of total branches/ plant	Number of effective branches/ plant	Total length of primary raceme	Effective length of primary raceme	Number of capsules on primary raceme	Seed yield/ plant	Shelling out turn	100-seed weight	Oil content
Between cross comparison														
Replications	2	2.68	4.42	4.83	0.26	0.60	0.29	1.04	0.56	34.74	143.27	0.25	0.30	0.27
Cross	4	3.49**	15.59**	300.51**	3.76**	13.39**	4.91**	159.91**	145.65**	403.21**	1631.49**	5.08**	4.44**	3.23**
Error	8	0.49	1.28	15.08	0.19	0.69	0.17	7.65	5.34	7.00	255.15	0.27	0.31	0.17
Between generations within cross comparison														
Cross I (SKI 324 x PCS124)														
Replications	2	6.78	11.84	123.44	0.96	5.55	0.73	40.63	22.44	55.47	537.18	2.37	0.25	1.35
Generations	5	41.73**	121.05**	865.57**	12.32**	29.80**	20.35**	321.95**	272.53**	832.16**	2879.42**	8.72**	4.79**	2.08**
Error	10	3.34	11.05	37.11	0.71	1.87	0.81	11.49	9.19	30.63	507.22	0.59	0.14	0.34
Cross II (ANDCI 10-7 x JH109)														
Replications	2	5.13	13.39	28.92	0.75	1.60	1.79	56.88	39.27	11.36	2003.06	2.16	1.63	0.63
Generations	5	23.35*	29.84*	87.76*	1.80*	10.76**	5.98**	67.73*	95.05**	156.58*	12166.13**	16.25*	6.11**	3.13**
Error	10	4.72	6.74	20.28	0.37	0.95	0.64	19.11	10.38	38.79	638.24	2.75	0.81	0.33
Cross III (ANDCI 8 x SKI 324)														
Replications	2	11.06	1.70	131.78	1.58	8.06	0.66	38.06	14.31	152.50	493.07	1.71	4.31	1.34
Generations	5	31.01**	67.38**	278.98**	3.70**	10.21*	5.37**	44.23*	30.07*	147.34*	3721.45**	7.96**	4.89*	2.80**
Error	10	4.18	13.39	39.56	0.58	2.31	0.76	9.60	7.32	42.40	650.04	1.08	1.09	0.34
Cross IV (JI 358 x SH 42)														
Replications	2	4.93	10.21	70.15	2.20	4.97	2.33	44.04	43.32	84.28	3376.62	1.66	2.82	1.28
Generations	5	20.78**	83.04*	260.88**	2.73*	10.84*	8.38**	76.92*	76.46*	416.26**	6201.67**	2.97**	15.73**	1.31*
Error	10	3.60	21.98	43.81	0.56	1.63	0.98	16.21	15.27	45.97	1060.80	0.52	0.72	0.33
Cross V (ANDCI 10-7 x SKI 324)														
Replications	2	0.03	20.12	36.81	0.74	0.17	0.35	10.23	12.16	72.97	574.06	0.22	0.11	1.14
Generations	5	11.80*	35.70*	285.66**	2.15**	9.37**	4.36**	45.48*	74.99*	242.54*	3185.63**	16.98**	2.21*	2.45**
Error	10	3.12	9.67	32.07	0.32	1.49	0.72	12.91	20.48	52.57	563.00	0.60	0.59	0.31

:*, ** Significant at p = 0.05%and p = 0.01% levels, respectively

Table 2 Estimates of simple scaling test and gene effects for different traits in five crosses of castor

Crosses	Gene effect													
	Scaling tests				Three parameters model				Six parameters model					
	A	B	C	D	m	$\hat{d}$	$\hat{h}$	χ^2 at 3 d.f.	M	$\hat{d}$	$\hat{h}$	$\hat{i}$	$\hat{j}$	$\hat{l}$
Days to flowering of primary raceme														
I	4.93	6.27**	17.60**	3.20	-	-	-	28.22**	53.17**	3.73*	-10.60*	-6.40	-0.67	-4.80
II	2.00	-1.67	10.53**	5.10**	-	-	-	15.98**	53.97**	4.97**	-9.13*	-10.20**	1.83	9.87
III	11.73**	3.67	13.20**	-1.10	-	-	-	29.37**	54.20**	5.30**	-3.73	2.20	4.03*	-17.60*
IV	6.53**	5.60**	14.33**	1.10	-	-	-	22.78**	53.30**	2.97*	-5.37	-2.20	0.47	-9.93
V	2.87	4.07*	6.00	-0.47	-	-	-	7.33	53.62**	-2.57*	-2.23	0.93	-0.60	-7.87
Days to maturity of primary raceme														
I	12.60**	5.60	29.20**	5.50	-	-	-	41.26**	123.70**	9.23**	-21.00*	-11.00	3.50	-7.20
II	5.53*	-3.27	14.60**	6.17*	-	-	-	24.53**	127.97**	7.10**	-12.83*	-12.33*	4.40**	0.10
III	19.60**	2.93	25.00**	1.23	-	-	-	57.01**	127.57**	9.70**	-8.83	-2.47	8.33**	-20.07*
IV	-2.93	3.67	11.73	5.50*	-	-	-	8.93*	124.01**	4.07**	-15.97**	-11.00*	-3.30	10.27
V	6.00*	6.60*	23.27**	5.33*	-	-	-	19.29**	128.02**	-0.90	-18.67**	-10.67*	-0.30	-1.93
Plant height upto primary raceme														
I	-23.13**	-3.07	-24.73*	0.73	-	-	-	10.39*	63.33**	13.60**	-14.90	-1.47	-10.03*	27.67
II	6.27	9.13	54.33**	19.47**	-	-	-	27.94**	100.75**	-2.43	-44.60**	-38.93**	-1.43	23.53
III	-12.33	-11.80	-12.27	5.93	79.87**	-9.23**	-19.89**	4.60	-	-	-	-	-	-
IV	-13.27	-20.27*	-49.87**	-8.17	-	-	-	16.44**	74.80**	4.77	0.06	16.33	3.50	17.20
V	-7.87	7.93	46.47**	23.20**	-	-	-	13.85**	94.37**	-10.40*	-68.30**	-46.40**	-7.90	46.33
Number of nodes up to primary raceme														
I	-2.20*	0.27	-2.80*	-0.43	-	-	-	8.75*	13.52**	1.60**	-0.90	0.87	-1.23*	1.07
II	1.13	1.87*	2.67	-0.17	-	-	-	5.60	17.03**	-0.77	1.60	0.33	-0.37	-3.33
III	-2.07*	-1.80	-2.47	0.70	-	-	-	6.89	15.00**	-0.43	-3.70*	-1.40	-0.13	5.27
IV	-1.93*	-2.53**	-3.73*	0.37	-	-	-	14.40**	13.57**	0.97**	-1.87	-0.73	0.30	5.20*
V	1.47	-0.33	1.53	0.20	16.28**	-0.86**	-0.82	4.67	-	-	-	-	-	-
Number of total branches/plant														
I	1.33	-1.20	3.67	1.77	16.15**	-3.85**	4.15**	2.41	-	-	-	-	-	-
II	4.53*	1.87	15.33**	4.47*	-	-	-	24.44**	15.42**	1.43	-6.90	-8.93*	1.33	2.53
III	-1.27	1.33	-5.67	-2.87*	-	-	-	6.24	14.98**	0.37	9.60**	5.73*	-1.30	-5.80
IV	-4.33**	-1.80	-5.87	0.13	-	-	-	8.23*	15.20**	1.00	2.67	-0.27	-1.27	6.40
V	2.47	3.93**	9.93**	1.77	-	-	-	18.90**	15.17**	-1.50	-0.90	-3.53	-0.73	-2.87
Number of effective branches/plant														
I	2.73*	-0.47	2.73	0.23	-	-	-	5.70	11.98**	-1.67*	3.20	-0.47	1.60	-1.80
II	2.60	1.47	9.67**	2.80*	-	-	-	15.57**	10.00**	0.80	-3.43	-5.60*	0.57	1.53
III	0.20	0.67	-0.53	-0.70	7.72**	0.75**	3.34**	0.87	-	-	-	-	-	-
IV	-1.40	0.87	-1.73	-0.60	7.99**	1.71**	2.86**	2.83	-	-	-	-	-	-
V	1.47	1.80	5.73**	1.23	-	-	-	15.56**	9.30**	-0.37	-0.07	-2.47	-0.17	-0.80
Total length of primary raceme														
I	-12.13**	0.40	-20.87**	-4.57	-	-	-	15.66**	40.05**	8.67**	5.40	9.13	-6.27*	2.60
II	6.33	3.27	-11.07	-10.33	56.85**	5.43**	3.43	3.66	-	-	-	-	-	-

Table 2 (contd...)

Table 2 (contd...)

III	-8.13	4.13	-21.93**	-8.97*	-	-	-	10.71*	53.13**	-8.63**	17.23*	17.93*	-6.13	-13.93
IV	-14.93**	-21.20**	-29.40**	3.37	-	-	-	17.70**	58.65**	-0.33	-4.87	-6.73	3.13	42.87**
V	11.60*	-2.60	-4.13	-6.57	-	-	-	7.96*	58.35**	9.07**	7.70	13.13	7.10*	-22.13
Effective length of primary raceme														
I	-14.60**	-1.40	-27.20**	-5.60	-	-	-	29.17**	32.07**	7.00**	7.60	11.20	-6.60**	4.80
II	-2.00	1.93	-11.00	-5.47	50.46**	7.82**	-1.13	2.15	-	-	-	-	-	-
III	-3.13	6.13	-15.53*	-9.27*	-	-	-	8.22*	46.67**	-6.13*	14.77	18.53*	-4.63	-21.53
IV	-17.07**	-20.80**	-28.60**	4.63	-	-	-	19.35**	51.17**	-0.63	-8.70	-9.27	1.87	47.13**
V	1.80	-4.60	-17.07*	-7.13	-	-	-	6.46	49.10**	8.00**	8.07	14.27	3.20	-11.47
Effective length of main raceme														
I	-14.60**	-1.40	-27.20**	-5.60	-	-	-	29.17**	32.07**	7.00**	7.60	11.20	-6.60**	4.80
II	-2.00	1.93	-11.00	-5.47	50.46**	7.82**	-1.13	2.15	-	-	-	-	-	-
III	-3.13	6.13	-15.53*	-9.27*	-	-	-	8.22*	46.67**	-6.13*	14.77	18.53*	-4.63	-21.53
IV	-17.07**	-20.80**	-28.60**	4.63	-	-	-	19.35**	51.17**	-0.63	-8.70	-9.27	1.87	47.13**
V	1.80	-4.60	-17.07*	-7.13	-	-	-	6.46	49.10**	8.00**	8.07	14.27	3.20	-11.47
Number of capsules on main raceme														
I	-23.07**	8.87	-31.87**	-8.83	-	-	-	21.04**	55.23**	8.50*	7.27	17.67	-15.97**	-3.47
II	-8.13	-15.20	-50.87**	-13.77	-	-	-	10.74*	82.44**	7.83	40.23*	27.53	3.53	-4.20
III	-5.27	13.67	-17.93	-13.17	89.06**	-5.21*	-13.05**	5.43	-	-	-	-	-	-
IV	-22.47*	-40.67**	-73.67**	-5.27	-	-	-	34.06**	77.82**	-2.77	12.33	10.53	13.10*	56.60*
V	4.80	-23.67**	-30.80*	-5.97	-	-	-	15.65**	79.72**	15.73**	-3.83	11.93	14.23**	6.93
Seed yield/plant														
I	62.00*	18.87	33.13	-23.87	-	-	-	3.95	267.68**	27.03	116.27*	47.73	21.57	-128.60
II	133.47**	114.80**	400.73**	76.23	-	-	-	30.15**	339.78**	35.47	-63.53	-165.47*	9.33	-95.80*
III	25.60	18.13	-88.67	-66.20*	-	-	-	5.17	261.82**	14.10	217.77**	132.40*	3.73	-176.13
IV	-129.93**	-76.53	-324.00**	-58.77	-	-	-	19.27**	273.37**	13.17	179.87*	117.53	-26.70	88.93
V	26.27	46.07	175.40**	51.53	-	-	-	11.88**	299.48**	-15.30	-40.33	-103.07	-9.90	172.73*
Shelling out turn														
I	1.34	-0.61	0.29	-0.22	59.75**	0.36	4.45**	1.44	-	-	-	-	-	-
II	3.88**	3.27	6.02*	-0.56	-	-	-	10.50*	64.35**	0.91	6.08*	1.13	0.31	-8.28
III	-3.27*	-0.89	-6.48*	-1.16	-	-	-	7.66	64.55**	0.41	5.57	2.32	-1.19	1.84
IV	-2.22	-1.65	-5.45	-0.79	63.20**	1.16**	-1.07	3.81	-	-	-	-	-	-
V	-1.86	-1.32	-3.18	-0.01	60.69**	-0.56	5.56**	3.44	-	-	-	-	-	-
100-Seed weight														
I	-1.14*	-1.51*	0.09	1.37*	-	-	-	9.95*	29.28**	1.54**	-0.68	-2.74*	0.18	5.39**
II	3.72**	1.42	8.21**	1.54	-	-	-	30.83**	31.75**	2.40**	-2.82	-3.07	1.15	-2.06
III	1.81	-0.21	5.66**	2.03*	-	-	-	14.47**	33.45**	1.05	-1.37	-4.06*	1.01	2.45
IV	-0.02	-1.83*	-4.04**	-1.10	-	-	-	9.82*	30.47**	3.86**	3.33*	2.19	0.91	-0.35
V	0.61	1.15	4.55**	1.40*	-	-	-	8.07*	32.06**	-0.57	-1.19	-2.80*	-0.27	1.04
Oil content														
I	0.11	-1.09*	1.16	1.07*	-	-	-	11.74**	51.93**	0.61**	-0.04	2.15*	0.60*	3.13*
II	0.66	-1.85**	6.19**	3.69**	-	-	-	87.48**	50.61**	1.49**	-6.01**	-7.38**	1.25**	8.58**
III	0.10	-1.85**	2.44*	2.10**	-	-	-	25.79**	50.07**	-0.17	-2.80**	-4.19**	0.97**	5.94**
IV	-2.09**	-2.28**	-1.11	1.63**	-	-	-	30.70**	49.65**	-0.38	-2.37*	-3.26**	0.09	7.63**
V	0.36	1.55**	2.00*	0.05	-	-	-	9.92*	51.17**	-1.40**	1.18	-0.09	-0.60	-1.82

M, Midpoint; *d*, additive; *h*, dominance; *i*, additive x additive; *j*, additive x dominance; *l*, dominance x dominance. *,**significant at p = 0.05% and p= 0.01% levels of significance, respectively. I. SKI 324 x PCS 124 II. ANDCI 10-7 x JH 109 III. ANDCI 8 x SKI 324 IV. JI 358 x SH 42 V. ANDCI 10-7 x SKI 324

The magnitude of gene effects varied with different characters in cross V (ANDCI 10-7 x SKI 324); as only additive gene effect for days to flowering of primary raceme, number of nodes up to primary raceme, effective length of primary raceme and oil content; only dominance gene effect for shelling out turn; additive and additive x dominance for total length of primary raceme; dominance and additive x dominance for days to maturity of primary raceme, both additive and dominance gene effects along with additive x additive for plant height upto primary raceme; additive x additive for 100-seed weight and only dominance x dominance for seed yield/plant were observed significant. In general, above results revealed that different gene effects were responsible for inheritance of the same trait in different crosses and for different traits in the same cross.

Similar results were reported by Patel *et al.* (2017) for days to flowering of primary raceme, plant height up to primary raceme, number of nodes up to primary raceme, number of effective branches/plant, effective length of primary raceme and 100 seed weight. While importance of non-additive gene effects was also observed by Punewar *et al*. (2017) for number of nodes up to primary raceme, total length of primary raceme, number of capsules on primary raceme and oil content. Kasture *et al.* (2014) and Aher *et al.* (2015) also reported non additive gene action for seed yield/plant corroborate the present results. Patel and Pathak (2010) showed preponderance of both additive and non-additive gene effect for days to flowering of primary raceme, plant height up to primary raceme, number of nodes up to primary raceme, effective length of primary raceme, total length of primary raceme, 100 seed weight and oil content.

Heterosis and inbreeding depression: The estimates of heterosis over mid parent, better parent and inbreeding depression calculated in five crosses of castor are presented in Table 3. Significant heterosis in desired direction was observed for number of effective branches/plant, seed yield/plant and oil content in all the five crosses; days to flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme, number of nodes up to primary raceme, number of total branches/plant, shelling out turn and 100 seed weight in cross I; number of total branches/plant, number of capsules on primary raceme, shelling out turn and 100 seed weight in cross II; days to flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme, number of nodes up to primary raceme, shelling out turn and 100 seed weight in cross III; days to flowering of primary raceme, day to maturity of primary raceme, plant height up to primary raceme, number of total branches/plant and 100 seed weight in cross IV and days to flowering of primary raceme, days to maturity of primary raceme, number of nodes up to primary raceme, number of total branches/plant, shelling out turn and 100 seed weight in cross V.

Significant heterobeltiosis in desired direction was found for days to maturity of primary raceme, seed yield/plant, shelling out turn and oil content in cross I; number of total branches/plant, number of effective branches/plant, seed yield/plant, shelling out turn and oil content in cross II; days to flowering of primary raceme, days to maturity of primary raceme, number of nodes up to primary raceme, number of effective branches/plant, seed yield/plant, shelling out turn and 100 seed weight in cross III; plant height up to primary raceme in cross IV and days to maturity of primary raceme, plant height up to primary raceme, number of total branches/plant, number of effective branches/plant, seed yield/plant and shelling out turn in cross V.

Earlier studies have reported relative heterosis in desired direction for various characters in castor like number of total branches/plant (Patel and Pathak 2006), number of effective branches/plant and number of capsules on primary raceme and 100 seed weight (Chaudhari *et al.,* 2017; Kugashiya *et al.,* 2017), seed yield/plant (Patel and Pathak, 2006; Sapovadiya *et al.,* 2015) and oil content (Thakkar *et al*., 2005). Chaudhari *et al.* (2017) also showed significant negative heterosis over better parent for days to maturity of primary raceme, plant height up to primary raceme and number of nodes up to primary raceme similar to the present investigation. The significant positive estimates of heterobeltiosis were also reported by Punewar *et al.* (2017) for number of total branches/plant; Sapovadiya *et al.* (2015) for effective length of primary raceme, shelling out turn, 100 seed weight and oil content; Dadheech *et al.* (2010), Kugashiya *et al.* (2017) and Punewar *et al.* (2017) for seed yield/plant.

The significant inbreeding depression was observed for many important characters in all the five crosses. Significant inbreeding depression observed for characters *viz.,* days to flowering of primary raceme, days to maturity of primary raceme, effective length of primary raceme, shelling out turn and 100 seed weight in cross I; days to maturity of primary raceme, plant height up to primary raceme and number of capsules on primary raceme in cross II; days to flowering of primary raceme, number of total branches/plant, number of effective branches/plant, seed yield/plant and shelling out turn in cross III; days to flowering of primary raceme, number of total branches/plant, number of effective branches/plant, total length of primary raceme, effective length of primary raceme, number of capsules on primary raceme, seed yield/plant, 100 seed weight and oil content in cross IV and days to flowering of primary raceme, plant height up to primary raceme and shelling out turn in cross V. The significant and positive inbreeding depression was also observed by Singh *et al.* (2013) for total length of primary raceme, effective length of primary raceme, number of capsules on primary raceme, 100 seed weight, seed yield/plant and oil content which are in accordance with the present results.

Heritability and genetic advance: High heritability in broad sense (Table 4) was observed for days to flowering of primary raceme in cross I, cross III, cross IV and cross V; days to maturity of primary raceme in cross I, cross II, cross III and cross V; plant height up to primary raceme in cross I, cross IV and cross V; number of nodes up to primary raceme in cross II, cross III and cross V; number of total branches/plant, number of effective branches/plant and 100 seed weight in cross I, cross II and cross IV; total length of primary raceme, effective length of primary raceme and seed yield/plant in cross I, cross II and cross V; number of capsules on primary raceme in cross IV and cross V; shelling out turn in cross I, cross II and cross III and oil content in cross II and cross III indicating the great deal of genetic diversity in the material studied and less influence of environmental factors on the expression of these characters in various crosses.

High narrow sense heritability coupled with high genetic advance was observed for days to flowering and maturity of primary raceme in cross II; plant height upto primary raceme and number of nodes up to primary raceme in cross II, cross III, cross IV and cross V; number of total branches/plant in cross I, cross II, cross IV and cross V; number of effective branches/plant in cross I, cross II, cross III and cross IV; total length of primary raceme in cross I, cross II, cross IV and cross V; effective length of primary raceme in cross IV and cross V; number of capsules on primary raceme in cross V and seed yield/plant in cross I, cross II and cross V. Therefore, these characters were mainly governed by additive gene action and hence, direct selection for improvement of these traits in segregating generations would be effective.

Low narrow sense heritability along with low genetic advance as/cent of mean was observed for the various traits i.e., days to flowering of primary raceme in cross I and cross III; plant height upto primary raceme in cross I, effective length of primary raceme in cross II; number of capsules on primary raceme in cross III and cross IV and shelling out turn in cross IV, revealing the importance of non-additive gene action in the inheritance of these characters. Thus, heterosis breeding would be profitably used for improvement of these characters.

Table 3 Relative Heterosis (RH %), heterobeltiosis (HB %) and inbreeding depression (ID%) for various characters in five crosses of castor

Characters	I. SKI 324 x PCS124			II. ANDCI 10-7 x JH 109			III. ANDCI 8 x SKI 324		
	RH (%)	HB (%)	ID (%)	RH (%)	HB (%)	ID (%)	RH (%)	HB (%)	ID (%)
Days to flowering of primary raceme	-8.26** (0.90)	0.43 (0.88)	-13.93** (0.97)	2.11 (1.40)	8.81** (1.50)	-4.05 (1.51)	-11.03** (0.96)	-8.88** (1.30)	-13.08** (1.15)
Days to maturity of primary raceme	-8.24** (1.01)	-3.69** (1.14)	-11.04** (1.40)	-0.40 (1.58)	1.81 (1.85)	-3.14* (1.81)	-5.12** (1.62)	-4.06** (1.90)	-7.99** (1.85)
Plant height up to primary raceme (cm)	-17.62** (3.46)	19.39** (3.31)	-0.85 (3.48)	-6.30 (3.95)	-5.25 (4.43)	-19.47** (3.89)	-18.98** (4.43)	-8.62 (4.72)	-7.06 (4.57)
Number of nodes up to primary raceme	-11.70** (0.50)	8.70 (0.55)	-1.43 (0.48)	8.07** (0.49)	10.89 (0.59)	-0.18 (0.54)	-13.71** (0.53)	-12.14** (0.51)	-3.66 (0.50)
Number of total branches/plant	24.90** (0.85)	-0.33 (1.04)	5.43 (1.00)	19.21** (0.78)	18.09* (0.90)	-22.38** (0.98)	26.68** (1.03)	13.64 (1.29)	18.28** (1.02)
Number of effective branches/plant	38.73** (0.74)	3.14 (0.97)	8.76 (0.79)	33.33** (0.70)	28.83* (0.76)	-15.34 (0.80)	41.40** (0.75)	28.14** (0.89)	15.83* (0.76)
Total length of primary raceme (cm)	-7.92 (2.04)	-30.08** (2.28)	7.72 (2.27)	5.94 (3.12)	-3.42 (3.12)	7.41 (3.20)	-1.19 (2.98)	-5.21 (3.07)	8.82 (2.80)
Effective length of primary raceme (cm)	-8.85* (1.70)	-31.70** (2.00)	13.49** (1.85)	-1.57 (2.76)	-15.14** (2.80)	4.69 (2.68)	-7.17 (2.52)	-9.75* (2.71)	4.11 (2.60)
Number of capsules/plant	-15.20** (3.83)	-37.54** (4.61)	4.77 (3.76)	14.31* (5.49)	9.03 (6.40)	18.79** (5.33)	-14.07* (5.75)	-17.07** (5.96)	-2.39 (5.68)
Seed yield/plant (g)	30.44** (15.78)	27.35** (17.51)	8.85 (17.59)	45.57** (21.25)	28.38** (23.53)	-19.61* (26.24)	35.38** (22.90)	29.80* (29.39)	19.85** (22.37)
Shelling out turn (%)	7.26** (0.63)	6.85** (0.65)	3.28** (0.72)	8.20** (1.07)	7.13** (0.92)	1.48 (0.83)	5.03** (0.68)	2.49* (0.84)	4.79** (0.83)
100 Seed weight (g)	7.30** (0.31)	2.40* (0.31)	3.33** (0.32)	0.81 (0.47)	-3.28* (0.50)	-6.47** (0.51)	8.77** (0.58)	8.62** (0.61)	-0.21 (0.63)
Oil content (%)	4.17** (0.46)	4.17** (0.57)	1.46 (0.45)	2.85** (0.25)	2.35** (0.32)	-1.73** (0.25)	2.85** (0.25)	0.50 (0.26)	0.18 (0.33)

Table 3 (contd...)

Table 3 (contd...)

Character	IV. JI 358 x SH 42			V. ANDCI 10-7 x SKI 324		
	RH (%)	HB (%)	ID (%)	RH (%)	HB (%)	ID (%)
Days to flowering of primary raceme	-6.18** (0.98)	-1.37 (1.09)	-10.74** (1.05)	-5.90** (0.93)	-2.32 (0.98)	-6.12** (1.08)
Days to maturity of primary raceme	-4.02* (2.29)	2.07 (2.51)	-4.57* (2.34)	-6.34** (1.70)	-5.89** (1.98)	-8.31** (1.85)
Plant height up to primary raceme (cm)	-17.05** (4.30)	-15.94* (5.96)	5.47 (3.78)	-23.37** (4.26)	-21.27** (4.43)	-31.43** (4.50)
Number of nodes up to primary raceme	-7.56* (0.54)	-3.26 (0.62)	2.58 (0.46)	-7.41* (0.57)	-0.46 (0.55)	-6.53 (0.54)
Number of total branches/plant	19.28** (1.04)	3.78 (1.10)	16.16** (1.00)	23.13** (0.71)	15.42* (0.76)	-8.36 (0.84)
Number of effective branches/plant	37.17** (0.63)	10.70 (0.71)	17.52** (0.68)	35.98** (0.47)	32.02** (0.52)	-2.54 (0.52)
Total length of primary raceme (cm)	2.86 (3.84)	-2.33 (4.04)	12.37* (3.86)	-8.74** (1.59)	-11.55** (2.35)	-2.96 (2.03)
Effective length of primary raceme (cm)	0.98 (3.65)	-3.19 (3.94)	12.68* (3.68)	-10.98** (2.28)	-17.95** (2.95)	2.33 (2.48)
Number of capsules/plant	1.88 (4.34)	-9.39* (5.05)	19.88** (4.88)	-16.54** (4.04)	-17.84** (4.56)	-0.24 (4.54)
Seed yield/plant (g)	19.29* (31.67)	6.19 (30.15)	29.09** (30.71)	27.97** (11.62)	24.96** (13.53)	-4.35 (15.80)
Shelling out turn (%)	0.65 (1.13)	-1.18 (1.16)	2.46 (1.16)	10.50** (0.79)	9.49** (0.93)	5.93** (0.83)
100 Seed weight (g)	3.66** (0.43)	-5.38** (0.46)	4.90** (0.42)	5.31* (0.67)	4.31 (0.69)	-1.07 (0.70)
Oil content (%)	1.80* (0.35)	0.82 (0.41)	1.43* (0.36)	2.54** (0.30)	0.92 (0.35)	0.27 (0.27)

*, **Significant at p =0.05% and p = 0.01 % levels, respectively and () - figures in parentheses represent S.Em. values

The above results are in fidelity with reports of Golakiya *et al.* (2007) and Dapke *et al.* (2016) who reported high heritability coupled with high genetic advance for plant height up to primary raceme, number of nodes up to primary raceme, number of capsules on primary raceme and seed yield/plant. Dapke *et al.* (2016) for number of effective branches/plant, total length of primary raceme and effective length of primary raceme; Golakiya *et al.* (2007) for days to flowering of primary raceme and Najan *et al.* (2010) for days to maturity of primary raceme reported high heritability along with high genetic advance similar to the present study.

From our experiments it could be concluded that (1) both additive and non-additive gene actions were important for the expression of seed yield and most of its component traits. However, some of the characters in various crosses were governed by fixable (additive and additive x additive) gene effects and hence, these characters could be improved through pedigree method of selection (2) Significant heterosis and heterobeltiosis in desired direction observed for seed yield and its majority of the components *viz.,* total and effective branches/plant, number of capsules on primary raceme, shelling out turn and 100-seed weight suggested the possibility of utilizing hybrid vigour on commercial scale (3) High estimates of broad as well as narrow sense heritability along with high genetic advance observed for seed yield/plant in cross I (SKI 324 x PCS 124), cross II (ANDCI 10-7 x JH 109) and cross V (ANDCI 10-7 x SKI 324) suggested the preponderance of additive/fixable gene effect and hence this character could be further improved by adopting selections in succeeding segregating generations and (4) parental genotypes SKI 324, ANDCI 10-7 and ANDCI 8 due to their presence in high heterotic combinations *viz.,* ANDCI 10-7 x JH 109 and ANDCI 8 x SKI 324 need to be further exploited in future castor breeding programme.

Table 4 Estimates of heritability and genetic advance as percent of mean for various characters in five crosses of castor

Crosses	Heritability (Broad sense) (%)	Heritability (Narrow sense) (%)	Genetic advance (% of mean)
Days to flowering of primary raceme			
I	89.94	11.34	2.93
II	14.96	98.70	21.13
III	80.62	16.91	4.17
IV	79.26	54.71	12.88
V	65.91	70.18	14.36
Days to maturity of primary raceme			
I	91.43	47.85	7.54
II	59.86	162.34	23.18
III	59.38	55.75	7.98
IV	3.36	84.79	11.06
V	54.68	103.90	13.67
Plant height up to primary raceme (cm)			
I	55.27	18.28	7.67
II	30.84	69.68	24.55
III	20.57	72.69	31.81
IV	65.84	78.63	33.00
V	78.39	83.96	46.85
Number of nodes up to primary raceme			
I	24.41	-	-
II	62.70	113.85	41.26
III	69.33	74.56	24.90
IV	37.28	99.32	27.09
V	67.37	83.02	29.64
Number of total branches/plant			
I	81.62	103.47	76.21
II	77.05	83.60	90.74
III	39.90	37.70	22.00
IV	55.24	79.43	48.99
V	48.05	51.25	36.12
Number of effective branches/plant			
I	63.91	102.26	88.39
II	63.30	54.32	68.49
III	18.15	74.53	54.69
IV	47.61	57.37	48.06
V	10.21	-	-
Total length of primary raceme (cm)			
I	59.20	69.73	34.02
II	69.14	65.47	38.04
III	31.89	26.24	10.35
IV	-	64.62	23.28
V	88.07	77.60	35.25

Table 4 (contd...)

Table 4 (contd...)

Effective length of primary raceme (cm)			
I	65.45	23.80	11.38
II	73.72	8.97	5.05
III	47.43	49.43	22.47
IV	-	56.73	22.12
V	65.80	69.98	32.82
Number of capsules on primary raceme			
I	25.24	-	-
II	38.77	-	-
III	16.48	14.53	6.70
IV	64.06	17.61	9.24
V	66.59	101.87	50.86
Seed yield/plant (g)			
I	61.98	90.37	69.19
II	64.43	96.82	133.96
III	27.92	37.47	27.31
IV	-	36.55	21.95
V	64.51	89.68	76.84
Shelling out turn (%)			
I	69.87	86.13	11.39
II	66.95	57.42	8.10
III	82.82	97.06	14.85
IV	-	18.99	2.12
V	37.60	83.33	9.30
100-Seed weight (g)			
I	84.92	124.95	18.57
II	74.71	73.08	14.14
III	24.59	-	-
IV	61.54	40.25	5.96
V	-	51.70	7.23
Oil content (%)			
I	4.53	147.35	9.29
II	87.35	59.93	4.10
III	78.68	143.87	10.90
IV	34.93	104.54	6.25
V	36.42	-	-

- Indicates abnormal negative values

I. SKI 324 x PCS 124 II. ANDCI 10-7 x JH 109 III. ANDCI 8 x SKI 324 IV. JI 358 x SH 42; V. ANDCI 10-7 x SKI 324

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Performance of elite castor (*Ricinus communis* L.) hybrids and varieties under rainfed *Alfisols*

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ABSTRACT

A field experiment was conducted during the rainy (*kharif*) seasons of 2018 and 2019 at Zonal Agricultural Research Station, University of Agricultural Sciences, Bangalore to study the *per se* performance, productivity and profitability of seven elite castor hybrids and varieties. Treatments comprised five hybrids (GCH-8, DCH-177 DCH-519, GCH-7, GCH-4) and two varieties (48-1, DCS-107). Based on the pooled analysis, castor hybrids (GCG-8, DCH-177 and DCH-519) showed significantly higher total dry matter production (TDMP) on account of significant superiority in crop growth rate (CGR), relative growth rate (RGR) and absolute growth rate (AGR). Nevertheless, the performance of genotypes in this study was not a true reflection of their growth attributes. Therefore, castor genotypes did not show consistency for seed yield over the years of their evaluation. It was mainly due to their differential reaction to incidence of gray mold. During 2018 significantly higher grain yield (2369 kg/ha), oil yield (1152 kg/ha), gross return (₹ 1,23,188/ha), net return (₹ 99,809/ha) and benefit: cost ratio (3.95) was recorded in GCH-8. Whereas, during 2019, 48-1 recorded significantly higher grain yield (1270 kg/ha), oil yield (602 kg/ha), gross return (₹ 66,040/ha), net return (₹ 36,897/ha) and benefit: cost ratio (2.27). Based on the pooled analysis, castor hybrid GCH-8 (1777 kg/ha) recorded significantly higher yield and closely followed by castor variety 48-1 (1476 kg/ha) and DCS-107 (1444 kg/ha).

Keywords: Castor, Economics, Hybrids, Oil-content, Oil-yield, Varieties, Yield

Castor (*Ricinus communis* L.) is an important non-edible oilseed crop cultivated extensively for bio-based raw material for a wide range of industrial applications. The oil is a mixture of saturated and unsaturated fatty acid esters linked to a glycerol (Mubofu, 2016). Presence of a hydroxyl group, a double bond, carboxylic group and a long chain hydrocarbon in ricinoleic acid offer several possibilities of transforming it into a variety of industrial materials. The oil can easily be extracted from castor seeds and used in a multitude of sectors such as medicine, chemicals and automobile industries (Ogunniyi, 2006). The demand for castor oil and its products in the world market is exhibiting steady increase over a period of time (Bagali *et al.,* 2010). It is mainly because of its renewable nature, non-competition with food, biodegradability, low costs, and eco-friendliness. It is now estimated that the oil has over 700 industrial uses and the uses have kept on increasing (Bagali *et al.,* 2010). In recent days, castor oil is also identified as a potential alternative to petroleum-based starting chemicals (González *et al.,* 2020). Because of its extended utility and enormous global demand, it is being cultivated extensively both under irrigated and rainfed agro-ecosystem. Presently, castor is being cultivated in 30 countries on a commercial scale of which India, China, Brazil, Russia, Thailand, Ethiopia and Philippines are the major castor growing countries accounting for nearly 88% of the world's production. India is the global leader in castor production and export, with more than 85 % of global production and the crop is cultivated in an area of 8.35 lakh ha, with the productivity potential of 1600 kg per hectare and India is producing about 12.2 lakh tones (ICAR-IIOR, 2020). Despite the vast area under cultivation, there is a huge disparity in its productivity over geographical area in India; especially productivity of castor in southern states seldom exceeds 600 kg/ha as against average productivity of 1600 kg/ha in India (ICAR-IIOR, 2020). Lack of elite genotype under cultivation is a major production constraint, besides vast area under cultivation in rainfed situation (Kumar and Yamanura, 2019). A study of production constraints in traditional and non-traditional areas of castor in Karnataka indicated that cultivation of poor yielding, old and obsolete varieties without any seed replacement are the major problems (Kumar and Yamanura, 2019). Castor is a highly cross-pollinated crop wherein sex reversion associated with elevated temperature mainly hinders realizing of the higher productivity. In the event of elevated prices of agro inputs and depleted natural resources, cultivation of old genotypes not only elevates the cost of production but also mismanages the natural resources in agro-ecosystem. Therefore, selection of adaptable, elite crop genotype in commercial cultivation and crop production plays a critical role in deciding the viability of agriculture. With intensive crop improvement programmes undertaken in castor at different parts of the country, several potent hybrids and varieties (Table 2) have been released for commercial cultivation during the last five years (Reddy *et al.,* 2020). In the present investigation, an attempt was made to study the

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performance of five elite hybrids and two varieties released from ICAR-Indian Institute of Oilseeds Research (ICAR-IIOR), Hyderabad and Sardar Krishinagar Dantiwada Agricultural University (SDAU), SK Nagar, Gujarat under rainfed *Alfisol* condition to endorse for commercial cultivation in Karnataka.

Table 1 Physico-chemical properties of soil in the experimental site

Parameter	Values	Status
pH	5.93	Moderately acidic
EC (dS/m)	0.11	Low
Organic carbon (%)	0.56	Medium
Nitrogen (kg/ha)	386.56	Medium
Phosphorus (kg/ha)	29.67	Medium
Potassium (kg/ha)	428.40	High
Calcium (meq/100 g)	5.30	High
Magnesium (meq/100 g)	1.05	Medium
Sulphur (ppm)	15.62	Medium
Iron (ppm)	38.64	Sufficient
Manganese (ppm)	18.63	Sufficient
Zinc (ppm)	1.05	Sufficient
Copper (ppm)	0.43	Sufficient

Table 2 Salient features of castor hybrids and varieties used in the study

Hybrid	Pedigree	Cultivar type	Duration to first picking (days)	Average yield (kg/ha)		Oil Content (%)	Special characteristics
				Rainfed	Irrigated		
GCH-4	VP-1 x 48-1	Hybrid	100-110	1200	2200	50	Resistant to wilt
DCH-177	DPC-9 x DCS-9	Hybrid	90-100	1800	2500	49	Tolerant to wilt
DCH-519	M-574 x DCS-78	Hybrid	105-110	1500	2200	49	Resistant to wilt
GCH-7	SKI-215 x SKP-84	Hybrid	100-110	1700	2450	49	Resistant to wilt and nematode complex
GCH-8	DCS-89 x JP-96	Hybrid	95-105	1895	3588	48	Resistant to wilt and tolerant to root rot
48-1	HO x MD	Variety	100-110	1000	1800	50	Resistant to wilt, capsule borer and Botrytis
DCS-107	DCH-177 X JI-133	Variety	110-120	1500	1700	46	Resistant to wilt and tolerant to leaf hopper

MATERIALS AND METHODS

A field experiment was conducted during the rainy (*kharif*) seasons of 2018 and 2019 at Zonal Agricultural Research Station, University of Agricultural Sciences, Bengaluru (Karnataka), to study the performance of castor hybrids and varieties in rainfed *Alfisols*. The soil of the experimental site was sandy loam, moderately acidic, medium in organic carbon and available nitrogen (386.56 kg/ha), medium in available phosphorus (29.67 kg/ha) and high in available potassium (428.40 kg/ha). The experiment was laid out in a randomized complete block design with three replications. Seven genotypes including five hybrids (DCH-177, DCH-519, GCH-4, GCH-8 and GCH-7) and two varieties (48-1 and DCS-107) were tested. Well decomposed farmyard manure @ 10 tonnes was incorporated uniformly three weeks before the sowing and seeds were treated with phosphorus-solubilizing bacteria and *Azospirillum* each @ 750 g/ha. The seed rows were maintained at 90 cm and inter-row spacing of 60 cm was maintained to obtain 18,518 plants/ha. Basal dose of nitrogen [50% of recommended dose (RD) of nitrogen], phosphorus (100% RD P_2O_5), potassium (RD K_2O) and were applied at the time of sowing and remaining nitrogen was applied in two splits each at 50 and 75 days after sowing. Observations on growth, yield attributes and seed yield were recorded as per the standard procedure. Growth indices such as Absolute Growth Rate (AGR), Relative Growth Rate (RGR) and Crop Growth Rate (CGR) were calculated between 30 to 60 DAS and 60 to 90 DAS using the formulae as proposed by Radford (1967). To know the crop weather relationship, daily data on precipitation, air temperature (2 m above ground level), solar radiation, humidity, evaporation and potential evapo-transpiration were obtained from All India Co-ordinated Research Project on Agro-meteorology located at the research station. The cost of cultivation, gross, net returns and benefit : cost ratios were calculated on the basis of prevailing market price of different inputs and output. Data were statistically analysed as suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Growth attributes: Pooled data of two seasons on growth attributing traits indicated that among the castor hybrids and varieties, DCH-519 showed significantly higher plant height and total dry matter production at harvesting followed by GCH-8 and DCH-177 (Table 3). Higher drymatter production with DCH-519 could be owing to significantly higher crop-growth rate, relative growth rate and absolute rate at 30-60 days after sowing (DAS) and 60-90 DAS. The hybrids and varieties under evaluation were at par in terms of number of nodes to primary raceme and leaf area index (LAI) at 90 days after sowing (DAS). Similar studies by Goodarzi *et al.* (2012) indicated that castor is the only oil-bearing crop under the genera of *Euphorbiaceae* and all wild and domesticated castor germplasm showed limited variation in respect of leafiness and node numbers and most importantly these traits exhibit meagre correlation with yield and oil content (Tewari and Mishra, 2013) as a result of which crop improvement programmes might not have targeted to bring variation in these traits. The superiority of hybrids (DCH-519, DCH-177 and GCH-8) could be attributed to higher combining ability, wider adaptability and stability in hybrid vigour and favourable genotypic basis. Significant excellence of DCH-519, DCH-177 and GCH-8 for yield and wilt resistance was earlier reported by Lavanya *et al.* (2018) and Manjunatha *et al.* (2019).

Yield attributes and seed yield: Yield is the manifestation of yield attributing traits (Kumar *et al*., 2019). Over the two years of experimentation, yield attributing traits were not consistent among the hybrids and varieties under evaluation. The yield attributes are the product of growth attributing traits and growth attributing traits in turn are the product of genotype, climate and management practices. In this study, the variation in yield attributing traits occurred mainly due to variation in weather elements at different crop growth stages. During 2018, there was a well distributed rainfall from vegetative stage to the post reproductive stage followed by bright sunny and rainless days during the capsule initiation to harvesting stage (Fig. 1) under this condition crop might have had the congenial condition required for better growth and development, as a result of which all the yield attributing characters were numerically higher over that seen in 2019 (Table 3 and Fig. 1 to 2). However, during 2019, in-spite of good weather and crop management practices all along the vegetative stage, heavy and persistent rainfall during the capsule development stage of three spike orders-primary, secondary and tertiary spike initiation stages the crop suffered due to heavy incidence of gray mold. Of the 915 mm total rainfall during 2019, about 408 mm was received in 37th to 45th standard meteorological weeks which coincided with the capsule formation to seed filling stage of the crop as a result of it major portion of yield was lost despite timely prophylactic and curative measures. However, during 2019, castor variety 48-1 showed high degree of disease tolerance perhaps due to its non-spiny and loose spike nature leading to favourable micro-climate *viz.,* free air movement and lower humidity around the capsule and spike in total. Further, DCS-107, a late maturing variety had partially escaped from the outbreak of gray mold. However, during 2018, GCH-8 recorded significantly higher seed yield of castor (2369 kg/ha) and was statistically superior over rest of the genotypes under evaluation. Whereas during 2019, castor variety 48-1 recorded significantly higher yield (1270 kg/ha) and was closely followed by DCS-107 (1242 kg/ha).

Oil content and oil yield: Oil content is genetically controlled trait. However, its plasticity is also combined with biotic and abiotic stresses (Mangin *et al*., 2017). With respect to oil yield/ha, during both the years, GCH-8 recorded significantly higher oil yield (1152and 567 kg/ha, respectively during 2018 and 2019) an account of higher seed yield (2369 and 1185 kg/ha, respectively during 2018 and 2019) and oil content (48.64 47.84%, respectively during 2018 and 2019). However, during 2019, GCH-8 was on par with 48-1 with respect to oil yield per hectare despite numerically lower oil content (Table 4).

Economic analysis: Among the hybrids and varieties, GCH-8 fetched significantly higher gross returns (₹ 123188/ha), net returns (₹ 99809/ha) and benefit: cost ratio (3.95) than the other hybrids and varieties during 2018 an account of significantly higher yield (Table 4). Whereas, during 2019, 48-1 registered significantly higher gross returns (₹ 66040/ha), net returns (₹ 36897/ha) and benefit: cost ratio (2.27) and was closely followed by DCS-107 and GCH-8 (Table 4). Similar opinion of increase in profitability with increased yield in castor was expressed by Keerthana *et al*. (2018).

The present study, indicated that the five castor hybrid and two varieties responded distinctly over the two years of study under rainfed Alfisols. Castor hybrids showed significantly higher dry matter production at harvest on account of significantly higher CGR, RGR and AGR at 30-90 DAS. During both the years of experimentation, superiority of growth was not reflected in productivity of the crop perhaps due to incidence of gray mold (*Botrytis*). Castor hybrid GCH-8 and variety 48-1 performed constantly well despite outbreak of gray mold by producing significantly higher seed yield in each years of experimentation. Further, economic analysis of castor production also indicated that GCH-8 and 48-1 were more profitable by registering higher gross return, net return and cost benefit ratio.

Table 3 Growth attributes of castor hybrids and varieties under rainfed Alfisols (Pooled data of 2 years)

Genotype	Plant height (cm)	Number of nodes to primary raceme	Leaf area index at 90 DAS	Total dry matter production (g/plant)	Crop growth rate ($g/m^2/day$)		Relative growth rate (g/g/day)		Absolute growth rate (g/day)	
					30-60 DAS	60-90 DAS	30-60 DAS	60-90 DAS	30-60 DAS	60-90 DAS
GCH-8	45.9	13.9	1.12	183.4	0.92	1.12	0.74	0.90	1.71	2.08
DCH-177	42.4	13.3	1.18	173.2	0.87	1.06	0.70	0.85	1.62	1.96
DCH-519	63.8	14.8	1.14	189.5	0.96	1.16	0.77	0.93	1.77	2.15
48-1	41.3	13.8	1.07	132.1	0.32	1.07	0.26	0.86	0.59	1.99
GCH-7	46.7	14.4	0.97	123.4	0.80	0.66	0.64	0.53	1.48	1.21
DCS-107	36.3	13.8	1.01	122.8	0.62	0.75	0.50	0.60	1.15	1.39
GCH-4	39.2	13.7	1.10	119.4	0.60	0.73	0.48	0.59	1.11	1.35
S. Em±	3.7	0.28	0.07	5.27	0.02	0.02	0.01	0.02	0.02	0.03
CD (P=0.05)	11.5	NS	NS	19.41	0.06	0.06	0.03	0.06	0.05	0.08
CV (%)	14.3	6.48	10.7	14.7	6.54	5.36	5.48	7.14	6.14	5.13

Table 4 Yield attributes of castor hybrids and varieties under rainfed Alfisols

Genotype	Primary spike length(cm)		Effective primary spike length (cm)		Number of effective spikes/ plant		Number of capsules/primary spike		Test weight (g)	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
GCH-8	47.1	31.3	36.2	34.1	9.2	5.2	58.2	21.1	26.2	25.5
DCH-177	39.7	26.2	41.2	32.7	5.4	6.6	48.2	22.2	25.9	25.7
DCH-519	52.4	20.9	45.4	28.7	5.4	5.4	52.9	12.1	24.3	23.9
48-1	37.7	18.8	30.1	27.4	9.2	6.0	45.1	18.9	25.6	26.9
GCH-7	41.3	32	33.8	43.5	6.8	6.1	50.6	20.3	25.6	25.2
DCS-107	33.3	20.8	44.8	29	6.5	9.4	52.0	17.9	27.3	26.7
GCH-4	34.3	28.9	34.1	36.5	7.6	7.4	62.4	16.7	21.8	23.5
S. Em (±)	3.2	0.6	3.1	1.1	0.5	0.3	2.8	0.7	0.6	0.2
CD (P=0.05)	10.5	1.9	8.9	3.5	1.7	0.8	8.7	2.1	1.8	0.7
CV (%)	14.5	11.2	14.8	15.5	13.9	18.8	9.2	17.2	4.0	4.4

Table 5 Seed yield, oil content, oil yield and economics of castor hybrids and varieties under rainfed Alfisols

Genotype	Yield (kg/ha)			Oil content (%)		Oil yield (kg/ha)		Gross return (₹/ha)		Net return (₹/ha)		B:C ratio	
	2018	2019	Pooled	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
GCH-8	2369	1185	1777	48.64	47.84	1152	567	123188	61620	99809	32477	3.95	2.11
DCH-177	1529	1201	1365	45.32	45.03	693	541	79508	62452	50658	33309	2.55	2.14
DCH-519	1373	756	1065	45.86	44.87	630	339	71396	39312	36967	10169	2.29	1.35
48-1	1681	1270	1476	47.16	47.43	793	602	87412	66040	52637	36897	2.80	2.27
GCH-7	1518	885	1202	47.72	45.12	724	399	78936	46020	52985	16877	2.53	1.58
DCS-107	1646	1242	1444	46.49	45.12	765	560	85592	64584	54937	35441	2.74	2.22
GCH-4	1615	1081	1348	47.07	47.18	729	510	83980	56212	57905	27069	2.58	1.93
SEm±	133	40	87	0.40	0.36	62	43	NA	NA	NA	NA	NA	NA
CD @ 5%	408	122	265	1.22	1.13	192	138	NA	NA	NA	NA	NA	NA
CV (%)	14	17	16	1.46	2.65	14	15	NA	NA	NA	NA	NA	NA

Market price of castor seed - ₹ 52/kg NA- Not analysed

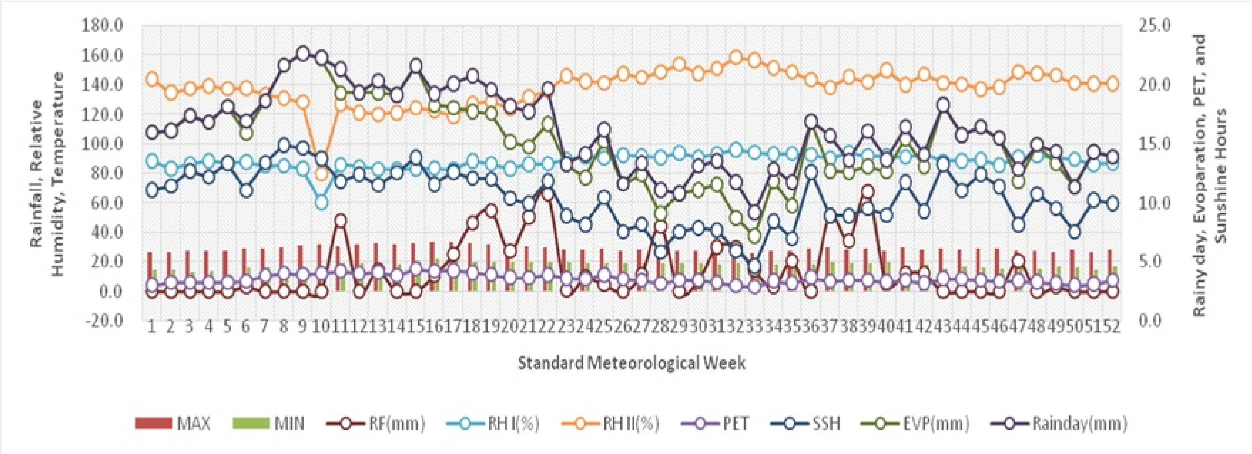

Fig. 1. Graphical representation of meteorological data of the cropping season for the year 2018-19

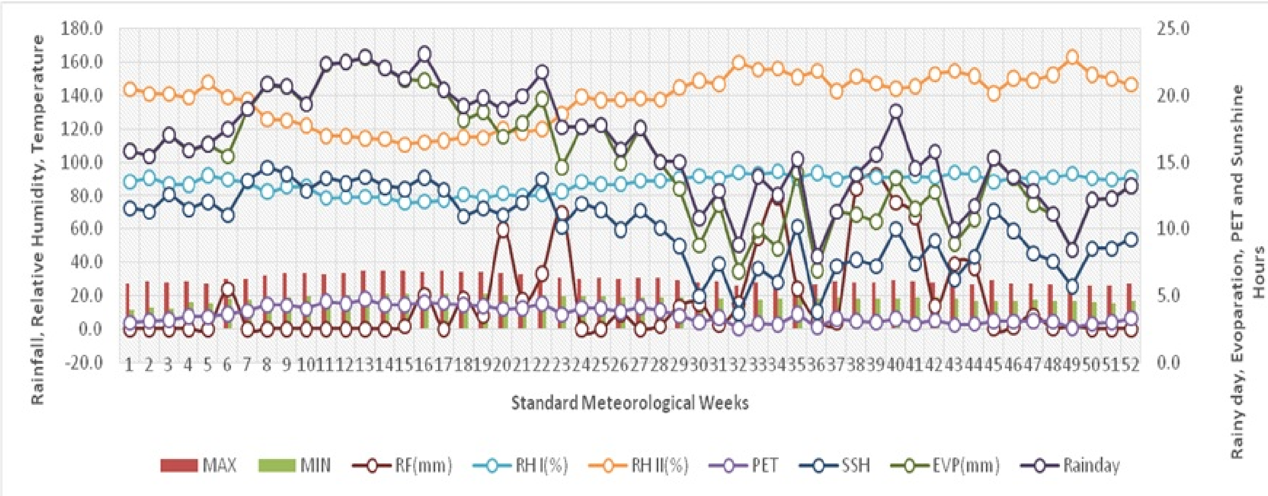

Fig. 2. Graphical representation of meteorological data of the cropping season for the year 2019-20

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Genetic variability and heritability studies among genotypes of sesame (*Sesamum indicum* L.)

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ABSTRACT

The evaluation of phenotypic variability, heritability and genetic advance in germplasm collections is important for both plant breeders and germplasm curators to optimize the use of the variability available. A total of 50 sesame accessions were used to determine the extent of genetic variability, heritability and genetic advance in this research work. Analysis of variance revealed significant differences among genotypes for all the characters studied. The number of capsules/plant and seed yield/plant recorded high genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV). High heritability coupled with high genetic advance of mean (GAM) was observed for days to 50% flowering, days to maturity, number of branches/ plant, number of capsules/plant, number of seeds/capsule, seed yield/plant and 1000 seed weight indicating that these characters are controlled by additive gene effect and phenotypic selection of these characters would be effective for further breeding purpose.

Keywords: GCV, Genetic advance, Genetic variability, Heritability, PCV, Sesame

Sesame (*Sesamum indicum* L.) is a self pollinated crop with diploid chromosome number of 2n=2X=26 and belongs to the family of Pedaliaceae. It can set seed and yield well under fairly high temperatures and can grow in stored soil moisture without rainfall and irrigation. However, continuous flooding or severe drought adversely affects the crop resulting in low yield (Mensah *et al.,* 2009). The seed contains 50 to 60% oil which has excellent stability due to the presence of natural antioxidants such as sesamolin, sesamin, and sesamol (Brar and Ahuja, 1979). Genetic variation survives for agronomically vital characters in sesame but its production is still very low in India. Traditional sesame land races as well as related wild species are an important source of genetic diversity for breeders and form the backbone of agricultural production. The progress in breeding for yield and its contributing characters of any crop is polygenically controlled, environmentally influenced and determined by the magnitude and nature of their genetic variability (Wright, 1935). The knowledge of genetic variability in germplasm will help in the selection and breeding of high yielding, good quality cultivars that will increase production. Keeping the above points in view, this study was carried out for assessing the genetic variability in 50 sesame accessions, heritability and genetic advance of some quantitative characters.

MATERIALS AND METHODS

The experiment was carried out at Regional Agricultural Research Station, Polasa, Jagtial during kharif, 2018. The research station is situated in Northern Telangana Zone, India at 18º 48' N latitude, 78º 56' E longitude and 281m altitude of mean sea level. The experimental material used in the present investigation comprised of 50 genotypes of sesame. These 50 genotypes included 43 advanced breeding lines developed at Regional Agricultural Research Station, Jagtial and 2 National Checks (TKG 22, GT 10) and one Zonal Check (Rama), and 4 Local Checks (YLM 11, YLM 66, YLM 17, Madhavi). The experiment was laid out in Randomized Block Design (RBD) with three replications. Each genotype was sown in three rows of two metres length, with inter-row spacing of 30 cm and intra row spacing of 10 cm. Sowing was done by dibbling the seed at 2-3 cm depth. All the standard package of practices were followed during the crop growth period. The data was recorded on yield and yield attributing characters from five randomly selected plants in each replication. Data were recorded for days to 50% flowering, days to maturity, plant height, number of branches/plant, number of capsules/ plant, height of the plant from first capsule formation, capsule length, capsule width, number of seeds/capsule, seed yield/plant, 1000 seed weight, harvest index and oil content.

Analysis of variance was computed for replicated data (RBD) as per the standard statistical procedure (Panse and Sukhatme, 1985). The significance was tested by referring to the values of "F" table (Fisher and Yates, 1963). The phenotypic and genotypic coefficients of variation were estimated according to the method suggested by Burton and de Vane (1953). Broad sense heritability (h^2) expressed as the percentage of the ratio of the genotypic variance ($\sigma^2 g$) to the phenotypic variance ($\sigma^2 p$) was computed as described by Allard (1960). Genetic advance in absolute unit (GA) and percent of the mean (GAM), assuming selection of superior

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5% of the populations was estimated according to the method illustrated by Johnson *et al.* (1955).

RESULTS AND DISCUSSION

All the sesame genotypes under study displayed a considerable amount of differences in their mean performance with respect to all the traits studied (Table 1) which indicated sufficient variability present among different genotypes for most of the characters. The knowledge of genetic variability present in a given crop species for the character under improvement is of paramount importance for the success of any plant breeding programme. Information on the coefficient of variation is useful in measuring the range of variability present in the characters. Heritability estimates along with genetic advance are normally more helpful in predicting the gain under selection than heritability estimate alone. It is therefore essential that selection on the basis of their genetic worth, that is, heritability along with genetic advance is both important for crop improvement (Hamouda *et al*., 2016).

Examination of the components of variance revealed that the phenotypic coefficients of variation (PCV) was higher than the corresponding genotypic coefficients of variation (GCV) for all the characters with a narrow difference indicating that the environmental influence was least and there was preponderance of genetic factors controlling variability in these traits. High magnitude of PCV and GCV were observed for the traits *viz.,* seed yield/plant followed by the number of capsules/plant. Results indicated greater scope for selection of these traits for further breeding work. The phenotypic and genotypic coefficients of variability, heritability estimates in broad sense and genetic advance as per cent of mean for the yield and yield attributing parameters are presented in Table 2.

Days to 50% flowering: The number of days to 50 % flowering ranged from 41.00 (TKG 22) to 65.00 days (JCS 3884) with 24.00 days variation and the overall mean of 53.00 days. Genotypic and phenotypic coefficients of variation were moderate with 12.97 and 13.11 per cent respectively. These results were in accordance with Divya *et al.* (2018). Days to 50% flowering showed high heritability (97.80 per cent) and high genetic advance as per cent mean of 26.43. These results are in agreement with the findings of Tripathy *et al.* (2016). High heritability coupled with high genetic advance as per cent of mean for this character unveiled the presence of additive gene action that offers the best possibility of effective selection through simple selection procedures.

Days to maturity: Maturity duration ranged from 85.00 days (YLM 66, YLM 17 and Madhavi) to 100.00 days (JCS 3980 and JCS 3985) with a mean of 94.00 days. Genotypic and phenotypic coefficients of variation were observed as low for this trait (5.27 and 5.34 per cent respectively) which were similar to the findings of Saxena and Bisen (2017). Variation in days to maturity is essential in the selection of varieties with different durations as per the objectives of improvement programmes. Days to maturity recorded high heritability (97.50%) coupled with a moderate per cent mean of genetic advance (10.73%). Similar results have been reported by Tripathy *et al.* (2016). High heritability and moderate per cent mean of genetic advance of this trait indicated that this trait is governed by additive gene interaction and this trait can be improved by simple selection. Plant height: The plant height varied from 76.83 cm (YLM 17) to 113.36 cm (JCS 3970) with an overall mean of 93.27 cm. Genotypes YLM 17 (76.83 cm) followed by YLM 11 (77.13 cm) showed dwarf nature which could withstand the lodging effect during adverse environmental conditions. Genotypic and phenotypic coefficients of variation were observed to be low with 7.39 and 10.21 per cent respectively. The same results were also observed by Rajani Bisen *et al.* (2013) and Tripathy *et al.* (2016). Plant height exhibited moderate heritability (52.40 per cent) with moderate per cent mean of genetic advance (11.02 per cent) which were on par with the results reported by Rajani Bisen *et al.* (2013). Moderate heritability coupled with moderate per cent mean of genetic advance connotes that this character is under the control of non additive gene action and simple selection would be ineffective for further improvement.

Number of branches/plant: Number of branches/plant varied from 2.00 (JCS 3884) to 3.00 (JCS 4036) with an overall mean of 2.00 branches/plant. All the genotypes were observed to be only two and three branched. JCS 3884, JCS 2420, JCS 2698 and many other genotypes were less branching type with only 2 branches, while JCS 4036, JCS 4060 and a few others were medium branching type with 3 branches. Genotypic and phenotypic coefficients of variation recorded moderate 12.57 and 13.94 per cent respectively. Number of branches/plant recorded high heritability (81.30 per cent) coupled with high per cent mean of genetic advance with 23.35 per cent, Hamouda *et al.* (2016) and Divya *et al.* (2018) also reported similar findings. The presence of high heritability and high per cent mean of genetic advance for this trait revealed the additive gene effect and can be effectively used in the selection procedure.

Number of capsules/plant: Range varied from 4.00 (JCS 3755) to 42.00 (JCS 3980) for this trait with an overall mean of 29.00 capsules/plant. Among all the genotypes, JCS 3755 (4.00), JCS 3884 (7.00) produced very less number of capsules while JCS 3980 recorded more number of capsules (42.00) per plant. High genotypic and phenotypic coefficients of variation of 31.44 and 32.97 per cent respectively were observed for this trait. The results were in conformation with the observations reported by Bharathi *et al.* (2014) and Divya *et al.* (2018). Number of capsules/plant recorded high heritability (90.90%) with a high per cent mean of genetic advance (61.77%). These reports were collinear with findings of Thirumala Rao *et al.* (2013) and Bharathi *et al.* (2014). Results indicated a possible scope for improvement through selection of this character and breeder may have reliable benefits in next generation with respect to this character.

Height of the plant from first capsule formation: The observed range of variation was from 36.86 cm (YLM 66) to 56.93 cm (JCS 3739) with an overall mean of 47.95 cm. Among all the genotypes, YLM 66 (36.86 cm) followed by YLM 17 (37.10 cm), Madhavi (39.10 cm), JCS 2477 (41.93 cm) recorded minimum height for the capsule formation while, JCS 3739 recorded maximum height for the capsule formation 56.93 cm. Genotypic and phenotypic coefficients of variation were moderate i.e., 10.00 and 11.37 percent respectively. Similar results were reported by Teklu *et al.* (2014). The high heritability (77.40) coupled with a moderate percent mean of genetic advance (18.12) for the trait has been reported by Teklu *et al.* (2014) also. The results revealed that the character is under the governance of additive gene action and therefore, amenable for improvement through a selection procedure.

Capsule length: The range of capsule length among the genotypes varied from 1.99 cm (JCS 3880) to 2.46 cm (JCS 3980) with an overall mean of 2.21 cm. Among 50 genotypes, JCS 3880 showed a minimum capsule length of 1.99 cm followed by JCS 3887 (2.02 cm), JCS 3910 (2.03 cm) while, the maximum was showed by JCS 3980 (2.46 cm). The genotypic and phenotypic coefficients of variation were 4.35 and 6.12 per cent respectively which were low. These results were on par with the reports of Singh and Singh (2004). The heritability for this trait is recorded as moderate i.e., 50.50 with a low percent mean of genetic advance (6.37%). This indicates that the trait is controlled by non additive gene action and simple selection for this trait is perhaps ineffective.

Capsule width: Capsule width ranged varied from 0.48 cm (JCS 2477) to 0.60 cm (GT 10) with an overall mean of 0.54 cm. JCS 2477 recorded minimum width of 0.48 cm while, maximum (0.60 cm) was recorded by GT 10, YLM 11 and YLM 66 followed by JCS 4053 (0.57 cm) and Swetha til (0.57 cm). The genotypic and phenotypic coefficients of variation were 4.44 and 5.57 per cent respectively which were low. The heritability for this trait is recorded as high i.e., 63.60 with low per cent mean of genetic advance (7.30). This indicates that the trait is controlled by non additive gene action and thus simple selection may not be rewarding.

Number of seeds/capsule: Number of seeds/capsule showed a variation range of 47.00 (JCS 2489) to 75.00 (GT 10) with an overall mean of 60.00. JCS 2489 recorded the minimum number of seeds/capsule of 47.00 while, maximum was recorded by GT 10 (75.00). Moderate genotypic and phenotypic coefficients of variation of 12.63 and 12.93 per cent respectively were recorded which were in accordance with the results reported by Bharathi *et al.* (2014). Number of seeds/capsule recorded high heritability (95.40%) with a high percent mean of genetic advance (25.14 per cent). These results were observed to be similar to the findings of Jhansi (2015). Presence of high heritability and high percent mean of genetic advance for this trait revealed the additive gene effect and suggesting the effectiveness of simple selection procedure.

Seed yield/plant: Range of variation observed for seed yield was 1.03 g (JCS 3755) to 6.20 g (JCS 3980) with an overall mean of 3.78 g. Among all the genotypes, JCS 3755 recorded low seed yield/ plant of 1.03 g followed by JCS 3884 (1.07 g) while, JCS 3980 (6.20 g) recorded high seed yield/plant. These genotypes can be used as parents in further breeding programmes to improve the seed yield character especially for the *kharif* season. High genotypic (40.61%) and phenotypic (41.95%) coefficients of variation were recorded for this character, which was in line with the report by Hamouda *et al.* (2016). Significant variability existed among the genotypes. The heritability was high (93.70%) coupled with a high per cent mean of genetic advance (80.97%) agreeing with the observations made by Tripathy *et al.* (2016). High heritability and high per cent mean of genetic advance for the trait indicated that this trait is controlled by additive gene effect even though seed yield is known to be influenced by yield contributing characters. Our observations also suggest that the phenotypic selection for this character would hasten the varietal improvement period.

1000 seed weight: The average 1000 seed weight was 3.07 g with a range of 1.90 g (JCS 4049) to 4.00 g (GT-10). JCS 4049 had low 1000 seed weight (1.90 g) while GT-10 recorded more (4.00 g). Moderate genotypic and phenotypic coefficient of variations of 17.55 per cent and 18.33 per cent were observed which were in accordance with the report by Vanishree *et al.* (2011). 1000 seed weight recorded high heritability (91.6%) with a high percent mean of genetic advance (34.60%) as reported by Vanishree *et al.* (2011) and Jadhav *et al.* (2012). High heritability indicates that the character is controlled by additive type of gene action and thus less influenced by environment. High per cent mean of genetic advance accompanied with a high degree of heritability estimates offer a more effective criterion of direct selection.

Table 1 Analysis of Variance for yield and yield attributing traits in sesame at RARS, Polasa, Jagtial during *kharif,* 2018

Character	Mean sum of squares		
	Replications	Genotypes	Error
Days to 50 % flowering	0.01	140.58**	1.04
Days to maturity	0.05	74.84 **	0.63
Plant height (cm)	0.00	185.84**	43.18
Number of branches per plant	0.02	0.31**	0.02
Number of capsules per plant	4.53	252.95 **	8.13
Height of the plant from first capsule formation (cm)	7.32	75.75 **	6.73
Capsule length (cm)	0.00	0.03**	0.01
Capsule width (cm)	0.00	0.002**	0.00
Number of seeds per capsules	4.94	172.73 **	2.74
Seed yield per plant (g)	0.05	7.23**	0.16
1000 seed weight (g)	0.04	0.89**	0.03
Harvest index (%)	0.02	7.04**	2.50
Oil content (%)	0.40	16.93**	0.24

*- Significance level at 5% level of probability (1.43); ** Significance level at 1% level of probability (1.65)

Table 2 Genetic parameters for yield and yield attributing traits in sesame

Trait	Range		Mean ± SEm	Variance		Coefficient of variation		h^2 (%)	Genetic Advance (GA) at 5%	GAM (%) at 5%
	Min	Max		Genotypic	Phenotypic	GCV (%)	PCV (%)			
Days to 50% flowering	41.00	65.00	52.57 ± 0.58	46.51	47.55	12.97	13.11	97.80	13.89	26.43
Days to maturity	84.00	100.00	94.28 ± 0.45	24.74	25.36	5.27	5.34	97.50	10.11	10.73
Plant height (cm)	76.83	113.36	93.27 ± 3.79	47.55	90.73	7.39	10.21	52.40	10.28	11.02
Number of branches/ plant	2.00	3.00	2.47 ± 0.08	0.09	0.12	12.57	13.94	81.30	0.57	23.35
Number of capsules/plant	3.76	42.43	28.7 ± 1.64	81.60	89.73	31.44	32.97	90.90	17.47	61.77
Height of plant from first capsule formation (cm)	36.86	56.93	47.95 ± 1.49	23.00	29.74	10.00	11.37	77.40	8.69	18.12
Capsule length (cm)	1.99	2.46	2.21 ± 0.05	0.009	0.02	4.35	6.12	50.50	0.14	6.37
Capsule width (cm)	0.48	0.60	0.54 ± 0.01	0.001	0.001	4.44	5.57	63.60	0.04	7.30
Number of seeds/capsule	47.00	75.00	59.58 ± 0.95	56.66	59.40	12.63	12.93	95.40	15.14	25.41
Seed yield/plant (g)	1.03	6.20	3.78 ± 0.23	2.35	2.51	40.61	41.95	93.70	3.06	80.97
1000 seed weight (g)	1.90	4.00	3.07 ± 0.09	0.29	0.317	17.55	18.33	91.60	1.06	34.60
Harvest index (%)	11.18	16.30	13.89 ± 0.91	1.51	4.016	8.85	14.42	37.70	1.55	11.20
Oil content (%)	37.59	48.07	43.43 ± 0.28	5.56	5.80	5.43	5.54	95.80	4.75	10.95

Harvest index (%): The range of harvest index varied from 11.18 per cent (JCS 3884) to 16.30 per cent (YLM 11) with an overall mean of 13.89 %. Among all the genotypes, JCS 3884 recorded a minimum harvest index of 11.18% while YLM 11 recorded a maximum of 16.30% followed by JCS 3980 (16.19%). The genotypic and phenotypic coefficients of variation were 8.85 and 14.42 per cent which were low and moderate respectively. Harvest index recorded moderate heritability (37.7 per cent) with a moderate percent mean of genetic advance (11.20 per cent). Results indicate that the trait was controlled by non additive gene action and further improvement can be made through heterosis breeding.

Oil content: Oil content ranged from 37.59 (JCS 4053) to 48.07 per cent (JCS 3981) with an overall mean of 43.43%. JCS 3981 (48.07%), JCS 4005 (46.65%), and JCS 3993 (46.55%) recorded high oil content. The genotypic and phenotypic coefficients of variation were 5.43 and 5.54 per cent respectively which was recorded as low. Heritability for this trait was recorded as high i.e. 95.8 per cent coupled with moderate per cent mean of genetic advance (10.95 per cent). These results were on par with the findings of Reddy *et al.* (2001). A trait with high heritability estimates can be utilized for genetic improvement as they have the potential for large genetic determination. This trait is governed by complex gene interaction important for control of additive genetic effects for the character and also indicates a response to selection.

The results of our studies for analysis of variance for different traits showed that there were highly significant differences among the 50 genotypes for all characters considered. The variation of different traits under this study revealed that the phenotypic coefficient of variation (PCV) was higher than the genotypic coefficient of variation (GCV) for all the characters indicating the role of environmental variance in the total variance. PCV and GCV were high for characters such as number of capsules/plant, and seed yield/plant. Moderate PCV and GCV were recorded for days to 50% flowering, number of branches/plant, height of plant from first capsule formation, number of seeds/capsule, 1000 seed weight and low for days to maturity, capsule length, capsule width, and oil content. Other characters, plant height and harvest index had shown low PCV and moderate GCV. This type of wide range of variation provides ample scope for selection of desired genotypes for further genetic improvement.

Genetic advance as per cent of mean (GA) is a more reliable index for understanding the effectiveness of selection in improving the traits because the estimates are derived by the involvement of heritability, phenotypic standard deviation and intensity of selection. Thus, genetic advance along with heritability provides a clear picture regarding the effectiveness of selection for improving the plant characters. Noor *et al.* (2004) had cautioned that high heritability *per se* is no index of high genetic gain hence it should be accompanied by high genetic advance. High heritability coupled with high genetic advance as per cent of mean was observed for days to 50% flowering, number of branches/plant, number of capsules/plant, number of seeds/capsule, seed yield/plant and 1000 seed weight suggesting that, these characters were controlled by additive gene action. This type of characters could be improved by simple phenotypic selection.

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Effect of potassium on chemical composition, uptake and soil properties of groundnut (*Arachis hypogaea* L.) grown in loamy sand soil

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ABSTRACT

A field experiment was carried out at Castor Mustard Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar (Gujarat) India in summer season to study the effect of potassium on chemical composition, uptake and soil properties of groundnut (*Arachis hypogaea*) grown in loamy sand soil. The soil of experimental site was low in organic carbon (0.2%); EC (0.1 /dSm) and available N (155.6 kg/ha); medium in available P_2O_5 (44.2 kg/ha) and available K_2O (256.1 kg/ha) with neutral soil pH of 7.2. The experiment was framed with ten treatments namely T_1: RDF (25:50:00 kg/ha), T_2: RDF + KSB, T_3: RDF + 20 kg K_2O, T_4: RDF + 40 kg K_2O, T_5: RDF + 15 kg K_2O + KSB, T_6: RDF + 30 kg K_2O + KSB, T_7: 75 % RDF + NPK consortium, T_8: NPK consortium, T_9: RDF + NPK consortium and T_{10}: Absolute Control in randomised block design with three replications using groundnut variety GG 2. The significantly higher seed yield of 2872 kg/ha was recorded in treatment T_9. The N, P and K content and uptake was found maximum in treatment T_9 (RDF + NPK consortium). Significantly the higher values of available N (184.5 kg/ha), P_2O_5 (51.4 kg/ ha) and K_2O (260.7 kg/ha) content in soil after harvest of crop was recorded with the treatment T_9. Except T_1, T_8 and T_{10} all treatments recorded the highest value of soil organic carbon (0.3%). The maximum potassium use efficiency was noted under treatment T_5 (RDF + 15 kg K_2O + KSB) (28.9 kg/ha). The maximum bacterial, fungul and actinomycets population was noted under treatment T_9 [RDF (25:50:00 kg/ha) + NPK consortium].

Keywords: Groundnut, Content and uptake, Microbial count, NPK consortium, Potassium, Potassium Use Efficiency

Groundnut (*Arachis hypogaea* L.) is known as 'King of oilseed' among all oilseed crops, botanically belongs to family Fabaceae. Groundnut seeds are rich source of edible oil (43-55%) and protein (25-28%). In India, groundnut is grown on 4.56 million hectare and production of 6.77 million tonnes with an average productivity of 1486 kg/ha (DAC and FW, 2016). Gujarat ranks first both in area and production in India. The Saurashtra region of Gujarat is considered as 'bowl of groundnut'. The area under groundnut is also increasing in potato growing areas of North Gujarat because of suitable agro-climatic conditions and coarse texture soil. With intensification of agriculture in Gujarat, the soils are over exploited for available plant nutrients when fertilized unjudiciously. The outcome of long term fertilizer experiments confirms the need of potassium fertilization in the soils of Gujarat (Malaviya *et al.,* 1999). Potassium is considered one of the primary nutrients responsible for quality of crop and ionic balance. Some farmers use potassium solubilizing bacteria (KSB) in high K requiring crop like Potato in North Gujarat but commercial use of KSB is new to farmers of North Gujarat. However, research on use of KSB in groundnut is very scarce. Keeping above facts in view, the present investigation was undertaken.

MATERIALS AND METHODS

A field experiment was conducted at Castor-Mustard Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Banaskantha, Gujarat which located at 72°19' East longitude and 24° 19' North latitude at 154.52 meters above the mean sea level during summer season of 2017. The region falls under North Gujarat Agro-Climatic Zone (AES-IV) of Gujarat (India). The soil of the experimental field was loamy sand in texture, low in organic carbon (0.2 %), EC (0.1/dSm) and available N (155.6 kg/ha); medium in available P_2O_5 (44.2 kg/ha) and available K_2O (256.1 kg/ha) with neutral soil pH of 7.2. Total ten treatments were tested namely T_1: RDF (25:50:00 kg/ha), T_2: RDF + KSB, T_3: RDF + 20 kg K_2O, T_4: RDF + 40 kg K_2O, T_5: RDF + 15 kg K_2O + KSB, T_6: RDF + 30 kg K_2O + KSB, T_7: 75 % RDF + NPK consortium, T_8: NPK consortium, T_9: RDF + NPK consortium and T_{10}: Absolute Control. The experiment was laid out in randomised block design with three replications. Groundnut variety GG 2 was used as a test crop.

Recommended dose of 25 kg N + 50 kg P_2O_2/ha along with seed treatment with Rhizobium and PSB in all the treatments @ 5 ml/kg seed was applied as common except absolute control. Source of N and P was urea and diammonium phosphate (DAP), respectively. Potassium was applied as MOP along with the seed treatment with KSB and commercially available NPK consortium @ 5 ml/kg seed at the time of sowing as per treatment. NPK consortium used in this expereiment was sourced from Anand Agricultural University, Anand. Groundnut cv. GG 2 was sown on 28th February, 2017 with recommended seed rate of 120 kg/ha by

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maintaining 30 cm distance between two rows. The seeds were sown manually at the depth of 5-6 cm in previously opened furrows and covered properly with the soil. All recommended agronomic practices were followed to raise a healthy crop.

Cropping history of the experimental plot: Details regarding cropping history with respect to crops grown in the experimental plot and fertilizers applied to the crops during preceding three years are given in Table 1.

The experiment was laid out in a Randomised Block Design (RBD) with three replications. The treatments were assigned at random in each replication. The gross plot size was having dimension of 4.0 m x 3.0 m while the net plot was 3.0 m x 1.8 m.

Table 1 Cropping history of the experimental site

Year	Season	Crop	Variety	Fertilizers applied (kg/ha)		
				N	P_2O_5	K_2O
	Summer	Fallow	-	-	-	-
2014	*Kharif*	Bajara	GHB 558	80	40	00
	Rabi	Fallow	-	-	-	-
	Summer	Fallow	-	-	-	-
2015	*Kharif*	Fallow	-	-	-	-
	Rabi	Mustard	GDM 4	50	50	00
	Summer	Fallow	-	-	-	-
2016	*Kharif*	Greengram	GM 4	20	40	00
	Rabi	Fallow	-	-	-	-

Climate and weather conditions: The climate of this region is sub-tropical monsoon type and falls under semi-arid region. In general, monsoon is warm and moderately humid, winter is fairly cold and dry, while summer is largely hot and dry. The standard week-wise meteorological data for the period of this investigation recorded at the Meteorological Observatory, SDAU, Sardarkrushinagar, District: Banaskantha District indicates that mean maximum temperature ranged between 32.6 to 43.4°C, while mean minimum temperature ranged between 11.6 to 27.1°C during the period of experimentation. The mean relative humidity recorded at morning and evening ranged from 76.0 to 87.7 per cent and 24.6 to 96.8 per cent, respectively and the mean bright sunshine hours ranged between 1.0 to 10.1 hours during crop period. Overall climatological data indicated that the weather conditions were observed normal and favourable for the satisfactory growth and development of the groundnut crop during summer season of 2017.

The first irrigation was given immediately after sowing and next irrigation four days after sowing to ensure proper seed germination and crop establishment. Remaining 12 irrigations were given during the crop growth cycle at nearly 7-10 days interval. Prior to sowing, a composite soil sample was collected to determine initial status of nutrients. After harvest of groundnut crop, representative soil samples were also taken from each plot at 0-15 cm soil depth to analyse available N, P_2O_5, K_2O and OC, EC, pH status and registered separately for each treatment. For estimation of nitrogen, phosphorus, potassium content in representative samples of pod and haulm were collected from each net plot at the time of harvest. The samples were then oven dried at 60ºC for 24 hrs., ground by using mechanical grinder. The standard methods, as outlined by Jackson (1973), were used for analysis of soil and plant samples. The uptake of nutrients were calculated by multiplying nutrient content (%) to the yield (kg/ha). The KUE was calculated using difference between potassium uptake in fertilized plot and potassium uptake in control plot divided by quantity of potassium fertilizer applied. KUE was calculated only for treatments T_3, T_4, T_5 and T_6.

KUE (%) = [(Yield in K fertilizer applied plot - yield in without K fertilizer application) / Quantity of K fertilizer applied]* 100

The microbial counts were recorded using serial dilution method. The statistical analysis of the data collected for different characters was carried out following the procedure of Randomized Complete Block Design of an experiment as described by Panse and Sukhatme (1967).

RESULTS AND DISCUSSION

Pod yield: Data presented in Table 2 revealed that significantly higher pod yield (2872 kg/ha) of groundnut was produced under the treatment T_9 (RDF + NPK consortium) as compared to rest of the treatments, but it remained at par with the treatment T_6 (RDF + 30 kg K_2O + KSB) and T_7 (75% RDF + NPK consortium). The treatment T_{10} (Absolute control) gave significantly lower pod yield as compared to all other treatments. Further, pronounced effect of NPK consortium on pod yield might be due to its ability to fix nitrogen, mobilize phosphorus and potassium as well as other hormones, enzymes and siderophores which might have helped in better nutrient uptake, optimum growth and higher yield. These results are in accordance with the findings of Chandra *et al*. (2006).

Nutrient content in kernel, haulm and shell: The nitrogen content in groundnut kernel, haulm and shell responded to application of potassium application over control as revealed by the data presented in Table 3. However, treatment T_9 (RDF + NPK consortium) had significantly higher nitrogen content (3.72 %) in kernel and (1.42%) in halum but it was found statistically at par with all treatments, except T_8 and T_{10}. While the treatment T_9 (RDF + NPK consortium) reported significantly higher nitrogen content (0.99%) in shell, it was found statistically at par with treatments T_4, T_6 and T_7. This could be due to inorganic fertilizers and NPK consortium application or other microbial inoculants promoted higher nitrogen fixation helping in increase of nutrient content due to release of nutrients at its optimum amount for a longer period. These results are in accordance with the findings of Patel and Patel (1988).

Table 2 Pod yield of groundnut as influenced by different treatments

Treatments	Pod yield (kg/ha)
T_1 : RDF (25 : 50 : 00 kg/ha)	2215
T_2 : RDF + KSB	2236
T_3 : RDF + 20 kg K_2O	2284
T_4 : RDF + 40 kg K_2O	2369
T_5 : RDF + 15 kg K_2O + KSB	2337
T_6 : RDF + 30 kg K_2O + KSB	2435
T_7 : 75 % RDF + NPK consortium	2529
T_8 : NPK consortium	2128
T_9 : RDF + NPK consortium	2872
T_{10} : Absolute control	1904
SEm. ±	163.56
CD at 5 %	485.95
CV %	12.15

Significantly higher P content in kernel (0.65 %), halum (0.19 %) and shell (0.048 %) was found with treatment T_9 (RDF + NPK consortium), whereas in case of kernel, T_9 was at par with treatment T_3(0.60%), T_5 (0.62 %) and T_7 (0.63%) and in case of Halum, treatment T_9 was at par T_5 (0.17%) and T_7 (0.18%). In case of shell, treatment T_9 was at par with treatments T_3 (0.045 %), T_5 (0.046 %), T_6 (0.044 %) and T_7 (0.047%). This could be due to more availability and mobility of phosphorus to the crop by application of inorganic fertilizers, NPK consortium as well as by KSB that are known to improve the absorption by plant roots and their transportation towards foliage and later on translocation in the pod by various metabolic activities (Borah *et al*., 2018). Significantly higher K content (0.51%) in kernel, (0.48%) in haulm was found with treatment T_9 (RDF + NPK consortium) which was at par with treatment T_4, T_6, and T_7. However, there was non significant difference in K content of groundnut shell. The higher availability of potassium available to the crop by application of NPK consortium and KSB might have improved the absorption of K by plant roots and their transportation towards foliage and later on translocation into the pod. These results are in accordance with the findings of Zizala *et al*. (2000).

Nutrient uptake by kernel, haulm and shell: A perusal of data presented in Table 4 revealed that total nitrogen uptake by groundnut was highest (195.80 kg/ha) under the influence of T_9 (RDF + NPK Consortium) treatment. Uptake of nitrogen increased significantly by the application of inorganic sources and NPK consortium. Increased N uptake is attributed to the application of NPK consortium to plant which in turn helps in vigorous root and shoot growth. Application of NPK consortium might have provided suitable soil environment for better N fixation, which in turn resulted in greater absorption of nitrogen from the soil.

Table 3 Nitrogen, phosphorus and potassium content in kernel, haulm and shell of groundnut as influenced by different treatments

Treatments	Nitrogen content (%)			Phosphorus content (%)			Potassium content (%)		
	Kernel	Haulm	Shell	Kernel	Haulm	Shell	Kernel	Haulm	Shell
T_1 RDF (25:50:00 kg/ha)	3.46	1.31	0.87	0.56	0.12	0.041	0.43	0.41	0.71
T_2 RDF + KSB	3.48	1.33	0.88	0.57	0.13	0.042	0.44	0.42	0.71
T_3 RDF + 20 kg K_2O	3.55	1.34	0.89	0.60	0.16	0.045	0.45	0.43	0.73
T_4 RDF + 40 kg K_2O	3.68	1.37	0.92	0.58	0.14	0.043	0.47	0.45	0.74
T_5 RDF + 15 kg K_2O + KSB	3.62	1.35	0.90	0.62	0.17	0.046	0.46	0.44	0.73
T_6 RDF + 30 kg K_2O + KSB	3.69	1.38	0.96	0.59	0.15	0.044	0.48	0.46	0.75
T_7 75 % RDF + NPK consortium	3.70	1.41	0.98	0.63	0.18	0.047	0.50	0.47	0.76
T_8 NPK consortium	3.38	1.30	0.86	0.55	0.11	0.040	0.42	0.40	0.69
T_9 RDF + NPK consortium	3.72	1.42	0.99	0.65	0.19	0.048	0.51	0.48	0.77
T_{10} Absolute control	3.24	1.21	0.84	0.54	0.10	0.039	0.40	0.38	0.68
SEm. ±	0.10	0.04	0.02	0.015	0.005	0.001	0.01	0.01	0.03
CD at 5 %	0.29	0.11	0.07	0.044	0.014	0.004	0.04	0.03	NS

Significantly highest total phosphorus uptake (28.30 kg/ha) by groundnut was obtained under the treatment T_9 (RDF + NPK consortium). This might be due to increased concentration of phosphorus in soil solution with the application of inorganic sources, NPK consortium and KSB. NPK consortium would have helped in continued supply of phosphorus by solubilizing the insoluble P resulting in higher uptake of phosphorus by the roots from the soil.

Significantly highest total potassium uptake (57.40 kg/ha) by groundnut was obtained under the treatment T9 (RDF + NPK consortium). This might have been again due to increased concentration of available potassium in soil solution continuously due to the effect of NPK consortium which would have facilitated conversion of insoluble K into soluble form and resulted in higher uptake of potassium from the soil. These results are in accordance with the findings of Shahid *et al*. (2000).

Effect on available nutrients status in soil: The data presented in Table 5 indicated that significantly the highest value of available N status in soil (184.5 kg/ha) after harvest of groundnut crop was estimated under the treatment receiving RDF + NPK consortium (T_9). Significantly higher available P_2O_5 (51.4 kg/ha) status in soil after harvest of crop was noticed with application of (25 : 50 :00 kg NPK/ha) RDF + NPK consortium (T_9) and it was statistically at par with treatments T_3, T_5 and T_7. Moreover, the significantly higher available K_2O (260.7 kg/ha) status in soil after harvest of the crop was noticed with application of (25:50:00 kg NPK/ha) RDF + NPK consortium (T_9) and it was statistically at par with treatments T_3, T_4, T_5, T_6 and T_7. The data also indicated that except T_1, T_8 and T_{10} all treatments recorded the highest value of organic carbon (0.3 %) which was significantly higher than rest of the treatments. The higher microbial activities due to addition of the bioagents through NPK consortium and KSB might have produced more carbon in respective treatments. These results are in accordance with the findings of Chaudhary *et al*. (2019).

Table 4 Nitrogen, phosphorus and potassium uptake by kernel, haulm and shell of groundnut as influenced by different treatments

Treatments	Nitrogen uptake (kg/ha)				Phosphorus uptake (kg/ha)				Potassium uptake (kg/ha)			
	Kernel	Haulm	Shell	Total	Kernel	Haulm	Shell	Total	Kernel	Haulm	Shell	Total
T_1 RDF (25 : 50 : 00 kg/ha)	76.7	44.3	19.1	140.1	12.4	4.2	0.9	17.5	9.5	14.0	15.8	39.3
T_2 RDF + KSB	77.7	45.7	19.7	143.1	12.7	4.6	0.9	18.2	9.9	14.3	15.8	40.0
T_3 RDF + 20 kg K_2O	81.0	47.1	20.2	148.3	13.8	5.6	1.0	20.4	10.3	15.2	16.6	42.1
T_4 RDF + 40 kg K_2O	87.1	51.3	21.7	160.1	13.7	5.2	1.0	19.9	11.2	16.9	17.6	45.7
T_5 RDF + 15 kg K_2O + KSB	84.7	48.9	21.0	154.6	14.6	6.2	1.1	21.9	10.8	15.9	17.2	43.9
T_6 RDF + 30 kg K_2O + KSB	89.5	54.0	23.4	166.9	14.3	5.9	1.1	21.3	11.8	18.2	18.2	48.2
T_7 75 % RDF + NPK consortium	93.5	57.0	24.8	175.3	15.9	7.3	1.2	24.4	12.6	19.1	19.2	50.9
T_8 NPK consortium	72.0	42.4	18.3	132.7	11.7	3.7	0.9	16.3	8.9	13.1	14.8	36.8
T_9 RDF + NPK consortium	106.6	60.7	28.5	195.8	18.8	8.1	1.4	28.3	14.6	20.8	22.0	57.4
T_{10} Absolute control	61.4	36.5	16.1	114.0	10.3	3.1	0.8	14.2	7.7	11.4	13.0	32.1
SEm. ±	5.85	2.90	1.26	2.62	0.80	0.46	0.09	0.65	0.78	2.88	1.17	0.31
CD at 5 %	17.39	8.62	3.76	7.79	2.38	1.37	0.25	1.92	2.32	0.97	3.46	0.91

Table 5 Soil physico-chemical parameters and organic carbon content and available nitrogen, phosphorus and potassium in soil after harvest as influenced by different treatments

Treatments	Parameters			Available soil nutrients after harvest (kg/ha)		
	pH	EC (Ds/m)	OC (%)	N	P_2O_5	K_2O
T_1 RDF (25 : 50 : 00 kg/ha)	7.3	0.1	0.2	163.6	42.8	242.7
T_2 RDF + KSB	7.2	0.1	0.3	164.2	43.1	245.7
T_3 RDF + 20 kg K_2O	7.3	0.1	0.3	169.8	48.3	247.9
T_4 RDF + 40 kg K_2O	7.3	0.1	0.3	176.6	44.2	253.4
T_5 RDF + 15 kg K_2O + KSB	0.1	7.4	0.3	172.6	49.4	249.4
T_6 RDF + 30 kg K_2O + KSB	0.1	7.3	0.3	178.6	46.0	255.6
T_7 75 % RDF + NPK consortium	0.1	7.5	0.3	180.2	50.8	258.2
T_8 NPK consortium	0.1	7.3	0.2	162.9	42.0	240.1
T_9 RDF + NPK consortium	0.1	7.4	0.3	184.5	51.4	260.7
T_{10} Absolute control	0.1	7.4	0.2	157.0	40.1	238.2
SEm. ±	0.001	0.116	0.01	4.36	1.58	4.74
CD at 5 %	NS	NS	0.02	12.95	4.69	14.09
Before sowing	7.2	0.1	0.2	155.6	44.2	256.1

Potassium use efficiency (KUE) and microbial count: Potassium use efficiency could be calculated only for treatments T_3, T_4, T_5, and T_6. The data (Table 6) showed that KUE (kg/ha) was influenced by the treatments. With increasing potassium rate from 20 kg/ha to 40 kg/ha, the KUE decreased from 19.0 kg/ha to 11.6 kg/ha. The maximum KUE (28.9 kg/ha) was noted under treatment T_5 RDF + 15 kg K_2O + KSB while the minimum KUE (11.6 kg/ha) was noted under treatment T_4 (RDF + 40 kg K_2O). The KUE increased with the use of potassium solubilizing bacteria as observed with treatment T_5 (RDF + 15 kg K_2O + KSB) and T_6 (RDF + 30 kg K_2O + KSB). Data presented in Table 7 indicated that bacterial, fungal and actinomycetes populations were higher in treatment RDF + NPK consortium (T_9) as reported by others (Jha, 2017 and Patel *et al*., 2021).

Table 6 Potassium use efficiency as influenced by different K fertilizer treatments

Treatments	KUE
T_3 RDF + 20 kg K_2O	19.0
T_4 RDF + 40 kg K_2O	11.6
T_5 RDF + 15 kg K_2O + KSB	28.9
T_6 RDF + 30 kg K_2O + KSB	17.7

Table 7 Microbial population in soil after harvest of crop as influenced by different treatments

Treatments	Bacteria	Fungi	Actinomycetes
T_1 RDF (25:50:00 kg/ha)	8.8 × 107	3.7 × 105	4.5 × 105
T_2 RDF + KSB	1.0 × 108	4.0 × 105	8.0 × 105
T_3 RDF + 20 kg K_2O	9.0 × 107	1.7 × 105	3.7 × 105
T_4 RDF + 40 kg K_2O	2.2 × 107	5.1 × 105	4.8 × 105
T_5 RDF + 15 kg K_2O + KSB	3.6 × 108	1.0 × 105	1.8 × 105
T_6 RDF + 30 kg K_2O + KSB	5.5 × 108	3.4 × 105	4.0 × 105
T_7 75 % RDF + NPK consortium	3.9 × 108	4.0 × 105	4.9 × 105
T_8 NPK consortium	8.5 × 107	3.7 × 105	2.7 × 105
T_9 RDF + NPK consortium	9.0 × 108	7.7 × 105	7.8 × 105
T_{10} Absolute control	1.3 × 107	4.1 × 104	2.3 × 105

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Effect of water stress on physiological traits of sunflower (*Helianthus annuus* L.) restorer lines

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ABSTRACT

A field experiment was conducted during *rabi,* 2018 to evaluate the performance of eight sunflower restorer lines *viz.,* RGP 21-P6, RGP 32-P1, RGP 33-P5, RGP 50-P1, RGP 60-P2, RGP 61-P1, RGP 61-P2 and RGP 95-P1 for physiological traits under water stress conditions in a split-plot design with three replications. Water stress was imposed in stress plots from flowering to harvest. Results indicated that the traits, leaf area index (LAI), total drymatter (TDM), proline accumulation, and crop growth rate (CGR) were more sensitive to moisture stress with above 30% reduction. Whereas, SPAD chlorophyll meter readings (SCMR) was less sensitive with less than 10% reduction due to water stress. Significant decrease and variation was observed among the restorer lines for LAI, SCMR, TDM, relative water content (RWC) and CGR, whereas leaf temperature and proline concentration increased due to water stress. Restorer lines RGP 21-P6, RGP 61-P1, RGP-61-P2, and RGP 95-P1 recorded superiority in LAI, CGR, TDM and leaf temperature among the physiological traits studied even under water stress.

Keywords: Physiological traits, Restorer lines, Sunflower, Water stress

Among abiotic stress factors, drought is the most significant one, which creates problems on the one third of the world's agriculture area. The amplified water shortage and recurrent drought in agricultural ecosystems have caused problems worldwide, causing the yield losses for many crops. The latest findings suggest that, in recent decades, the frequency of occurrence of drought has significantly increased in India (Aadhar and Mishra, 2017). And this frequency is set to increase between 2020 and 2049 (Collison *et al*., 2000). India has about 140 M.ha of cultivable land. 42% of the country's cultivable land lies in drought-prone areas/districts. Moreover, 54% of India's net sown areas depend on rain, and rainfed agriculture plays an important role in the country's economy (BMEL, India Country Report, 2016). It is therefore important to breed drought-resistant crops to ensure food security.

Sunflower (*Helianthus annuus* L.) is the most important source of cooking oil and the third largest oilseed crop in the world. The productivity of sunflower is greatly affected by drought (Debaeke *et al.,* 2017), though it is considered moderately tolerant to drought stress (Tahir *et al.,* 2002). It is well known that sunflower yield decreases under drought stress (Erdem *et al.,* 2006) and is dependent on the level of water deficit and cultivar (Rodriguez *et al.,* 2002).

Major area of sunflower is occupied by hybrids which are developed using a 3 line system (CMS, maintainer and restorer) where R lines act as male parent. In this context, the identification of water stress-tolerant parental lines to develop resistant varieties or hybrids through breeding programme may constitute long-lasting measures to mitigate the negative impacts of global warming and resultant climate change. Moreover, seed-based technologies are easy to transfer to a farmer's field compared to the management technologies that require skill. The identification and development of water stress tolerant types will let more active utilization of dry lands (Ucak, 2017). Therefore, the objective of this study was to evaluate the effect of water stress on physiological characteristics of sunflower restorer lines for superior line identification under water stress.

MATERIALS AND METHODS

A field trial was conducted during *rabi,* 2018-2019 at ICAR-IIOR Narkhoda farm in a split-plot design with control and water stress as main plot treatments and restorer lines as subplot treatments replicated thrice. The weather data during the crop period was presented in the Fig.1. The subplots included eight sunflower R-lines *viz.,* RGP 21-P6, RGP 32-P1, RGP 33-P5, RGP 50-P1, RGP 60-P2, RGP 61-P1, RGP 61-P2, RGP 95-P1 and two checks DRSH-1, 298R developed at ICAR-Indian Institute of Oilseeds Research (ICAR-IIOR). Plots were irrigated at 10 days interval until crop reached flowering stage, water stress was imposed by withholding irrigation to the stress plots from flowering till harvest. The crop was subjected to stress intensity index of 0.33 which is considered as moderate. Each treatment plot size was 3.6 m^2 and the row spacing of 60 cm and intra row spacing of 30 cm. Sowing was done by dibbling and applied recommended fertilizer dose [60 Kg N (2 splits) + 90 Kg P_2O_5 + 30 kg K_2O], and other package of practices were followed to raise a healthy crop. Prophylactic measures were

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adopted against pests and diseases. Non-destructive analysis data was taken by tagging 5 plants in each replication. SCMR values were measured in upper, middle, and lower leaves at five points on each leaf using SPAD meter (Konica Minolta). The average of these five readings was considered as SCMR reading of the leaf. The leaf temperature was measured on the same leaf using Infra-Red thermal gun (AGRI-THERM-6210L). The total leaf area per plant was measured by LI-3100C Leaf area meter. From the leaf area of these five plants, the LAI was calculated using the formula LAI = leaf area/ground area. RWC was determined from the youngest fully expanded leaves, and calculated by the formula modified by Smart and Bingham (1974). Proline content was estimated by following the method of Bates et al. (1973). TDM was obtained by uprooting three plants from each treatment and separating them into component parts like stem, leaf, and capitulum and kept in brown paper bags and dried to a constant weight in a hot air oven at 80°C. CGR was calculated from the TDM.

RESULTS AND DISCUSSION

Assessment of various physiological characteristics of the sunflower restorer lines under water stress is essential to identify lines with superior traits. The variation for traits - LAI, SCMR, RWC, proline concentration, TDM, and CGR was significant among the restorer lines and also between the control and stress treatment (drought intensity index of 0.33).

Leaf area expansion and division are affected by water stress causing decrease in leaf area. Lines that maintain better water status even under water stress record minimal reduction. LAI ranged from 0.9 to 1.5 among different lines in stress with 54% reduction and the maximum was recorded in RGP 61-P2. Restorer lines RGP 21-P6, RGP 61-P1, RGP 61-P2, RGP 95-P1, and hybrid check DRSH-1 were on par with each other and have significantly ($p=0.05$) higher LAI than restorer check 298R (Table 1). Hussain *et al.* (2017) and Umar and Siddiqui (2018) also reported similar decrease of LAI due to water stress. Among these lines, RGP-21-P6 and RGP 61-P2 also recorded higher seed yield in water stress (Yasaswini *et al*., 2020).

SCMR was the only physiological trait that was affected least due to water stress (4%). SCMR ranged from 34.3 to 47.0 and 33.8 to 46.1 under control and stress treatments respectively among the genotypes tested (Table 1). All the restorer lines under study had significantly higher SCMR values than check 298R under control and stress treatments except RGP 21-P6. Most of the R-lines under study recorded higher SCMR values than hybrid check DRSH-1. RGP 61-P1, RGP 61-P2 had higher SCMR under water stress conditions. A similar trend of reduction in SCMR under stress was confirmed by the findings of Santhosh *et al.* (2016) and Ucak *et al.* (2017). Relative water content (RWC) which indicates plant water status, ranged in different lines from 71-79 and 61-73 respectively in control and water stress with mean reduction of 15% due to stress (Table 1). A decrease in RWC could inhibit the photosynthesis capacity of sunflower and thereby affecting the yield (Tezara *et al.,* 2002). High RWC was reported by check 298R followed by RGP 21-P6 under control and water stress. All the restorer lines were on par with 298R and significantly greater than DRSH-1 under control. RGP 21-P6 was the only restorer line that was on par with check 298R under stress. Similar results were also reported by Gholinezhad *et al.* (2009) and Umar and Siddiqui (2018).

Proline content ranged from 2.5-4.2 µmole/g and 3.9-16.3 µmole/g under control and water stress respectively. It was increased by 45% due to water stress (Table 1). All the restorer lines were on par with each other under control conditions. DRSH-1 recorded the least proline accumulation under stress and RGP 60-P2 recorded significantly high proline under water stress followed by RGP 95-P1, which were on par with check 298R. Proline acts as an osmolyte, and also propels cellular signalling processes that promote cellular apoptosis or survival (Xinwen Liang *et al.,* 2013). Increased proline concentration under water stress was reported by Oraki *et al.* (2012) and Umar and Siddiqui (2018).

A significant decrease in TDM at 70 DAS (32%) and during harvest (36%) was observed due to water stress. TDM ranged from 27-60 g/plant and 18-39g/plant under control and stress respectively at 70 DAS (Table 2). During harvest, the TDM recorded was 57-94g/plant and 35-69g/plant under control and stress respectively. RGP 61-P2 recorded significantly higher TDM (94 g/plant) than checks in control. RGP 61-P2 followed by RGP 95-P1 recorded TDM at par with restorer check 298R. Least percent reduction under stress was shown by checks DRSH-1 and 298R closely followed by RGP-95-P1. Reduction in biomass due to water stress was observed in almost all genotypes of sunflower studied by Tahir and Mehid (2001) and Geetha *et al.* (2012) and the present findings were in tune with them.

Restorer lines under study showed significant variation for CGR at 40-70 DAS and 70 DAS-harvest (Table 2). Water stress reduced the CGR by 32 and 36% at 40-70 DAS and 70 DAS to harvest respectively. A common adverse effect of water stress on crop plants is the reduction in fresh and dry biomass production (Farooq *et al.,* 2009). High CGR both under control and water stress was recorded by RGP 21-P6 and RGP 61-P2 respectively at 40-70 DAS and 70 DAS-harvest respectively. RGP 61-P2 recorded significantly higher CGR compared to checks under control during 70 DAS-harvest. Highest CGR under stress was recorded by DRSH-1 and no restorer line under study was on par with it. All the restorer lines except RGP 32-P1, RGP 33-P5 and RGP 50-P1 were on par with the check 298-R. Reduction in biomass due to water stress was observed in almost all genotypes of sunflower (Tahir and Mehid, 2001).

Table 1 LAI, SCMR, RWC, proline concentration and membrane stability of the restorer lines under control and water stress (mean values of 15 plants of the three replications under each treatment)

R Line	LAI		SCMR		RWC(%)		Proline (µmole/g)	
	Control	Stress	Control	Stress	Control	Stress	Control	Stress
RGP 21-P6	3.4	1.2	36.4	34.5	79	72	2.7	6.9
RGP 32-P1	1.7	0.9	42.1	41.8	78	63	4.2	5.3
RGP 33-P5	2.4	1.0	40.5	38.6	76	61	3.5	3.8
RGP 50-P1	2.6	1.0	47.0	42.0	77	65	2.7	5.0
RGP 60-P2	2.3	1.1	44.5	42.4	76	62	3.8	16.3
RGP 61-P1	2.4	1.3	46.3	42.7	76	63	2.5	3.9
RGP 61-P2	2.6	1.5	45.3	43.6	75	65	3.6	5.0
RGP 95-P1	2.2	1.3	40.0	39.4	74	62	3.8	9.8
DRSH-1	3.8	1.3	41.8	41.1	71	62	2.4	3.5
298-R	2.4	0.9	34.3	33.8	79	73	2.8	14.5
Mean	2.6	1.1	42	40	76	65	3.2	7.4
CD (P=0.05)								
Stress	0.5		1.3		1.0		2.5	
R lines	0.3		1.6		6.0		4.0	
Interactions	0.6		NS		NS		5.7	

Table 2 TDM, CGR and leaf temperature of the restorer lines under control (C) and water stress (WS)

R Line	TDM(g/plant)				CGR ($g/m^2/d$)				Leaf temperature (˚C)			
	70 DAS		Harvest		70 DAS		Harvest		65 DAS		75 DAS	
	C	WS	C	WS	C	WS	C	WS	C	WS	C	WS
RGP 21-P6	60	29	71	43	8.5	4.1	10.1	6.0	20.6	24.4	20.5	24.2
RGP 32-P1	31	18	76	35	4.4	2.6	10.7	4.9	23.2	23.9	22.2	25.7
RGP 33-P5	27	24	57	35	3.9	3.4	8.1	5.0	23.6	23.7	22.7	23.5
RGP 50-P1	41	21	78	37	5.9	3.0	11.1	5.2	23.6	24.7	20.6	23.8
RGP 60-P2	41	24	71	40	5.7	3.4	10.0	5.6	23.1	23.9	22.0	25.3
RGP 61-P1	40	28	66	45	5.6	4.0	9.4	6.3	23.3	25.1	20.8	24.3
RGP 61-P2	43	41	94	50	6.1	5.8	13.3	7.1	22.9	23.5	20.5	25.0
RGP 95-P1	41	31	64	49	5.9	4.4	9.1	6.9	22.7	22.8	21.2	23.8
DRSH-1	49	39	70	69	6.9	5.5	9.9	9.8	21.5	23.5	21.5	24.0
298-R	46	27	67	52	6.6	3.8	9.5	7.4	21.6	23.6	20.7	24.4
Mean	42	28	71	45	5.9	4.0	10.1	6.4	22.6	23.9	21.3	24.4
CD (P=0.05)												
Stress	1.4		2.0		NS		0.9		0.6		NS	
R lines	2.2		2.7		1.5		2.0		0.9		0.7	
Interactions	3.3		4.1		2.3		NS		1.3		1.1	

A significant increase in leaf temperature of stressed plants was observed at 65 DAS (Table 2). However, significant variation among restorer lines was observed both at 65 and 72 DAS. Maximum and minimum temperatures ranged from 20.6-23.6°C and 22.8-25.1°C under control and stress respectively at 65 DAS. RGP 95-P1 (+0.1°C), RGP 61-P2 (+0.6°C), RGP 60-P2 (+1.1°C), RGP 32-P1 (+0.7°C) and RGP 33-P5 (+0.1°C) showed a minimal increase in temperature and were having significantly lower temperatures compared to checks at 65DAS. Among the restorer lines, RGP 95-P1 and RGP 33-P5 showed significantly lower temperatures under water stress even at 75 DAS. Similar results were reported by Canavar (2013).

Based on several parameters, the restorer lines RGP 21-P6, RGP 61-P1, RGP-61-P2, and RGP 95-P1 that recorded high values for the traits - LAI, proline, RWC and CGR under stress condition with negligible increase in leaf temperature could be considered as water stress tolerant lines and they could be used in breeding programmes aimed at developing water stress tolerant hybrids.

Table 3 Summary table for superiority in physiological traits

	RGP 21-P6	RGP 32-P1	RGP 33-P5	RGP 50-P1	RGP 60-P2	RGP 61-P1	RGP 61-P2	RGP 95-P1	DRSH-1	298-R
LAI (> 1.1)	✓					✓	✓	✓	✓	✓
TDM (> 45 g/plant) at harvest						✓	✓	✓	✓	✓
SPAD (> 40.0)		✓		✓	✓	✓	✓		✓	
Leaf temperature (< 24.4°C at 75 DAS)	✓		✓	✓	✓		✓		✓	✓
RWC (>65%)	✓			✓			✓			✓
Proline (> 7.4 μ mole per g FW)					✓			✓		✓
CGR (> 6.4 g $m^{-2}day^{-1}$) at harvest							✓	✓	✓	✓

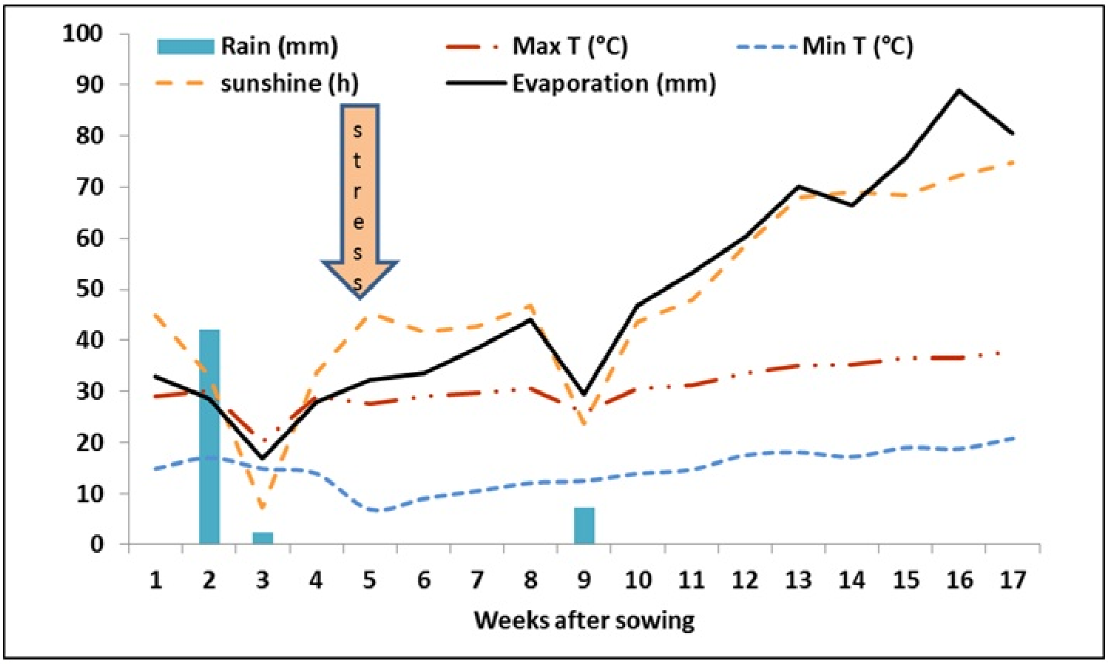

Fig. 1. Weekly weather data (temperature, evaporation, sunshine hours and rainfall) during crop growth period from 01-12-2018 to 29-03-2019

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Quality assessment of meal protein and oil of thirty four promising genotypes of mustard [*Brassica juncea* (L.) Czern & Coss.]

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ABSTRACT

Rapeseed mustard is an important source of edible oil in Indian diet especially in Eastern and North-Western India. The present investigation was carried out to assess some seed quality traits in thirty four genotypes/varieties of Indian mustard [*Brassica juncea* (L.) Czern&Coss] grown in U.P. We analyzed traits such as moisture content, protein content, test weight, polyphenol content, oil content, glucosinolate and nutritional quality index. The overall range of variability of moisture content, test weight, contents of oil, protein, polyphenol and nutritional quality index were 2.45-6.89%, 2.80-5.8g, 33.52-42.15%, 19.53-27.27%, 7.24-30.86 mg/100g, 7.56-12.78, respectively.

Keywords: Glucosinolate, Oil, Polyphenol, Rapeseed mustard, Seed meal

Indian mustard [*Brassica juncea* (L.) Czern & Coss.] is one of India's most important oilseed crops and cultivated for its high content of edible oil and meal protein. *Brassicas* are one of the most common agronomically important oilseeds, with a wide range of species that can be used as oilseed, vegetable, and fodder crops. If the nutritional value of oil seeds is established, their consumption and multipurpose applications will expand. *Brassica* species are distinguished by their high seed oil content, which ranges from 17 to 40%. Flavonoids, tocopherols, ascorbic acid, and other nutrients can be found in mustard seed cake or meal. The protein content and quantity of the mustard oil cake obtained are both high (Chowdhury *et al.*, 2014). Mustard is a fast-yielding seed oil with moderately high oil content (Riley, 2004). Mustard seeds have a high energy content, containing 28-32% oil and a high protein content (28-36 percent). Mustard seed meal is mostly used as animal feed, but it can also be used to make value-added items after antinutritional factors are removed (Bala and Singh, 2012). Gulcosinolates, also known as GSLS (alkyl aldoxime-O-sulphate esters with a ß-D-thioglucopyranoside group), are a group of secondary plant metabolites found in abundance in the seeds and green tissues of Brassicaceae plants. Both GSLs and their degradation products have anti-nutritive and toxic effects, which limits the use of seeds and seed meals in human and animal feed (Gupta *et al.*, 2012). Because of the importance of phenolic antioxidants in human nutrition and health, the beneficial effects of endogenous bioactive phenolic compounds from plants and oilseeds have gotten a lot of publicity in the last two decades (Mayengbam *et al.*, 2014). The present investigation was carried out to measure these constituents in a set of selected genotypes of mustard.

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MATERIALS AND METHODS

During the *rabi* season, the experiment with thirty-four genotypes/varieties was conducted in a Completely Randomized Design (CRD) with three replications of mustard at Oilseed Research Farm, Kalyanpur, under uniform agronomic conditions (80 kg N+60 kg P_2O_5+60 kg K_2O/ha). Irrigation was given twice to the crop. Before chemical examination, seeds were sun-dried and then oven-dried after harvesting. As defined by AOAC 2020, the oil content in seed was determined using a Soxhlet extraction apparatus and petroleum ether (40-60°) with a boiling point of 40-60°C. After cooling and weighing the oil, the percentage of oil was determined. The test weight was determined by counting one hundred seeds of each variety/genotype and recording their weight on an electronic balance and 1000 seed weight was derived. The moisture percentage was determined as per AOAC (2019). Protein content (fat free) was estimated in mustard seed meal as per Gold (1990). The color of oil was measured at 575 nm using a UV Spectrophotometer. The TES-TAPE system (visible observation) was used to calculate the amount of glucosinolate in seeds, with Keto-Diastix reagent strips used to estimate sugar in urine (Court *et al.,* 1972) and the genotypes were categorized based on the colour intensity [(++++) Very high, (+++) High, (++) Moderate, (+) Low, Trace, (-) No color change]. The total polyphenol content of mustard seed powder was calculated using procedure given by Malik and Singh (1980). The principle of the method used was that in an alkaline medium, phenols react with phosphomolybdic acid in the Folin-Ciocalteau reagent to create a blue-colored complex (Molybdenum blue) which could be quantified and based on that the phenol content could be estimated. Nutritional quality index (NQI) was calculated by method given by Carpenter *et al.* (1976).

RESULTS AND DISCUSSION

The biochemical traits in the current study showed a lot of variation among the different entries tested (Table 1). There was a significant variation in oil content among the genotypes (Table 1), ranging from 33.52-42.15 percent. Oil content was found to be lowest in genotype KMR-17-5 and highest in variety Varuna, respectively. The genotypes TM-108 and TM-179, as well as the varieties Rohini and Urvashi, had oil content of 40.06 percent, 40.16 percent, 40.18 percent, and 40.39 percent, respectively, which was statistically comparable to Varuna. The average oil content was found to be 37.67 per cent. These findings are in line with those of Abul-Fadl *et al.* (2011), Gupta *et al.* (2011), Chowdhury *et al.* (2010) and Singh (2002).

Test weight: The total seed weight of genotypes varied significantly from 2.80 g to 5.80 g with a mean value of 3.80 g (Table 1). The lowest value of 1000 seed weight was found in KMR-18-407, whereas the maximum seed weight was found in Urvashi. The results were consistent with the findings of Gadi *et al.* (2020). The test weight ranged from 3.43g to 6.43g in the Indian mustard variety-Jawar Mustard 02. Mondal and Wahab (2001) reported that the test weight ranged from 2.50 to 2.65 g in the case of improved Toria (B. campestris). According to Mamun *et al.* (2014), toria test weight ranged from 2.90-3.20 g. Reductions in thousand seed weight, oil, protein, and glucosinolate content were linked to lower test weight values. Reduced test weight was linked to an increase in palmitic, stearic, linoleic, and eicosenoic acid, as well as a decrease in linolenic acid content in seed oil. Selection for high test weight stable across environments appears to be a significant selection trait because of its effect on seed quality traits (Velasco *et al.,* 2001).

Moisture content: The data (Table 1) clearly indicated that there was a significant variation in moisture content among the genotypes. The genotype-TM-117 (7.75%) had the highest moisture level, while genotype-KMR-16-304 (2.45%) had the lowest, with a mean value of 4.30 percent. Similar findings were also reported by Manorch and Disody (2006), who reported moisture content ranging from 7.32 to 8.5 percent. Ahmad *et al.* (2012) reported that the moisture content was highest in the *Brassica* genotype-Oscar (7.09 per cent) and the lowest in the Peela Raya variety (4.51 per cent). The moisture content of the different varieties of mustard ranged from 4.1 per cent to 4.52 per cent, as reported by Sharif *et al.* (2017).

Meal protein content: The protein content (Table 1) varied from12.07 percent to 30.09 percent, with an overall mean value of 19.55 percent. TM-117, genotype-KMR-16-302, and genotype-KMR-18-405 were the genotypes with the highest protein content, while genotype-KMR-18-405 had the lowest. Mustard meal has a high protein content of about 40%, according to a nutritional analysis, and the amino acid composition of mustard protein is well balanced (Etten *et al.,* 1967). Defatted mustard meal crude protein is rich in biological value, with significant amounts of albumin, glutelin, and globulin (Klockeman *et al.,* 1997). These results were in line with the earlier reports (Chowdhary *et al.,* 2010; Abul-Fadl *et al.,* 2011).

Glucosinolate: Glucosinolates, anionic sulfur-rich secondary metabolites, have been extensively studied because of their effect on human and animal health. Genotypes such as Ashirwad, KMR-16-308, KMR-16-302, KMR-18-409, KMR-18-405, KMR-15-5, KMR16-5, KMR17-6, Urvashi, Rohini, Varuna, TM-117, TM-108 exhibited trace amounts of glucosinolates, while the genotypes TM-117, TM-108-1, KMR-18-403, KMR-18-404, KMR-18-407, KMR-18-16-303 showed almost no glucosiolates. Kumari *et al.* (2017) found 42.80-79.79 μmol/g in defatted seed meal in *Brassica juncea,* which was in close agreement with our findings. Glucosinolates in fat-free meal in mustard ranged from 60-68 μmol/g as reported by Singh *et al.* (2007).

Total polyphenol content: Polyphenol content ranged from 7.23 mg/100g to 30.85 mg/100g. The mean total phenol content was 15.32 mg/100g. The highest level of polyphenols was found in genotype-TM117, while the lowest level was found in genotype-KMR16-303. This result was similar to that of earlier researchers such as Dubie *et al.* (2013), who found that total polyphenol content varied between 8.53 and 13.79 mg/100g. Brassica vegetables are known for their anti-inflammatory properties and its increase in health has been linked to their antioxidant ability (Singh *et al.,* 2007). Since they are known to act as chemopreventive agents against oxidative stress-induced damage, phenolic compounds have gotten a lot of publicity (Rajamurgana *et al*., 2012)

Nutritional Quality Index (NQI): The data on NQI in Table 1 revealed that the value of NQI ranged from 7.56 to 16.96, with the mean value being 11.75 among the genotypes tested. The genotype KMR-18-406 had the lowest value, while the variety Rohini had the highest. The NQI scoring system was linked to a lower risk of chronic disease and death from any cause (Chiuuve *et al.,* 2011).

Correlation coefficient studies: The moisture content was negatively and non-significantly associated with the test weight value. The amount of protein in a meal was not significant, and it had a negative relationship with moisture content and test weight. Polyphenol content, on the contrary, had a positive and non-significant relationship with moisture content, test weight, and meal protein content. The nutritional quality index was negatively correlated with moisture and oil content, but the relationship was not statistically significant.

Characteristics	Moisture content	Test weight	Meal protein content	Polyphenol content	Oil content
Test weight	0.403951	-	-	-	-
Meal protein content	-0.32708	-0.13725	-	-	-
Polyphenol content	0.430219	0.352397	0.061245	-	-
Oil content	0.503947	0.563102	-0.28572	0.30847	-
Nutritional quality index	-0.00077	0.004018	0.123808	0.023729	-0.23642

Table 1 Oil content and physico-chemical characteristics in the selected promising genotypes of Indian mustard

Genotypes/ varieties	Moisture content (%)	Test weight (g)	Meal protein content (%)	Gluco-Sinolate (µmol/g)	Polyphenol content (mg/100g)	Oil content (%)	Nutritional quality index
TM-117	7.75	4.46	30.09	Trace	30.85	39.22	10.45
TM-108	5.45	5.50	15.45	Trace	11.46	40.06	9.20
TM-106	7.60	4.60	15.63	-	15.08	39.85	13.59
TM-108-1	4.76	3.15	18.83	-	16.87	38.98	14.51
TM-179	4.71	5.24	14.01	Trace	19.46	40.16	8.76
Varuna	6.19	4.85	15.94	Trace	20.80	42.15	10.24
Rohini	6.89	4.55	17.63	Trace	28.59	40.18	16.96
Urvashi	4.21	5.80	15.73	Trace	26.51	40.39	8.97
KMR-17-5	3.22	3.09	25.11	+ +	13.71	33.52	12.89
KMR-17-6	4.08	3.22	25.36	Trace	12.51	35.11	11.05
KMR-16-5	2.89	3.47	26.10	Trace	13.71	36.19	13.49
KMR-16-6	3.06	3.34	14.27	+	15.83	35.12	7.73
KMR-15-5	4.54	3.29	20.77	Trace	29.95	33.78	12.87
KMR-15-6	3.03	3.29	25.60	+ +	11.38	35.79	11.05
KMR-18-401	5.32	3.73	14.72	+	25.95	38.88	12.87
KMR-18-402	4.91	3.05	12.31	+	11.46	36.51	7.84
KMR-18-403	4.15	3.60	13.53	-	16.06	38.12	8.03
KMR-18-404	4.06	3.70	12.31	-	8.66	38.25	10.19
KMR-18-405	4.33	3.43	12.07	Trace	9.46	39.13	9.37
KMR-18-406	4.29	3.56	16.18	+	12.55	36.56	7.56
KMR-18-407	5.35	2.80	13.28	-	9.42	37.15	11.17
KMR-18-408	4.62	3.25	12.80	-	12.40	39.69	8.94
KMR-18-409	3.93	3.80	15.69	Trace	9.25	38.11	10.12
KMR-18-410	4.00	3.75	14.73	+	7.61	36.12	10.20
KMR-16-301	2.85	3.49	34.96	+	8.14	38.16	9.25
KMR-16-302	2.72	3.69	27.27	Trace	10.17	38.16	8.05
KMR-16-303	4.04	3.69	22.71	_	7.23	35.23	9.11
KMR-16-304	2.45	4.04	23.90	+	7.91	33.72	16.80
KMR-16-305	3.78	3.94	21.38	+	13.95	35.23	41.38
KMR-16-306	2.96	3.34	19.53	+	7.68	38.11	15.03
KMR-16-307	3.89	3.84	24.35	+ +	9.42	36.25	10.57
KMR-16-308	2.57	3.84	25.37	Trace	29.80	39.10	8.00
Ashirwad	3.55	3.60	23.42	Trace	11.44	39.68	11.24
Vardan	4.34	3.54	23.74	+	25.80	38.19	12.23
Mean	4.30	3.80	19.55		15.32	37.67	11.75
C.D.	0.26	0.23	1.20		0.93	2.22	0.77
S.E.(±)	0.13	0.08	0.42		0.33	0.78	0.27

Our analysis indicated that the seed meal of Indian mustard genotype TM-117 was qualitatively superior in terms of protein, antioxidant, and glucosinolate, and therefore it could be used as a natural antioxidant in the food industry and as a meal in animal feed.

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Influence of elicitor molecules on chlorophyll content in groundnut plants challenged with stem rot pathogen (*Sclerotium rolfsii*) under greenhouse conditions

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ABSTRACT

Groundnut is an important edible oil crop plant whose quality and yield are greatly affected by biotic and abiotic stress. The process of mechanisms of recovery from stress are also critical to its productivity, but are currently poorly characterized. The present investigation was carried out to understand the ability of different elicitors (piperine, reserpine and β-sitosterol) to induce resistance against stress in groundnut. The chlorophyll content in groundnut leaves was measured using SPAD chlorophyll meter following the seed treatment, foliar application and micro-injection of phytochemicals. The SCMR (SPAD chlorophyll meter reading) of phytochemical-treated plants was found to be more in comparison with the untreated plants. All the three phytochemicals were found to be effective in increasing the chlorophyll content in groundnut leaves. Maximum SCMR (42.14) was observed in plants treated with piperine through foliar application method.

Keywords: Chlorophyll content, Groundnut leaves, Phytochemical

Groundnut is called the 'King' of oilseeds. It is one of the most important food and cash crops of our country. Groundnut is also called 'wonder nut' and 'poor man's cashew nut'. It is a low priced commodity, but a valuable source of all the nutrients. Seeds are a rich source of oil (35-56%), protein (25-30%), carbohydrates (9.5-19.0%), minerals (P, Ca, Mg and K) and vitamins (E, K and B) (Gulluoglu *et al.,* 2016). It is cultivated throughout tropical, subtropical and warm temperate regions of the world. The major groundnut producing countries in the world are India, China, Nigeria, Senegal, Sudan, Burma and the United States of America (Madhusudhana, 2013). India occupies the first place, with respect to both the area and the production in the world. In India, groundnut is mostly grown in five states *viz.,* Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka and Maharashtra, which accounts for 80 per cent of the total area and production of groundnut (Reddy, 1992). In Telangana, groundnut is cultivated in an area of 1.7 lakh ha with an annual production of 3.5 lakh tonnes and productivity of 2114 kg/ha. The leading groundnut growing districts in Telangana are Nagarkurnool, Wanaparthi, Mahbubnagar, Gadwal, Mahaboobabad, Vikarabad, Suryapet and Nalgonda (USDA, 2020). Due to the residual problem and toxicity to the living environment, chemical pesticides are not suitable for crop production. Therefore, products of plant origin have recently gained enormous importance in the quest to develop better alternatives to chemical pesticides (Arun *et al.,* 2010; Peita *et al.,* 2005; Pastucha, 2008; Lucas., 2012; Raja and Masresha, 2015). Medicinal plants are being used in many ways. This includes isolating and defining secondary plant-generated metabolites, which are used in medicinal preparations as active principles (Taylor *et al.,* 2001). Plants have limitless ability to synthesize aromatic secondary metabolites, most of which are phenols or their oxygen-substituted derivatives (Geissman, 1963). The so-called secondary metabolites contribute greatly to unique plant odors, tastes and colours. Such constituents (phytochemicals) include alkaloids, flavonoids, saponins, tannins, phenols, terpenoids, glycosides, anthraquinones, coumarins, polyphenols, phlobatannins and steroids.

In all organisms, reactive oxygen species (ROS), such as O_2 and hydrogen peroxide (H_2O_2), are formed as by-products of normal, unstressed cellular metabolism. In plants, respiratory and photosynthetic processes responsible for this production take place in several organelles, including mitochondria and chloroplasts (Wojtaszek, 1997; Grene, 2002). The photosynthetic electron transport system, a major source of ROS in plants, resides in the thylakoid membranes of chloroplasts (Foyer *et al.,* 1994). Several forms of biotic and abiotic stress, such as pathogen attack or excess light (Karpinski *et al.,* 2003) can damage plant tissues. This in turn may result in the release of chlorophyll from the thylakoid membranes. In such a situation, the chlorophyll

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needs to be degraded quickly to avoid cellular damage by their photodynamic action (Takamiya *et al.,* 2000). Thus, failure in chlorophyll degradation can increase the amount of ROS produced to an extent where the detoxification capacity of the antioxidant systems may be overridden. The toxic molecules formed may result in damage of the organelle and in cell death, or they may act as cellular signals (Foyer *et al.,* 1994; Wojtaszek, 1997). It is therefore crucial that the breakdown of chlorophyll is both efficient and tightly regulated (Hendry *et al.,* 1987; Matile and Hörtensteiner, 1999; Takamiya *et al.,* 2000). The present study was conducted to know the effect of phytochemicals on chlorophyll content of groundnut leaves in healthy as well as in stem rot pathogen inoculated and fungicide treated plants.

MATERIALS AND METHODS

Isolation of the pathogen: Isolation of the pathogen *S. rolfsii* from the stem rot infected groundnut plants was carried out by the tissue segment method under aseptic conditions (Aneja, 2003). Briefly, groundnut stem parts containing both the diseased and healthy tissue were cut into small bits with the help of a sterile scalpel. The bits were then surface sterilized by immersing in 1 per cent sodium hypochlorite for one minute followed by washing with three changes of sterile water and dried by blotting on sterile paper towels. The sterilized bits were transferred to PDA plates under aseptic conditions and incubated at 25 ± 2°C for 3-4 days (Ali *et al.,* 2006). The fungal growth emerging from diseased tissues was transferred to PDA plates with sterilized needle under aseptic conditions and pure culture with light brown sclerotia was obtained.

Phytochemicals: Phytochemicals used in the present study were Piperine, Reserpine and β-Sitosterol. They were procured from Department of Pharmacy, Birla Institute of Technology and Science, Pilani-Hyderabad. Solubility of these phytochemicals was tested in different solvents such as water, ethanol, methanol, methanol + chloroform.

Groundnut variety Kadiri-6 (K -6) was used for the evaluation of the effect of phytochemicals (Piperine, Reserpine and β-Sitosterol) on chlorophyll content of groundnut leaves. Seeds were sown in polythene covers (12 × 09 cm) containing sterile soil at the rate of 5 seeds per pot in a glass house. The potential phytochemicals were applied in three methods: seed treatment, foliar spray and microinjection.

Seed treatment with phytochemicals was done prior to sowing. Five ml of phytochemical solution @ 2000 ppm concentration was prepared by dissolving 10 mg of phytochemical in 5 ml of solvent. Seeds were treated with the suspension of phytochemicals for 30 minutes, air dried and sown.

Foliar application was performed on 4-week-old plants (Ameer *et al.,* 2006). For foliar spray, the phytochemical was sprayed on leaves of the plant. 5 ml of phytochemical solution was used for spraying on each plant. In microinjection method, 25 µl of phytochemical was injected at the stem region of each plant using a microsyringe.

In all the above experiments, the following treatments were maintained (n=4) (i) Healthy (ii) *S. rolfsii* challenged (iii) Piperine sprayed @ 2000 ppm, (iv) Reserpine sprayed @ 2000 ppm (v) β-Sitosterol sprayed @ 2000 ppm (vi) Piperine sprayed @ 2000 ppm and challenged with *S. rolfsii* (vii) Reserpine sprayed @ 2000 ppm and challenged with *S. rolfsii* (viii) β-Sitosterol sprayed @ 2000 ppm and challenged with *S. rolfsii* (ix) Propiconazole sprayed @ 0.1% (x) Propiconazole sprayed @ 0.1% and challenged with *S. rolfsii*. During the experiment, *S. rolfsii* was inoculated near the stem region of 4-week old plants with a mycelia block/disc. The inoculated plants were used for determination of chlorophyll content. Further, the plants were observed for the development of the symptom and disease scoring.

Chlorophyll measurement: Chlorophyll content of groundnut leaves, after the seed treatment, foliar application and microinjection of phytochemicals, was measured after 45, 60 and 75 days after challenging with or without *S. rolfsii* according to the method given by Falke *et al.* (2019). Chlorophyll content was measured in the upper, middle and lower leaves by using SPAD chlorophyll meter to record on each leaflet of the tetrafoliate leaf beside the midrib. Care was taken to ensure that the SPAD meter sensor fully covered the leaf lamina and the interference from veins and midribs was avoided.

RESULTS AND DISCUSSION

Leaf chlorophyll content (SCMR) was recorded using SPAD chlorophyll meter on the upper, middle and lower leaves from the top on the main stem of five randomly selected plants in each treatment. The SCMR was recorded on 45th, 60th and 75th day following treatment with phytochemicals and challenged with or without *S. rolfsii* and the results are presented in Table 1.

The SCMR of phytochemical-treated plants was recorded to be more in comparison with the untreated plants. All the three phytochemicals were found to be effective in increasing the chlorophyll content of groundnut leaves. Maximum SCMR was observed in plants treated with the piperine by foliar application method in all the three stages of observation.

On the 45th day, the chlorophyll reading in plants treated with seed treatment of phytochemicals was found to be less when compared with foliar application and micro-injection. Highest chlorophyll reading was observed in foliar application of piperine followed by micro-injection. Upper leaves were observed to have more chlorophyll content followed by the lower leaves and then the middle leaves. Similar trend of SCMR was observed in the groundnut plants on 60th day. Maximum chlorophyll content was observed in plants treated with foliar application of piperine. Minimum chlorophyll content was recorded in lower leaves and also in seed treated plants. The SCMR of groundnut plants on 75th day was similar to the reading at 45 and 60 days samples. Maximum chlorophyll content was recorded in the foliar application of phytochemicals followed by micro-injection and seed treatment methods. Upper leaves showed more chlorophyll content followed by middle and lower leaves. All the three phytochemicals were effective in reducing the disease incidence in inoculated groundnut plants and a slight variation in PDI among the three methods of inoculation was observed.

Table 1 Chlorophyll content of groundnut leaves following seed treatment, foliar application and microinjection of phytochemicals at 45, 60 and 75 days old plants challenged with or without *S. rolfsii*

Treatment	Chlorophyll (SPAD units)								
	Days after sowing								
	45			60			75		
	Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper
Healthy / control	40.82	20.91	37.78	46.3	23.65	43.22	49.46	47.44	47.06
Only *S. rolfsii*	40.62	21.31	39.08	41.98	21.99	42.64	44.36	44.62	47.74
Propiconazole @ 0.1 %	37.68	20.34	37.36	37.34	20.17	41.4	41.34	41.4	43.14
Propiconazole @ 0.1 % + *S. rolfsii*	37.06	20.53	38.06	38.22	21.11	40.42	41.32	40.92	43.18
Piperine @ 2000 ppm seed treatment	35.02	20.01	39.16	33.52	19.26	41.22	41.5	43	40.34
Reserpine @ 2000 ppm seed treatment	31.86	18.93	35.88	34.94	20.47	36.36	35.54	37.42	37.92
β-Sitosterol @2000 ppm seed treatment	36	21.5	40.14	38.32	22.66	38.36	40.02	44.98	42.16
Piperine @ 2000 ppm foliar application	42.14	25.07	44.86	47.34	27.67	50.52	41.9	44.82	47.22
Reserpine @ 2000 ppm foliar application	39.68	24.34	43.2	41.66	25.33	50.86	42.28	42.4	45.38
β-Sitosterol @ 2000 ppm foliar application	38.46	24.23	43.84	44.88	27.44	45.62	40.04	42.68	45.62
Piperine @ 2000 ppm micro injection	39.5	25.25	44.4	45.72	28.36	47.08	42.16	42.12	44.26
Reserpine @ 2000 ppm micro-injection	40.94	26.47	42.98	40.96	26.48	47.48	42.84	46.42	45.8
β-Sitosterol @ 2000 ppm micro-injection	36.4	24.7	43.28	40.4	26.7	47.6	40.78	41.74	45.36
Piperine @ 2000 ppm seed treatment + *S. rolfsii*	40.74	27.37	42.72	44.12	29.06	45.36	46.18	48.46	47.24
Reserpine @ 2000 ppm seed treatment+ *S. rolfsii*	35.5	25.25	36.6	35.76	25.38	38.66	37.96	37.02	40.34
β-Sitosterol @ 2000 ppm seed treatment+ *S. rolfsii*	38.74	27.37	39.56	41.02	28.51	39.06	44.4	45.12	42.66
Piperine @ 2000 ppm foliar application+ *S. rolfsii*	36.16	26.58	36.74	39.5	28.25	39.84	42.26	41.76	42.9
Reserpine @ 2000 ppm foliar application+ *S. rolfsii*	34.7	26.35	38.06	40.58	29.29	40.7	45.5	40.64	43.28
Piperine @ 2000 ppm micro-injection + *S. rolfsii*	37.14	28.57	40.88	38.9	29.45	42.08	40.52	43.26	43.6
Reserpine @ 2000 ppm micro-injection + *S. rolfsii*	39.5	30.25	43.82	37.28	29.14	40.24	40.18	41.54	42.38
β-Sitosterol @ 2000 ppm micro-injection + *S. rolfsii*	39.74	30.87	41.68	42.38	32.19	41.98	43.00	43.82	45.08
CD	5.24	3.28	4.30	4.37	6.14	3.48	3.25	2.92	3.23
SE(m)	1.86	1.16	1.52	1.55	2.18	1.23	1.15	1.04	1.62
SE(d)	2.63	1.65	2.16	2.20	3.08	1.75	1.63	1.47	1.62

The results clearly showed that the chlorophyll content of phytochemical-treated plants was more in comparison with non treated plants and plants treated with fungicide and pathogen. Phytochemicals increased the chlorophyll content of treated plants. It was also observed that, foliar application method was superior to seed treatment and micro-injection in increasing the chlorophyll content. The phytochemical piperine was found to be more effective in enhancing the chlorophyll content of treated groundnut leaves.

Photosynthesis, pathogen infection, and plant defense related signaling molecules or their precursors are generated in the chloroplast and these signals crosstalk and regulate photosynthesis and plant defense. Chloroplast-targeted effectors and phytotoxins produced by elicitors applied, manipulate chloroplastic functions, especially photosynthesis to suppress the plant defense and promote pathogenicity. Chloroplast plays a central role in the interplay between photosynthesis, pathogen infection, and plant defense. Plant defense is also regulated by photorespiration and light. The roles of photorespiration and photoreceptors in plant defense, had been reviewed by Kangasjärvi *et al.* (2012) and Ballaré (2014).

Arunyanark *et al.* (2008) reported that stability in peanut chlorophyll content was related to drought tolerance due to the ability to keep constant biomass production, despite unfavorable conditions. Our findings revealed that chlorophyll content maintained unaltered, and this may be related to a higher root biomass production to increase its exploratory surface in order to improve water uptake. Besides, chlorophyll content may allow plants to deliver sufficient energy to deal with the energy-consuming adaptations to stress. Another possibility is that chlorophyll has a role in control of redox homoeostasis, that is, it participates in heat dissipation of excess excitation energy within light-collecting chlorophyll and the carotenoid-binding protein complexes of photosystem (PS) II, which are considered as major photo protective mechanisms.

Currently, phytochemicals mediated ISR has received considerable attention as a sustainable approach to manage pests and disease and these chemicals are more ecologically sustainable than the use of synthetic fungicides. Besides phenolic compounds, there are several other phytochemical-mediated plant metabolites like pathogen-related (PR) proteins and defense enzymes that have been found to be associated with the induction of resistance in the host as many of them are found to be antifungal (Ameer et al., 2016). The present study is an initiative and it helps in understanding and employing phytochemicals which are useful components of integrated management of soil borne diseases of groundnut. The results obtained in this investigation have demonstrated that plant based phytochemicals could be exploited for management of diseases on a commercial scale as they are safe, effective and persistent alternative to chemical pesticides.

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Crop management and socio-economic determinants of soybean yield variability in Central India: a regression tree approach

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ABSTRACT

Crop management, socio-economic, environmental and soil quality factors play a pivotal role in enhancing crop productivity. Variation in crop productivity among farmers under real farm situations was observed. Therefore, the premise of this study is to investigate the relative importance of these factors in determining soybean yield variability across farms in the villages of Madhya Pradesh state in Central India. Data were collected using the personal interview of 376 randomly selected farmers, conducted in eight villages of four districts. Crop input application and management practices followed and yield data are presented as mean data and correlations, and individual farmer's information is represented by regression tree (RT) analysis to unravel the associations between crop management, socio-economic and soil variability and soybean yield, and the technical efficiency (TE) measure. Soybean yield realized by sample farmers varied widely from 5 to 28 q/ha. RT analysis showed that yield variability across farmers was affected by multiple and interacting production and socio-economic constraints such as extension contact and source of information, use of plant nutrients and soil amendments, seed rate and treatment, plant density, pests and disease management, land topography and soil fertility, labour and capital management. Technical efficiency analysis suggested that optimal use of farm inputs and the elimination of socio-economic and structural constraints can improve efficiency in soybean production. In conclusion, the analysis results suggested that the farm yield variability can be reduced by adjusting crop management practices of low yielding farms through integrated and targeted extension approaches.

Keywords: Determinants, Regression tree, Technical efficiency, Yield variability

Growing global demand for food necessitates increased crop productivity (Godfray *et al*., 2010) to ensure food security. The importance of edible oils in human dietary needs is of paramount importance to provide an active and healthy life. Domestic demand for edible oils in India is consistently rising owing to the ever-increasing population as well as increasing per capita income leading to improvement in living standards (Birthal *et al*., 2010; Gowda *et al*., 2009). The demand for edible oils in India is projected to be 21.3 m.t. by 2030 (Kumar *et al*., 2016). Meeting the ever-increasing demand for edible oils continues to pose a major challenge, as the chances of area expansion under oilseeds are negligible. Enhancing the average productivity realization from oilseeds cultivation would not only increase the supply of edible oils, but would also affect the consumer price and thus its consumption.

Soybean in India, introduced for commercial cultivation during the early 1970s, has established itself as a leading oilseed crop of the country grown during the rainy season. While area and production had shown unparallel growth in the past five decades, productivity growth was not so impressive and skewed. The increase in area was mainly due to the economic superiority of the crop over other competing crops and the adoption of soybean in place of keeping it fallow during the rainy season (Chand 2007; Sharma *et al.,* 2015; Sharma, 2016a). Although the productivity of soybean in India has more than tripled from mere 4.3 q/ha during the early 1970s to 13.5 q/ha recently, there exists a large yield gap across production regions (Bhatia *et al*., 2008; Billore *et al*., 2009b). The large yield gaps are mainly due to variations in crop management practices followed, resource endowments, climate, soil, institutional and socio-economic factors (Bhatia *et al*., 2008; Jha *et al*., 2011). There is a considerable potential to bridge the yield gap between the actual and potential yield through the adoption of appropriate improved resource management strategies. Bridging the yield gap or improving the average productivity realization would not only enhance the domestic availability of edible oils in the country but also increase farm efficiency and profitability (Sharma, 2018).

Soybean is predominantly grown in Central India (contributing >90% area and production), mainly in the state of Madhya Pradesh (accounting for ~ 50% of area and production), on *Vertisols* and associated soils. These soils are characterized by poor infiltration, poor drainage, excessive run-off and soil loss, and depletion/loss of nutrients and soil biota (Wani *et al*., 2016). These soils are potentially productive, if managed properly in terms of overcoming soil, water and nutrient management constraints. Currently, these soils have low and variable crop productivity. Due to

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inappropriate soil, water and crop management practices, crop canopy development is slow and poor which results in continuous degradation of soil.

Considerable yield variations often exist not only across districts but also among adjacent fields managed by different growers. Thus, improvement in yields in low-yielding farms through adjustments in crop management practices or targeted extension approaches would make an important contribution in enhancing efficiency and increasing oilseeds production especially soybean to keep up with growing edible oil demand. Identification of various crop management and socio-economic factors behind yield variability helps to analyze the reasons for variation in performance and in developing specific strategies for future growth and development.

Although, research and extension efforts for increasing and sustaining soybean productivity in India have effectively focused on overcoming abiotic, biotic and agronomic management constraints individually (Agarwal *et al*., 2013; Sharma *et al*., 2016a), comparatively less attention was given to socio-economic constraints and their interactions with these factors. Assessing the relative importance of these factors determining the yield variability and its gap is indispensable to target technical interventions and advice to farmers. For the comprehensive diagnosis of crop yield variability, it is imperative to assess the interactions and impact of crop management, socio-economic, environmental and soil-related factors.

To relate yield variability to agronomic and other factors, many researchers used correlation, regression, principal component analysis, or cluster analysis. The data collected through farm surveys contain continuous, discrete, and categorical variables, and are often highly skewed. To deal with the non-linear relationships, multivariate analysis essential to predict the multiple interactions between target and explanatory variables (Tsien *et al*., 1998). Some studies have used classification and regression tree (CART) analysis to deal with such complexities (Tittonell *et al*., 2008; Zheng *et al*., 2009; Delmotte *et al*., 2011). CART aims to explain the response of a categorical variable (classification tree) or a continuous variable (regression tree) from a set of explanatory variables using binary recursive partitioning rules (Breiman *et al*., 1984; Steinberg and Colla, 1997). In terms of target and explanatory variables, CART categorizes groups of observations that are homogeneous and can be analyzed individually and comparatively.

The adoption of improved crop production technologies improves the welfare of rural households by increasing income and thus, reduces poverty (Asfaw *et al*., 2012; de Janvery and Sadoulet, 2001). The studies reported moderate adoption of best crop management practices by farmers of Madhya Pradesh (Dupare *et al*., 2011; Sharma *et al*., 2018) leading to low crop productivity. The farmers' ability for crop yield improvement and optimization of economic returns depends on the efficient adoption of crop management practices (Sharma *et al*., 2018; Thiam *et al*., 2001). Enhancing the technical efficiency, the ability of a decision-making unit (such as a farm) to produce maximum possible output with a given set of inputs and technology (Kalirajan and Shand, 1994; Coelli *et al*., 2005), is important to enhance the potential benefits from existing technology, rather than considering new technology (Kalirajan *et al*., 1996) which is time-consuming, for its effective adoption. Very few studies were conducted to analyze the farm-specific technical efficiency of soybean growers in India. In this study, we compared the key practices underlining soybean production in four districts of Madhya Pradesh. With this approach, we intend to identify the opportunities, wherein, soybean growers in Madhya Pradesh can be responsive to technological changes and hitherto will help plan specific targeted extension activities to be carried out.

There is a dearth of research studies covering this aspect and the factors affecting the yield variation at the farmers' level. Thus, this study was undertaken to understand the level of yield variation across farms, the efficiency of soybean production and determining factors.

MATERIALS AND METHODS

Farm survey: The study is mainly based on the primary data collected from selected farmers through the personal interview method for the crop year 2016-17 using a pre-structured and pre-tested interview schedule designed specifically for this purpose. A multi-stage random sampling method was used for sample selection. At the first stage, four major soybean producing districts, namely Indore, Dewas, Jhabua, and Ratlam from Malwa plateau in Central India, were randomly selected from top producing districts in the state. At the second stage, one leading soybean producing tehsil was selected from each district in consultation with district-level officials of the Agriculture Department, Government of Madhya Pradesh, India. From each tehsil, two villages were selected in consultation with block-level Agricultural officers. After drawing a list of soybean growing farmers in each selected village, 20 percent of the farmers were selected randomly using the nth sampling method. In total, 376 farmers have been surveyed through the personal interview method with the help of a pre-tested questionnaire.

Regression tree analysis: The Regression tree (RT) analysis (Breiman *et al*., 1984; De'ath and Fabricius, 2000) was used to determine the primary associations between soybean yield and variables related to crop management, soil and socio-economic factors. The RT is a nonparametric modelling approach and the main aim of the model is to explain the responses of a dependent variable (Y-variable) from a set of independent continuous or categorical variables

(X-variables). The RT model recursively partitions the data into subsets and helps in finding increasing homogeneity based on independent variable splitting criteria using variance minimizing algorithms. The dependent variable data are split into a series of descending left and right child nodes derived from parent nodes (Breiman *et al.*, 1984). The partitioning process stops when no X-variables provide any additional information at the end nodes, designated as terminal nodes (Harding and Payne, 2012).

The least square method of regression tree was used in this study to predict yield responses to interventions such as crop management, environmental and socio-economic variables. Variables such as farmers' perception of soil fertility and land topography recorded during the farmer's survey were included as a proxy variable representing environmental or soil-related variables. Following Tittonell *et al.* (2008), the optimum regression tree was selected, within one standard deviation of the minimum relative error, through 10 fold cross-validation. The relative error of the regression model decreases with the increase in terminal nodes and beyond a certain number of terminal nodes the relative error may increase again, as adding a new explanatory variable does not improve the model (Delmotte *et al.*, 2011). In the present study, the Y-variable is soybean yield and X-variables include continuous variables, ordered categorical variables and unordered categorical variables (Table 1). Although variety is an important determinant in soybean yield variability, is not included as a variable in RT due inconsistency in responses by farmers on this variable.

Technical efficiency: Technical efficiency is one of the measures of overall resource use efficiency and is the ratio of actual output to its own maximum possible frontier output of farm units for a given level of inputs and the chosen technology and the variation in its efficiency levels is determined by production environment in which a farm operates (Kalirajan and Shand 1994). Coelli *et al.* (2005) proposed a stochastic frontier model taking into consideration the influence of uncontrollable exogenous shocks in the estimation process. For the present study, a stochastic frontier production function model was used. We used the computer program FRONTIER Version 4.1 (Coelli, 1996) to estimate TE based on a Cobb-Douglas production function (Aigner and Chu, 1968) using the data collected from selected farmers.

The farm-level technical efficiency can be estimated through a stochastic frontier production function model (Sharma *et al.*, 2016b) of the form:

$$Y_i = f(x_i;\ \beta) + \varepsilon_i i = 1,2,\ldots\ldots\ldots n \qquad (1)$$

$$\varepsilon = v_i - u_i \qquad (2)$$

Where, Y_i represents the output level of the i^{th} soybean farmer; $f(x_i;\ \beta)$is a function such as Cobb-Douglas or translog production function of vector, x_i denoting the actual inputs used by i^{th} farmer, and vector β of unknown parameters. The ε is the error term that is composed of two elements; v_i is the symmetric disturbances assumed to be identically, independently and normally distributed as N (0, σ^2_v) which is associated with random factors, u_i denotes a non-negative random variable associated with farm-specific factors, which hinders the i^{th} farm from attaining maximum efficiency (technical inefficiency); and N represents the number of farms included in the cross-sectional survey. The Maximum Likelihood Estimation (MLE) method enables us to obtain the maximum possible output function (Battese and Coelli, 1995). The technical efficiency of the individual farm was worked out using formula (3):

$$TE = Yi/Yi^* \qquad (3)$$

Where, Yi* is the frontier yield and Yi is the actual yield.

The variables included in the model and the analysis results are presented in annex table 3.

RESULTS AND DISCUSSION

Soybean yield variations at farm fields: Soybean yield of the sample farmers varied between 5 to 28 q/ha, with a mean yield of 15.32 q/ha and a standard deviation of 4.36 (Fig. 1). Of the total 376 farmers under this study, 35 farmers realized soybean yield of lesser than 10 q/ha, 120 farmers produced 10-15 q/ha, 149 farmers realized 15-20 q/ha, 64 farmers achieved 20-25 q/ha, and only 8 farmers produced more than 25 q/ha of soybean. Among the districts, the highest average soybean yield was observed in Jhabua (16.98 q/ha), followed by Indore (15.57 q/ha), Ratlam (14.87 q/ha) and lowest in Dewas (13.50 q/ha). Jhabua district is mainly dominated by a tribal population largely dependent on farming and agriculture labour. Although, the yield difference between districts was not too wide, however across farmers the yield difference was found to be wide. Tribal farmers on an average applied 41 kg/ha N, 42.7 kg/ha P and 7.5 kg/ha K nutrients as against 25 kg, 49 kg and 16.2 kg/ha by other farmers. Tribal farmers used higher human labour (290 man days/ha) as compared to other farmers (216 man days/ha).

Socio-economic factors, crop management practices and soybean yield variability: The average age of respondents was 47 years and had on an average 29 years of experience in farming and the majority of them were either illiterate or educated only up to middle standard (Table 2). There was no significant effect of education on soybean yield realization (Table 2), as there was not much difference in yield realization across education classes. A perusal of the data on yield class shows that majority of the farmers with higher than or equal to 20 q/ha yield were either illiterate or educated up to middle standard. The farmers belonging to the ethnic origin of a scheduled caste or scheduled tribe achieved the highest average soybean yield followed by farmers belonging to other backward castes and general category.

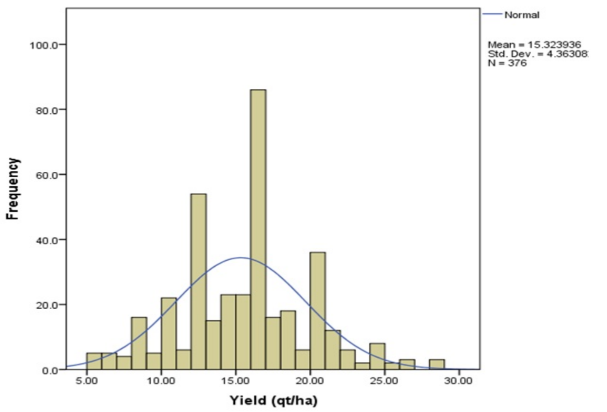

Fig. 1. Histogram of soybean yield realized by selected farmers

Soybean farmers applied on an average less than the recommended inorganic fertilizers coupled with higher seed rate leading to lower yield realization. The rate of application of inorganic phosphorous (P) and potassium (K), and farm yard manure (FYM) was significantly and positively correlated with the soybean yield (Table 3). Seed rate was negatively correlated with soybean yield. Seed treatment with *Bradyrhizobium japonicum* and phosphorus solubilizing bacteria is highly recommended for soybean cultivation, and adoption of the practice by farmers was significantly correlated with the crop yield. Planting of soybean on recommended row-to-row spacing or maintaining optimum plant geometry led to higher yield realization. Since more than half of the farmers use farm-saved seed and do not perform germination test before sowing, they tend to use higher than recommended seed rate to ensure proper germination/ plant population, presuming that adverse rainfall at sowing may affect plant population. Many of them try to maintain recommended plant geometry for enabling manual inter-cultural operations. About two-fifth of the farmers do not insulate crop from soil and seed-borne diseases through seed treatment before sowing resulting in lower crop productivity at their fields (average 13.62 q/ha) as compared to that treated seed before sowing (16.57 q/ha).

Deep summer ploughing once in three years is recommended to facilitate solar disinfection, degradation of crop residues, weed control, improve infiltration/ permeability to conserve rainwater in the soil profile and improve groundwater. Nearly 70 per cent of the farmers follow deep summer ploughing once in three years and were able to attain higher soybean yield (Table 2). The use of human labour and mechanical power for different operations in soybean crop was found to be significantly correlated with the crop yield realization. On average, about 243 hours of human labour was employed per hectare in soybean cultivation and 10.5 hours of machine power for different operations (Table 3). The majority of the farmers spray herbicides at the rate of about 0.7 kg/ha, mainly either at the pre-emergence or post-emergence stage. To control insect or disease infestation, farmers used plant protection chemicals as recommended or even non-recommended chemicals and many a time ritual 2-3 sprays were carried out by the farmers, irrespective of the incidence of the pest. However, the application of plant protection chemicals and herbicides was found to be significantly and positively correlated with soybean yield. Agricultural output market and input shops were located at an average distance of 20 km and 10 km, respectively from homestead and output market distance turned out to be positively correlated with the soybean yield.

The relationship between some of the continuous variables and soybean yield was found to be significant (Table 5). Although for many of the variables, it was difficult to arrive at a statistically significant relationship with soybean yield, indicating the predominance of a complex multi-dimensional system in a multivariate system. Input use pattern in the cultivation of soybean by selected farmers classified as per different yield groups revealed that farmers with low soybean yield used higher seed rate than the recommended quantity. The farmers with higher soybean yield applied, on average, a recommended amount of productive and protective inputs such as plant nutrients, farmyard manure, protective irrigation, seed treatment, and pest and disease management. Average soybean yield realization at the high yield class was found to be nearly three times higher as compared to the low yield group. The investment in soybean cultivation increases with the increase in yield realization and turned out to be significantly affecting the yield realization.

Regression tree

Crop management and soybean yield: To determine the contribution of crop management practices and identify the important agronomic practices followed by farmers, we fitted a regression tree for soybean yield against all the crop management variables. The variables considered for analysis under crop management practices were; summer deep ploughing done once in three years, the number of tillage operations done, seed rate used in kg/ha, the quantity of N, P, K and S nutrients applied in kg/ha, farmyard manure applied (t/ha), herbicides and plant protection chemicals applied (kg/ha), seed treatment, row to row/ plant to plant spacing maintained (plant geometry) and protective irrigation applied. The regression tree of soybean yield as a function of crop management variables with minimum relative error explained 63.8 per cent variation in productivity across farms and yielded nine splitting nodes and 11 terminal nodes (Fig. 2).

Table 1 Variables used in the regression tree model

Variables	Description
Crop management	
Tillage	Number of tillage done before sowing
Nitrogen	Amount of nitrogen applied through inorganic fertilizers (kg/ha)
Phosphorous	Amount of phosphorous applied through inorganic fertilizers (kg/ha)
Potassium	Amount of potash applied through inorganic fertilizers (kg/ha)
Sulphur	Amount of sulphur applied through inorganic fertilizers (kg/ha)
FYM	Farm yard manure applied (t/ha)
RxR	Spacing between two rows of soybean (1=Optimum, 2= Dense and 3= Very dense)
Seed rate	Quantity of soybean seed used (kg/ha)
Seed treatment	Seed treatment before sowing (1= yes, 0= no)
Herbicide	Active ingredients of herbicides used (kg/ha)
PP Chemicals	Active ingredients of plant protection chemicals used (kg/ha)
Human labour	Total family and hired labour used for all operations related to soybean cultivation (man hour/ha)
Machine power	Total machine hours used for all operations related to soybean cultivation (hour/ha)
Deep ploughing	Summer deep ploughing once in three years (1= yes, 0= no)
Double sowing	Re-sowing of seed (1= yes, 0= no)
Irrigation	Number of irrigations applied in case of dry spell (number)
Environment/ Soil related	
Topography	Whether the land is 'level' or 'undulated' as perceived by the respondent (1=Level, 2=Undulated, 3=Slopy)
Fertility status	Perceived fertility level of farm land (3=Good; 2= Average; 1=Poor)
Soil depth	Depth of soil (3=Deep, 2=Medium, 1=Shallow)
Parcels	Number of land parcels
Socio-Economic and other variables	
Age	Age of the head of farm household (years)
Experience	Number of years the farm family is engaged in crop cultivation (years)
Family members	Number of members in a farm family (Absolute number of members)
Extension contact	Have regular extension contact (1= yes; 0= otherwise)
Extension source	Extension contact with (5= extension personnel, 4=KVK/ college/ res. institute, 3= TV/ mobile/ radio; 2= input shop/private; 1= other farmers, 0= no contact)
Seed source	Seed procured from (government = 3; private = 2; own = 1)
Distance to plot	Distance from home to farm plots (km)
Distance to input dealers	Distance from home to input shop (km)
Distance to market	Distance from home to output market (km)
Soybean yield	Production of soybean per unit area (quintal/ha)

Table 2 Background categorical variables and soybean yield analysis

Variables	Frequency Distribution (N=376)		Av. Yield (q/ha)[a]	p value (t/F significance)
	Class	Frequency (%)		
Education	Illiterate	90 (23.9)	15.47±4.95	0.865
	Up to 8th	166 (44.2)	15.16±4.28	
	Up to 12th	100 (26.6)	15.34±3.96	
	Above 12th	20 (5.3)	15.93±4.39	
Category	General	57 (15.2)	13.98±4.53	0.008
	OBC	182 (48.4)	15.18±3.72	
	SC/ST	137 (36.4)	16.07±4.92	
Extension contact	Yes	316 (84.0)	16.28±3.90	0.000
	No	60 (16.0)	10.30±2.97	
Extension/ Knowledge source	Extension personnel	110 (29.3)	17.03±2.90	0.000
	KVK/ Res. Institutes	117 (31.1)	18.47±3.45	
	Television and mobile phone	20 (5.3)	14.95±2.51	
	Private	47 (12.5)	11.65±2.24	
	Other Farmers	22 (5.9)	11.95±2.51	
	No	60 (16.0)	10.30±2.97	
Soil depth	Shallow	97 (25.8)	12.44±3.45	0.000
	Medium	111 (29.5)	16.71±4.58	
	Deep	168 (44.7)	16.07±3.92	
Land topography	Undulated	50 (13.3)	10.20±2.43	0.000
	Slope	87 (23.1)	14.88±3.60	
	Level	239 (63.6)	16.56±4.12	
Soil Fertility	Poor	83 (22.1)	10.93±2.95	0.000
	Average	112 (29.8)	15.23±3.74	
	Good	181 (48.1)	17.40±3.72	
Deep summer ploughing	Yes	265 (70.5)	16.67±3.96	0.000
	No	111 (29.5)	12.11±3.51	
Seed Source	Government/ Cooperative	80 (21.3)	20.57±3.41	0.000
	Private	96 (25.5)	15.86±3.08	
	Farm saved	200 (53.2)	12.97±3.15	
Plant geometry	Optimum	151 (40.2)	18.41±3.39	0.000
	Dense	98 (26.1)	15.93±2.88	
	Very Dense	127 (33.7)	11.19±2.77	
Seed treatment	Yes	217 (57.7)	16.57±4.23	0.000
	No	159 (42.3)	13.62±3.96	
Double sowing	Yes	86 (22.9)	11.25±3.05	0.000
	No	290 (77.1)	16.53±3.94	
Herbicide application	Yes	322 (85.6)	15.59±4.31	0.004
	No	54 (14.4)	13.76±4.38	

[a] Average yield (q/ha) ± Standard Deviation. 1 quintal (q) = 100 kilograms

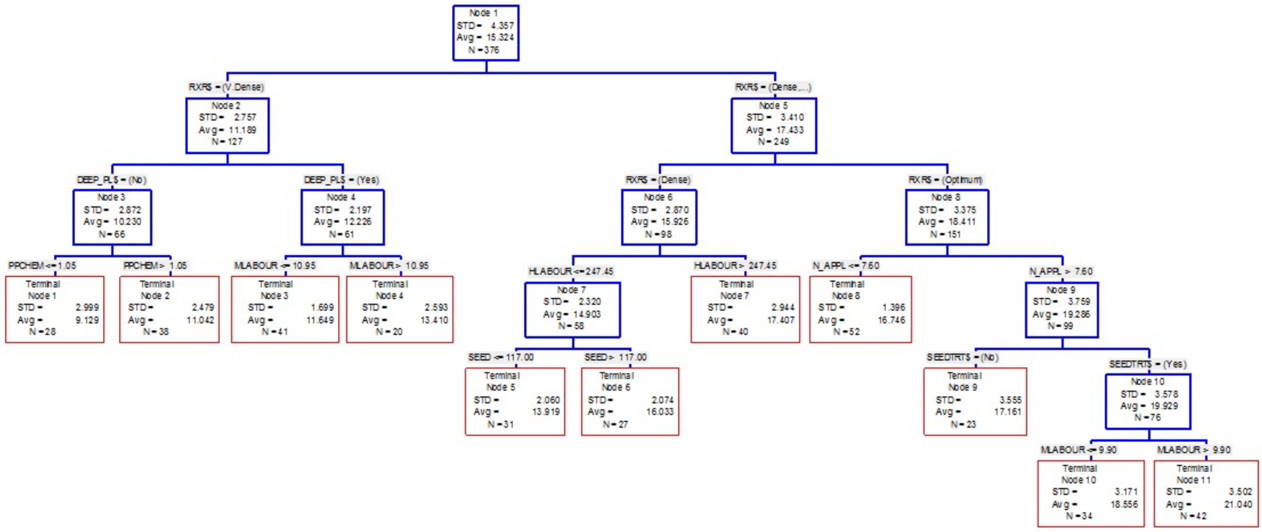

Fig. 2. Regression tree predicting soybean yield from crop management variables. In each node box, average yield, standard deviation, and the number of farmers (N) were shown and node number was marked in each box

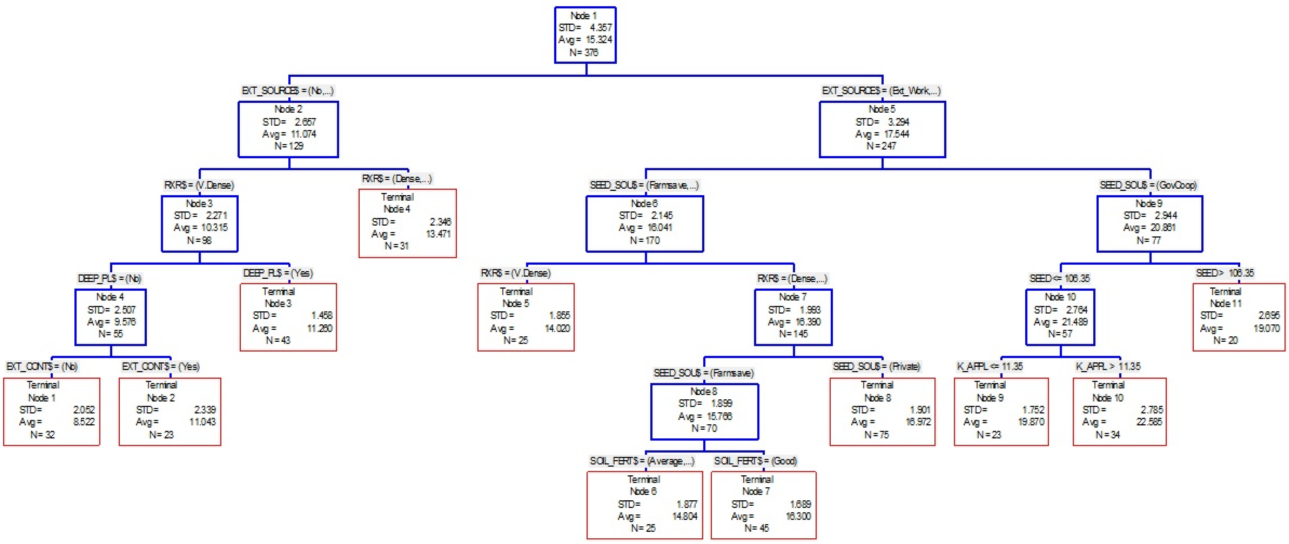

Fig. 3. Regression tree predicting soybean yield from all variables including crop management, soil, socio-economic and other variables. In each node box, average yield, standard deviation, and the number of farmers (N) were shown and node number was marked in each box

Table 3 Descriptive statistics of background variables and their correlation with soybean yield

Factors	Mean	Std. Error	Correlation
N application (kg/ha)	30.785	1.781	-0.018
P application (kg/ha)	46.677	1.892	0.120*
K application (kg/ha)	13.001	0.923	0.188**
S application (kg/ha)	11.429	0.921	0.001
Tillage (Nos.)	2.81	0.052	0.094
Seed (kg/ha)	108.938	1.001	-0.477**
Income *per capita* (₹/year)	20577	15.54	0.013
Age of respondent (years)	47.29	0.677	-0.022
Farming experience (years)	28.95	0.689	-0.011
Members working on farm (Nos.)	4.51	0.111	-0.041
Land parcel (Nos.)	1.89	0.056	0.083
FYM (Mg/ha)	4.788	0.309	0.276**
Human labour (hours/ha)	243.294	4.925	0.343**
Machine labour (hours/ha)	10.546	0.286	0.335**
Chemicals (kg/ha)	1.526	0.076	0.166**
Herbicides (kg/ha)	0.701	0.021	0.289**
Distance to market (km)	19.66	0.618	-0.264**
Distance to input (km)	9.68	0.404	-0.002
Total operational cost (₹/ha)	25773	6.44	0.439**

* and ** indicate significant correlation at 0.05 and 0.01 level.

Table 4 Maximum likelihood estimates of the stochastic frontier production function and factors influencing inefficiency of soybean production in the study area

Variables	Coefficient	t-ratio
beta 0	1.817***	4.514
Human labour	0.154***	4.513
Machine labour	0.036	1.636
Seed	-0.051	-0.631
Capital	0.062***	4.754
Inefficiency Parameters		
delta 0	1.089***	6.306
Age of head of household in years	0.001	0.569
Education (class)	0.006	1.424
Family income per capita	-0.041**	-1.991
Soil depth (ft)	-0.005	-0.222
Land slope (deep=3, medium=2, less=1)	-0.135***	-5.852
Extension contact (yes=1, no=0)	-0.316***	-8.059
Re-sowing done (yes=1, no=0)	0.149***	3.725
Number of land parcels	-0.022	-1.633
Distance of field to home (km)	0.033**	2.170
Seed source (3=govt/coop, 2=private, 1= oth. farmers/ own)	0.069***	2.661
Variance Parameters		
Sigma-squared ($\sigma 2$)	0.047***	8.125
Gamma (γ)	0.724***	7.675
log likelihood function	83.68	
LR test	244.76	

*** and ** denotes significance level at 1% and 5% level, respectively.

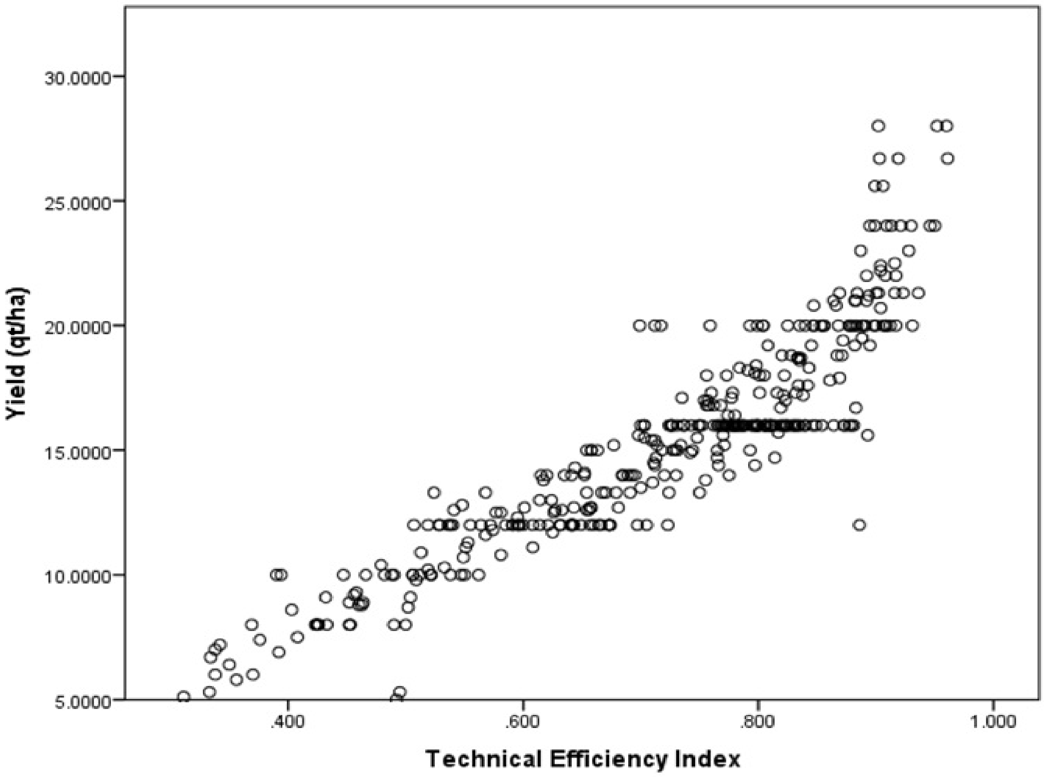

Fig. 4. Soybean productivity and technical efficiency

Table 5 Input use pattern in cultivation of soybean by sample farmers

Variables	Yield class Ia (51)b	Yield class II (115)	Yield class III (171)	Yield class IV (39)	p value
N application (kg/ha)	38.04	34.05	26.21	31.70	0.097
P application (kg/ha)	36.56	47.57	47.44	53.92	0.136
K application (kg/ha))	8.39	10.17	14.86	19.25	0.005
S application (kg/ha)	9.42	10.75	13.18	8.38	0.309
FYM (Mg/ha)	3.88	3.78	4.90	8.45	0.000
Seed (kg/ha)	125.32	115.66	102.86	94.35	0.000
Human labour (hours/ha)	224.58	220.04	247.15	319.42	0.000
Machine labour (hours/ha)	8.01	8.93	11.81	13.11	0.000
Chemicals (kg/ha)	1.13	1.42	1.60	2.02	0.028
Herbicides (kg/ha)	0.52	0.65	0.75	0.89	0.000
Tillage (Nos.)	2.75	2.70	2.85	3.05	0.237
Age of respondent (years)	48.65	45.70	48.06	46.77	0.412
Farming experience (years)	29.82	27.17	30.12	27.92	0.285
Members working on farm (Nos.)	4.76	4.55	4.45	4.28	0.727
Land parcel (Nos.)	1.69	1.93	1.84	2.23	0.101
Distance to market (km)	22.25	22.20	18.62	13.33	0.000
Distance to input (km)	10.67	9.33	9.40	10.69	0.592
Income *per capita* (₹/year)	12950	21942	23157	15159	0.002
Total operational cost (₹/ha)	22296	23632	26558	33213	0.000

[a] Yield class I, < 10 q/ha; Yield class II, 10.01-15.00 q/ha; Yield class III, 15.01-20.00 q/ha; Yield class IV, >20 q/ha; b Number of farm households

Regression tree analysis showed that plant geometry as the main contributing factor to high yield (Node 2 and 5 in Fig. 2). Farmers who adopted recommended row to row spacing or dense plant population (Node 5, n=249) realized higher average yield (17.43 q/ha), whereas, the farmers who planted soybean crop very dense (Node 2, n=127) realized an average yield of only 11.19 q/ha. Moreover, farmers following optimum row to row spacing (further split of Node 5 to Node 8, n=151) achieved an average soybean yield of 18.41 q/ha, while farmers following dense planting harvested 15.93 q/ha of soybean (Node 6, n=98) on an average. Node 8 is further split by rate of nitrogen application, wherein growers using nitrogenous fertilizers achieved a yield of 19.29 q/ha (Node 9, n=99), whereas farmers without application of nitrogen or less than recommended nitrogen application only realized 16.75 q/ha (Terminal Node 8, n=52) soybean yield. Seed treatment was another important variable causing a further split in Node 9. Farmers doing seed treatment harvested a higher soybean yield of 19.93 q/ha (Node 10, n=76) as compared to the farmers with no seed treatment before sowing (TN 9, n=23). Node 10 was further split by the hours of machine power used, with farmers using more than 9.90 hours/ha of machine power for different farm operations achieved the highest average yield of 21.04 q/ha (TN 11, n=42), whereas farmers using less than 9.90 hrs/ha machine power achieved an average yield of 18.56 q/ha (TN 10, n=34).

Among the farmers with very dense planting, following deep summer ploughing once in three years turned out to be an associated variable for yield difference. Farmers sowing soybean very densely and without deep summer ploughing once in three years and using less plant protection chemicals harvested a lower average yield of soybean (Terminal Node 1, n=28).

Crop management, soil-related and socio-economic variables and soybean yield: The regression tree model for the soybean yield as a function of all crop management, socio-economic, soil-related, and other variables (Table 1) is presented in Fig. 3. The regression tree explained a large part of the variation (78%) in yield realization. The results indicated that the extension source was the most important variable accounting for about 50 percent of the total variation in yield. The farmers having contact with the public extension (extension personnel of agriculture department, KVKs, Research Institutes) could realize an average yield of 17.54 q/ha (Node 5, n=247 in Fig. 3), whereas farmers seeking crop management information from private sources, fellow farmers or those without any extension contact could harvest only 11.07 q/ha on an average (Node 2, n=129). The splitting node representing institutional extension source (Node 5) was further split again based on the source of seed. Farmers in contact with institutional extension personnel and procured seed from cooperative or government sources (Node 9, n=77) could achieve an average soybean yield of 20.86 q/ha, than those who used farm-saved seed or procured from private sources (Node 6, n=170) realized lower yield (16.04 q/ha). Node 9 is further split by the amount of seed used for sowing. Soybean farmers who used less than 106.35 kg/ha seed could produce on an average soybean yield of 21.5 q/ha (Node 10, n=57), whereas farmers resorting to the use of higher than 106.35 kg/ha could realize an average yield of 19.07 q/ha (TN 11, n=20). Node 10 is further split by the application of potassium fertilizers, the farmers who applied less than 11.35 kg K/ha could realize a lower average soybean yield of 19.87 q/ha (TN 9, n=23) than those who applied potassium more than 11.35 kg/ha (22.59 q/ha) as per TN 10 (n=34) (Fig. 3).

The regression tree also identified row to row spacing or plant geometry as an important variable determining yield variability of soybean across farmers. The farmers who planted soybean very dense resulted in lower soybean yield realization (Node 3, n=98 and TN 5, n=25). The soil fertility status as perceived by the farmers also determined soybean yield variability (TN 6 and TN 7). Farmers with no extension contact and without deep summer ploughing once in three years and those who planted soybean very densely realized the lowest average yield (TN 1, n=32).

Technical efficiency in soybean production: Frequency distribution of technical efficiency of sample farmers revealed that about 10.6 per cent farmers were in the technical efficiency level of below 50 per cent, 12 per cent in the level of 50-60, 16 per cent in 60-70 per cent level, 25.8 per cent in 70-80 per cent level, 27.7 per cent in 80-90 per cent level and only 8 per cent soybean farmers were in the efficiency level of more than 90 per cent (Fig. 4 and Table 6). Results further revealed that the mean technical efficiency of soybean farmers ranged from 31 per cent to 96 per cent, with an average of 72 per cent. This implied that the soybean output of the 'average farmer' could be increased by 28 per cent by motivating and training them to adopt technologies considered as 'best practice' by the farmers. A positive relation was found in the technical efficiency index and yield realized by the farmers. Plot of technical efficiency index and soybean yield (Fig. 5) revealed that the technical efficiency increases with the increase in soybean yield realization by farmers.

The estimates of the stochastic frontier production reflect the efficient use of available technology and coefficients denotes production elasticity, and sum of coefficients is returns to scale. The positive and significant coefficients of human labour (0.154) and capital (0.062) implied that these variables were under-utilized (Table 4). The soybean output increases by about 0.15 per cent and 0.06 per cent for each extra percentage utilization of human labour and capital, respectively. The results of technical inefficiency effects indicated that variables such as *per capita* family income, slope of land, extension contact, re-sowing done, distance to field and seed source had significant impact on the efficiency of soybean production. The negative and significant coefficient of per capita family income, slope of land, extension contact suggests that higher family income, land with lower slope and contact of farmers with extension agencies reduces the inefficiency in soybean production or in other words improves technical efficiency.

Soybean is predominantly grown in Central India, mainly in Madhya Pradesh state which contributes to more than half of the area and production of soybean in the country, and is popularly known as 'soy state'. In Madhya Pradesh, soybean cultivation is mainly concentrated in Malwa Plateau and Nimar valley regions on medium black soils with an average rainfall ranging from 800 to 1200 mm/year, mostly received during the rainy season (June to October). The crop, by and large, is sown as rain-fed with the onset of rainfall in June-July and harvesting starts from the last week of September. The yield difference across farmers was wide, perhaps due to management practices they follow, soil and other related variables.

Table 6 Distribution of soybean growers under different levels of technical efficiency

Efficiency level (%)	Number of farms	Percentage to total farms	Av. Technical Efficiency (%)
30-40	14	3.7	35.7
40-50	26	6.9	45.6
50-60	45	12.0	54.9
60-70	60	16.0	65.4
70-80	97	25.8	75.8
80-90	104	27.7	84.9
>90	30	8.0	92.0
Total	376	100.0	71.8

Crop management practices and soybean yield: In similar agro-climatic settings, soybean production is greatly affected by optimizing crop management practices. Applying knowledge into practice is the key to achieve higher yields from crop production as well as improving the efficiency of farmers. The analysis results revealed that the use of recommended crop management practices, such as balanced nutrient application, plant geometry, variety and seed use, weeds and insect-pest management, by farmers influenced the level of yield realized by the farmers and the efficiency in crop production.

Maintaining optimum plant geometry and density (row-to-row and plant-to-plant spacing), is reported to be the important factors to achieve higher crop yield (Billore and Srivastava, 2014; Singh, 2011). The plant spacing influences leaf area and shoot biomass of the crop, and higher than optimum plant population or higher seeding rate results in poor growth due to competition for nutrients, light and space which impacts yield realization. For achieving higher yield the plant population according to row and plant spacing has been optimized for soybean (Billore and Srivastava, 2014; Whigham, 1998; Whigham and Lundvall, 1996). Results of the present study also indicated that farmers who followed optimum plant geometry realized higher soybean yield. Generally, farmers use farm-saved seed for sowing and do not perform germination test before sowing and thus use a higher seed rate (Dupare *et al*., 2012) to ensure proper germination (Dupare *et al*., 2011) and weed control through close canopy cover. This practice also leads to a higher than optimum plant population leading to poor yields. Many farmers maintained optimum row and plant spacing through intercultural operations, even though they applied a higher seed rate than recommended and were able to achieve higher soybean yield. The source of seed, availability of quality seed from a trusted source, also plays an important role in ensuring the higher productivity of the crop, as evidenced from the results of farmers' survey (Table 2 and Fig. 4). The productivity of soybean was highest for the farmers who procured/ purchased seed from government channels. Since many farmers use farm-saved seed or purchased from fellow farmers (Sharma, 2015), they go for sowing the crop without assuring the adequate spell of rain on the onset of monsoon and sometimes resulting in re-sowing due to immediate high rainfall or long dry spell. To sow the crop in hurry with a good first spell of rainfall, many of them do not carry seed treatment with fungicides and inoculation with bio-fertilizers. Treating/ inoculating seed before sowing provides insurance against seed and soil-borne diseases/ nutrition acquisition and thus improves yield realization (Table 2 and Fig. 3).

The application of balanced plant nutrients as per recommendations plays a pivotal role in crop yield realization (Van Roekel *et al*., 2015). Soybean yield at farmers' fields was found to be positively correlated with P and K application and with soil amendment in the form of farmyard manure (Table 3). Results in Table 5 further revealed that the higher soybean yield was achieved by the farmers who followed balanced plant nutrition as recommended. Phosphorus is a very vital nutrient for soybean mainly at flowering and pod development stages, as it stimulates the setting of pods, decreases the number of the unfilled pod and hastens maturity, leading to yield improvements (Subba Rao and Ganeshmurthy, 1994; Villamil *et al.,* 2012). The soybean crop is found to be moderately responsive to K application in some parts of the country (Billore *et al*., 2009a; Tiwari *et al*., 2001; Vyas *et al*., 2007). The application of organic manures is considered as an important input for soil improvement and as a source of plant nutrients, as it helps improve the soil quality (Bandyopadhyay *et al*., 2010). Organic manure contributes not only to the restoration of soil fertility in depleted fields but also in nutrient mobilization and acquisition in the legume-cereal rotations. Supply of balanced plant nutrition integrated with FYM could enhance soybean yield to the tune of 26 per cent at farmers' fields (Bandyopadhyay *et al*., 2010; Wani *et al*., 2016). Fertilizer use is highly variable among sample farmers and normally resource-constrained farmers apply lower quantities of external inputs and in imbalanced quantity (NAAS, 2017) leading to poor yields. Degradation of soil fertility mainly due to the multi-nutrient deficiency in rainfed soils (Chander *et al*., 2012; Sahrawat *et al*., 2010) identified as the main cause for low crop yields (NAAS, 2017), therefore need appropriate nutrient management approaches to bridge the existing gap between farmers' current yields and achievable potential yields. A soil health assessment of crop fields in Madhya Pradesh (Wani *et al*., 2016) revealed variable soil fertility in respect of plant nutrients and deficiencies of secondary and micronutrients in most fields, which farmers are not aware of and are absent from their fertilizer management practices, and so apparently holding back the realization of higher yields. The ongoing soil health card scheme of the government may be strengthened to familiarize farmers for soil test based on optimal plant nutrients and soil amendments.

The continuous mono-cropping sequence also has led to soil health degradation and crop susceptibility for insect-pests and diseases (Wrather *et al*., 2010) requiring appropriate management practices. Thus, soybean cultivation is gradually becoming capital and labour-intensive (Sharma *et al*., 2015; Sharma, 2016b). Soybean yield in the survey area also depended on investment by farmers in adopting different crop management practices, as the investment and soybean productivity were found to be positively and significantly correlated.

Socio-economic factors, extension contact and technology adoption: Access to institutional extension services affects the farmers' knowledge on improved crop production practices and in turn the yield realization. Many farmers were in constant touch with the public extension sources, such as extension personnel of Research Institutes, Agriculture College, Krishi Vigyan Kendra or State Agriculture Department. Those farmers with better access to technologies and seed of improved varieties were better able to use the crop management technologies optimally and in turn harvested higher yields, as evident from the results presented in Table 2 and Fig. 4 given in the previous section. Although, experienced farmers are usually more likely to accept new practices, however, the risk-bearing ability of these farmers after a certain age is supposed to decline (Feder *et al*., 1985; Feder and Umali, 1993). Lack of access to information or extension severely limits the farmer's ability to increase their productivity (Glendenning *et al*., 2010).

Soybean research system in India recommends agro-climatic zone wise package of practices for realizing higher yield at farmers' level. However, the adoption of the production technology is not prudent resulting in low yield realization and higher yield gap in major growing states (Dupare *et al*., 2010; Dupare *et al*., 2011; Sharma *et al*., 2018; Singh *et al*., 2013). The low level of adoption of improved production technology was mainly due to various socio-economic constraints faced by the farmers such as non-availability of quality inputs, high cost of inputs, lack of access to capital, lack of knowledge, poor extension support, etc. (Dupare *et al*., 2011; Kumar *et al*., 2012; Singh *et al*., 2013). Although, as reported earlier, the high adopters of production technology achieved about 36 to 48% higher yield as compared to low adopters (Sharma *et al*., 2018). The higher soybean yield realization with the adoption of an improved package of practices is continuously being demonstrated every year through conducting frontline demonstrations at farmers' fields across the country and the results are well documented (Billore *et al*., 2004; 2005).

The technology adoption was medium to high for the farmers who are in contact with public extension sources (Dupare *et al*., 2011). The appropriate advice is being extended by public/institutional extension sources on full package information (from soil preparation to harvesting). Whereas, advice to farmers by private entities or input dealers is mainly driven by the profit motive leading to the use of more than recommended and non-recommended plant protection chemicals and imbalanced fertilizers and thus resulting in lower yields. It is generally perceived that better educated and more experienced farmer are more likely to adopt improved crop management practices (Liu *et al*., 2018; Sharma *et al*., 2018) and efficiently utilize the available resources for output maximization, however, the ability to take risk declines after a certain age (Feder *et al*., 1985). Moreover, the divergent views were expressed on the adoption of crop management technologies affected by age, education and experience of farmers (Feder and Umali, 1993; Liu *et al*., 2018). Perhaps regular extension contact with institutional sources might have helped in sustaining higher productivity irrespective of educational credentials. Farmer education and training is important for the adoption of soybean technologies (Strauss *et al*., 1991). Further, SC/ST farmers realized higher soybean yield as they are mainly dependent on agriculture and agriculture labour for their livelihood and are traditionally engaged in farming and were better able to manage the crop. Moreover, sub-optimal utilization of inputs by soybean growers (Mruthyunjaya *et al*., 2005; Sharma *et al*., 2016b) led to low technical efficiency and poor yield realization. For raising the technical efficiency of the soybean farmers, policy attention is needed to improve the extension services and ensuring the availability of quality seed and other inputs to farmers.

Environmental factors and soybean yield: Crop environment or soil-related parameters are also important variables in deciding the soybean productivity in the same agro-climatic settings. In undulating terrains and land with higher gradient, excessive runoff from rainwater creates moisture stress (NAAS, 2017) in the upper land zone as well as in low lying areas. Although soybean is a low water-intensive crop (Chauhan and Joshi, 2005), highly water-stressed (low or high) conditions can result in poor yield. Water stress particularly during pod formation and filling stage can affect soybean yield significantly (Korte *et al*., 1982; Momen *et al*., 1979; Yan *et al*., 2013) and can reduce productivity by 50% in various parts of the world (Lisar *et al*., 2012), as the series of changes occur in plant morphology, physiology and biochemistry under water stress conditions leading to retarded growth and low yield.

Soil fertility status as perceived by the farmers is another important factor affecting potential yield realization. The lower soybean yields were observed on the farms where soil fertility was perceived poor by farmers (Table 2). Regression tree analysis also identified soil fertility as an important factor in determining soybean yield variability across farmers (Fig. 4). These environmental constraints were further aggravated by the less than efficient management of resources. The important constraints of soybean productivity are; imbalanced plant nutrition (Joshi and Bhatia 2003; Tiwari, 2001); lack of availability of quality seed; poor soils (Sharma, 2014) and lack of knowledge and low adoption of improved practices. Due to continuous mono-cropping sequence with legumes, regular application of nitrogenous and phosphate fertilizers with the scant application of organic manures and the very nature of the soils like high pH (>7.8), calcium carbonate, low organic carbon content resulting in micronutrient affecting not only soybean productivity but also the quality of produce (Ramesh *et al*., 2014).

Land topography, perceived soil fertility and soil depth also play a greater role in yield realization, as crop yields were low on shallow soils, land with higher slope or undulated resulting in improper moisture retention from rainfall. Sometimes, the incidence of higher rainfall just after sowing followed by dry spell lead to poor germination and plant stand due to soil compaction, and therefore many soybean farmers resort to re-sowing which also affects yield realization. For raising the productivity and efficiency of the soybean farmers, they may be guided to reduce the slope of land through land leveling.

The large spatial variation in soybean yield in Central India was observed both across farms and districts. Regression tree analysis was used to identify the most important yield determining factors at the farm level, despite non-linear relationships. Technical efficiency analysis was also attempted using stochastic frontier production function to know the resource use efficiency of the farmers and the determining factors. The results of the study indicated that farmer to farmer soybean yield variability was largely dependent on the farmers' access to public extension facilities, availability of quality seed and crop management practices. RT analysis revealed that farmer to farmer soybean variability is mainly affected by multiple and interacting production and socio-economic constraints. The lower yield of the farmers was associated with the extension contact and source of information, use of plant nutrients and soil amendments, seed rate and treatment, row and plant spacing, management of pests and diseases, land topography and soil fertility, summer deep ploughing, labour and capital management. These constraints for soybean productivity varied among different farmers. Stochastic frontier production function analysis suggested that optimal use of farm inputs and elimination of socio-economic and structural constraints can improve efficiency in soybean production. These conclusions signify that farm yield variability can be reduced by adjusting crop management practices of low yielding farms through integrated and targeted extension approaches, use of soil test based nutrient application and broadening the scope of ongoing soil health card scheme and managing biotic and abiotic stresses. The interacting production constrictions should be tackled simultaneously taking into account the need of different farmers.

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Co-integration of major soybean markets in India

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ABSTRACT

This study tested long-run spatial market integration between price pairs of soybean in five major markets *viz.,* Indore, Nagpur, Kota, Bidar and Nizamabad of the India by adopting important econometric tools like Johansen's multivariate Co-integration approach, Augmented Dickey-Fuller (ADF), Granger causality test, and Vector Error Correction Model (VECM). The study has confirmed the presence of co-integration, implying the five years price association among the markets. To get the additional evidence as to whether and in which direction price transmission is occurring between the market pairs, Granger causality test was used, which confirmed Indore to be the price-determining market. Indore was found comparatively more efficient as it showed most bidirectional causal relations with other markets. The results showed that Indore market influenced the prices in the other two major markets i.e., Nagpur and Kota.

Keywords: Co-integration, Granger Causality, Market Integration, Soybean, VECM

Soybean has an important place in world's oilseed cultivation scenario, due to its high productivity, profitability and vital contribution towards maintaining soil fertility. The crop also has a prominent place as the world's most important seed legume, which contributes 25% to the global vegetable oil production, about two thirds of the world's protein concentrate for livestock feeding and is a valuable ingredient in formulated feeds for poultry and fish. About 85% of the world's soybeans are processed annually into soybean meal and oil. Approximately 98% of the soybean meal is crushed and further processed into animal feed with the balance used to make soy flour and proteins. Of the oil fraction, 95% is consumed as edible oil; the rest is used for industrial products such as fatty acids, soaps and biodiesel (https://www.oilseed.com; http://www.grain.com).

World soybean production in 2018-19 was 348.71 million tonnes from a total area of 124.92 million hectares. In India, as on 18^{th} September 2020 area under soybean during 2020-21 was 121.21 lakh hectares as against 113.40 lakh hectares during 2019-20. Among the states, Madhya Pradesh stood first with 58.54 lakh ha followed by Maharashtra (43.21 lakh ha), Rajasthan (11.00 lakh ha), Karnataka (3.32 lakh ha) and Telangana (1.60 lakh ha). In Telangana, among the districts, Kamareddy stood first with 3399 ha followed by Adilabad (3133 ha), Nirmal (3085 ha), Nizamabad (2992 ha) and Sangareddy (2900 ha) (www.agritelangana.gov.in).

An indirect means of analyzing market efficiency is to test for market integration. Three types of market integration are identified: inter-temporal, vertical and spatial. Inter temporal market integration relates to the arbitrage process across periods. Vertical market integration is concerned with stages in marketing and processing channels. Spatial integration is concerned with the integration of spatially distinct markets i.e. if price changes in one market are fully reflected in alternative markets then these markets are said to be spatially integrated. The concept of market integration has normally been applied in studies involving spatial market inter-relatedness. Market integration is a central issue in many contemporary debates concerning the issues of market liberalization. Market integration is perceived as a precondition for effective market reform in developing countries. The high degree of market integration means the markets are quite competitive and provide little justification for extensive and costly government intervention designed to improve competitiveness to enhance market efficiency. Markets that are not integrated may convey inaccurate picture about price information that might distort production decisions and contribute to inefficiencies in markets, harm the ultimate consumer and lead to low production and sluggish growth.

Goletti and Babu (1994) studied the extent of market integration of maize markets in Malawi in order to understand how it had been affected by market liberalization. Several measures of integration were used to analyze both the co movement of prices and the price adjustment process over time using monthly retail prices of maize at eight main locations over the period between January 1984 to December 1991. The study concluded that liberalization increased market integration. Afolami (2001) investigated the degree of cowpea market integration in Uganda using such measures as bi variate correlation coefficients, co-integration and Granger-Causality. Campiche *et al.* (2007) studied the relation between crude oil prices and variation of agricultural

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commodities using a vector error correction model. Co integration results showed that corn and soybean prices were co integrated with crude oil price during 2006-2007. Awal and Sabur (2009) examined the pricing efficiency of exportable fresh vegetables markets in Bangladesh and its export markets by using Engle-Granger (EG) test, Co integration Regression for Durbin Watson (CRDW) test and Error Correction Methods (ECM). Zhang *et al.* (2010) used VEC model and Granger test on the monthly data from 1989 to 2008 and reported that there was no long run and short-run causality between the fuel (oil, gasoline and ethanol) and agricultural commodity (corn, soybeans, wheat, sugar and rice) prices. Nazlioglu *et al.* (2013) investigated the relationship between the world oil prices and the agricultural commodity prices by using the monthly data from 1980 to 2010 and the panel co-integration and the Granger causality techniques. The results of their study showed that the change in oil prices and the weak dollar have a strong impact on many agricultural commodity prices. Esposti and Listorti (2013) investigating on national and international markets observed that trade policy regime had an important role in price transmission mechanisms and they put forward a trade policy intervention to mitigate the impact of price exuberance. The authors analyzed agricultural price transmission during price bubbles, in particular, considering Italian and international weekly spot (cash) price data over years 2006-2010. Kumari *et al.* (2019) assessed co-integration of major redgram markets and price movement in major markets in India using important econometric tools like Augmented Dickey-Fuller (ADF), Johansen's co-integration test, granger causality test and vector error correction model (VECM). The results of the study indicated that in the long-run there was a two direction relationship between market prices.

MATERIALS AND METHODS

For price integration, simple bivariate correlation coefficients measure price movements of a commodity in different markets. This is the simplest way to measure the spatial price relationships between two markets. Early inquiries on spatial market integration, for example Lele (1967) and Jones (1968) have used this method. However, this method clearly has some limitations, as it cannot measure the direction of price integration between two markets. The co-integration procedure measures the degree of price integration and takes into account the direction of price integration. This econometric technique provides more information than the correlation procedure does, as it allows for the identification of both the integration process and its direction between two markets.

Market Integration Test:

Market integration is tested using the co-integration method, which requires that (i) Two variables, say P_{it} and P_{jt} are non-stationary in levels but stationary in first differences i.e. $P_{it} \sim I(1)$ and $P_{jt} \sim I(1)$.

There exists a linear combination between these two series, which is stationary i.e. P_{it} (=P_{it} -α - βP_{it}) ~I (0).

So the first step is to test whether each of the univariate series is stationary. If they are both *I* (1) then we may go to the second step to test cointegration. The Engle and Granger (1987) procedure is the Common way to test cointegration.

Unit Root Test

The regression analysis of non-stationary time series produces spurious results, which can be misleading (Ghafoor *et al.,* 2009). The most appropriate method to deal with non-stationary time series for estimating long-run equilibrium relationships is cointegration, which necessitates that time series should be integrated of the same order. Augmented Dickey- Fuller (ADF) and Phillips-Perron test (PP) is used to verify the order of integration for each individual series. The ADF test, tests the null hypothesis of unit root for each individual time series. The rejection of the null hypothesis indicates that the series is non-stationary and vice-versa (Dickey and Fuller, 1981). The number of the appropriate lag for ADF is chosen for the absence of serial correlation using Akaike Information Criterion (AIC). The ADF test is based on the Ordinary Least Squares (OLS) method and requires estimating the following model.

$$\Delta lnP_t = \alpha_0 + \delta_1 t + \gamma lnP_{t-1} + \sum_{j=1}^{q} \vartheta_j \Delta lnP_{t-j} + \varepsilon_t$$

Where, P the price in each market, Δ is the difference parameters (i.e., Δ P1 = P_t- P_{t-1}, P_{t-1} = P_{t-1} -P_{t-2} and P_{n-1}= P_{n-1} - P_{n-2}) and so on, α_0 is the constant or drift, *t* is the time or trend variable, *q* is the number of lags length and ε_t is a pure white noise error term.

Johansen Cointegration

If two series are potentially co-integrated, at least one co-integration relationship exists. Co-integration may be affected by some factors, such as transportation cost, tariffs, and so on. The two tests, i.e., trace and max Eigen statistics of Johansen's approach based on the vector autoregressive model (VAR) were put into the application to analyze the co-integrating vectors between the selected Soybean markets.

The maximum likelihood (ML) method of cointegration is applied to check long-run wholesale prices relation between the selected markets of India (Johansen, 1988; Johansen and Juselius, 1990). The starting point of the ML method is vector autoregressive model of order (k) and may be written as:

$$P_t = \sum_{i=1}^{k} A_t P_{t-1} + \mu + \beta_t + \varepsilon_t : \; (t=1, 2, 3 \ldots T)$$

Where, (n*1) denotes the vector of non-stationary or integrated at order one, i.e., I (1) prices series. The procedure for estimating the cointegration vectors is based on the Vector error correction model (VECM) representation given by:

$$\Delta P_t = \prod P_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \, \Delta P_{t-i} + +\beta\mu_t + \varepsilon_t$$

Where, $\Gamma_i = -(I - \Pi_i - \ldots, T); \; i=1,2,\ldots k-1$

$$\Pi = -(I - \Pi_s - \ldots\ldots\ldots \Pi_k)$$

Both i and Πi are the n*n matrixes of the coefficient conveying the short and long run information respectively, μ is a constant term, t is a trend, and ε_t is the n-dimensional vector of the residuals that is identical and independent distributed. The vector ΔP_t is stationary P_t is integrated at order one I(1) which will make unbalance relation as long as Π matrix has a full rank of k. In this respect, the equation can be solved by inversing the matrix Π^{-1} for Pt and as a linear combination of stationary variable (Kirchgässner *et al.*, 2012). The stationary linear combination of the Pt determines by the rank of Π matrix. If the rank r of the matrix Π r=0 the matrix is the null and the series underlying is stationary. If the rank of the matrix Π is such that 0 < rank of (Π) = r < n then there are n × r cointegrating vectors. The central point of the Johansen's procedure is simply to decompose Π into two n × r matrices such that Π=αβ'. The decomposition of Π implies that the β'Pt are r stationary linear combination.

Johansen and Juselius (1990) proposed two likelihood ratio test statistics (Trace and Max Eigen test statistics) to determine the number of cointegrating vectors as follows:

$$J_{trace} = -T \sum_{i=r+1}^{N} \ln\left(1 - \hat{\lambda}_1\right)$$

$$\lambda_{max} = -T \ln\left(1 - \hat{\lambda}_{r+1}\right)$$

Where, r is the number cointegrated vector, $\hat{\lambda}_1$ is the eigen value and $\hat{\lambda}_{r+1}$ is the(r + 1)th largest squared eigen value obtained from the matrix Π and the T is the effective number of observation. The trace statistics tested the null hypothesis of r cointegrating vector(s) against the alternative hypothesis of n cointegrating relations. The Max Eigen statistic tested the null hypothesis (r =0) against the alternative (r + 1).

Vector Error Correction Model (VECM)

If price series are I (1), then one could run regressions in their first differences. However, by taking first differences, we lose the long-run relationship that is stored in the data. This implies that one needs to use variables in levels as well. Advantage of the vector error correction model (ECM) is that it incorporates variables both in their levels and first differences. By doing this, VECM captures the short-run disequilibrium situations as well as the long-run equilibrium adjustments between prices. Even if one demonstrates market integration through cointegration, there could be disequilibrium in the short-run i.e. price adjustment across markets may not happen instantaneously. It may take some time for the spatial price adjustments. VECM can incorporate such short-run and long-run changes in the price movements.

A VECM formulation, which describes both the short-run and long-run behaviors of prices, can be formulated as:

$$\Delta P_{it} = \gamma_1 + \gamma_2 \Delta P_{jt} - \pi \hat{v}_{it-1} + v_{it}. \qquad (4)$$

In this model, γ_2 is the impact multiplier (the short -run effect) that measures the immediate impact that a change in P_{jt} will have on a change in P_{it}. On the other hand, π is the feedback effect or the adjustment effect that shows how much of the disequilibrium is being corrected, that is the extent to which any disequilibrium in the previous period effects any adjustment in the P_{it} period of course

$$\hat{v}_{t-1} = P_{it-1} - \hat{p}_1 - \hat{p}_2 P_{ji-1}$$

and therefore from this equation we also have P_2 being the long-run response.

Granger Causality Test

If a pair of series is cointegrated then there must be Granger causality in at least one direction, which reflects the direction of influence between series (in our case prices). Theoretically, if the current or lagged terms of a time-series variable, say P_{jt}, determine another time-series variable, say P_{jt}, then there exists a Granger causality relationship between P_{jt} and P_{it}, in which P_{it} is Granger caused by P_{jt}. Bessler and Brandt (1982) firstly introduced this test into research on market integration to determine the leading market.

From the above analysis, the model is specified as follows:

$$\Delta P_{it} = \theta_{11}\Delta P_{it-1} + \ldots + \theta_{1n}\Delta P_{it-n} + \theta_{21}\Delta P_{jt-1} + \ldots \theta_{2n}\Delta P_{jt-n} - \gamma_1(P_{it-1} - \alpha P_{jt-1} - \delta) + \varepsilon_{1t}$$

$$\Delta P_{jt} = \theta_{31}\Delta P_{jt-1} + \ldots + \theta_{3n}\Delta P_{it-n} + \theta_{41}\Delta P_{it-1} + \ldots \theta_{4n}\Delta P_{it-n} - \gamma_2(P_{it-1} - \alpha P_{jt-1} - \delta) + \varepsilon_{2t}$$

The following two assumptions are tested using the above two models to determine the Granger causality relationship between prices.

$$\theta_{21} = \ldots = \theta_{2n} = \cdots = \gamma_1 = 0 \text{ (No causality from } P_{jt} \text{ to } P_{it})$$

$$\theta_{41} = \ldots = \theta_{4n} = \cdots = \gamma_2 = 0 \text{ (No causality from } P_{it} \text{ to } P_{jt})$$

EViews software was used for the analysis.

RESULTS AND DISCUSSION

Our price data consisted of monthly modal prices of Soybean (₹/q) in five major markets *viz*., Indore, Nagpur, Kota, Bidar and Nizamabad of the India using monthly Soybean prices over the period from January 2016 to December 2020. The data was taken from the websites of agriculture marketing government of Telangana (http://tsmarketing.in/; https://agmarknet.gov.in/). The soybean modal price trend of all the selected markets is presented in Fig. 1, which shows the symmetric behavior in the movement of prices in all the selected markets except Kota, The maximum modal price of ₹ 4196/q prevailed in Kota and the minimum price was found in Nizamabad ₹2375/q followed by Nagpur ₹ 2554/q.

Descriptive statistics: Summary statistics result showed that the price of Soybean remained most volatile in Bidar followed by Nagpur as measured by coefficient of variation. Indore is the biggest of Soybean markets in India and the prices are dependent upon the demand of the other markets. The highest average prices of Soybean were found in Kota market, while lowest average prices were in Nizamabad (Table 1).

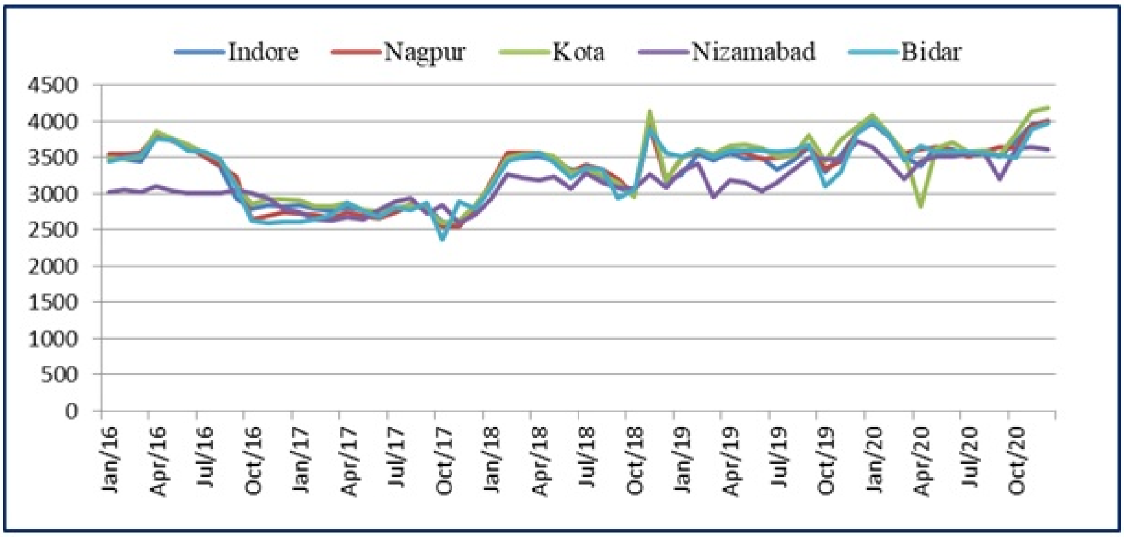

Fig. 1. Price behavior (₹/quintal) of Soybean crop in major selected markets in India

Table 1 Summary Statistics of the monthly modal Prices for Soybean in major markets for India from January, 2016 to December, 2020 (in ₹/q)

	Indore	Nagpur	Kota	Bidar	Nizamabad
Mean	3323	3343	3380	3141	3325
Median	3464	3511	3505	3096	3499
Maximum	4004	4019	4196	3728	4005
Minimum	2578	2554	2603	2597	2375
Std. Dev.	389	417	418	295	417
CV	11.71	12.48	12.38	12.54	9.41

Order of the integration: In order to check the stationarity of price series of soybean, the standard ADF and PP unit root tests, were applied to determine the order of integration. The unit root test regression implies that regressing the first difference of a series with its one period lag and several lags (as suggested by the various lag length criterion) of the first differenced series. The null hypothesis of ADF and PP tests is accepted or rejected based on the critical value and corresponding probability value. The results of the ADF and PP test values were below the critical value at 5% level of significance indicating the non existence of unit root test. This implied that the Soybean price series are non stationary at level in all the major markets in India Indore, Nagpur, Kota, Bidar and Nizamabad. All the major markets i.e., Indore, Nagpur, Kota, Bidar and Nizamabad were stationary at first difference I (1).

Co-integration analysis: Johansen's Co-integration test for selected Soybean markets for the long-run co-integration was performed. The results of Johansen's maximum likelihood tests (maximum Eigen-value and trace test) are presented in Table 3. The first null hypothesis of maximum eigen-value and trace test, tests the no co-integration ($r = 0$) against the alternative hypothesis ($r \geq 1$) of at least one co-integrated equation prevailed in the VAR system. Both, the maximum Eigen-value and trace test reject the null hypothesis of no co-integration. The rejection/acceptance of the null hypothesis is decided by the trace max- Eigen test statistic values against their critical value and corresponding probability value which is less than test statistic in the first null hypothesis. Similarly, the null hypotheses from $r \leq 1$ to $r \leq 3$ and $r \leq 4$ for both the statistics were rejected against their alternative hypotheses from the $r \geq 1$ to $r \geq 4$ and $r=5$ as their critical values were less than the test statistics and the corresponding probability values were also less than 0.05. This implied that there were five co-integrating relationships in the joint co-integration analysis of all five Soybean markets.

Granger causality test: After confirming the integration of price series, we performed pair-wise Granger causality test for five major Soybean markets to comprehend causal relation between them. The result of the Granger causality analysis presented in Table 4 explicates that bidirectional causality market pair is Indore-Nagpur. In these cases, the former market in each pair Granger causes the modal price formation in the latter market, which in turn provides the feedback to the former market as well. A unidirectional causality markets pair is Bidar-Nagpur and Nagpur-Nizamabad. It means that a price change in the former market in each pair Granger cause the price formation in the latter market. The remaining markets did not show causality. It meant that the price change in the latter market did not feed back into the price in the former market.

Table 2 ADF and PP tests for unit root in the modal prices of soybean

Augmented Dickey-Fuller test results at level				Phillips-Perron test results at level		
	t-Statistic	Prob.*	Remarks	t-Statistic	Prob.*	Remarks
Indore	-2.05	0.26	Non-stationary	-1.84	0.33	Non-stationary
Nagpur	-1.94	0.30	Non-stationary	-1.78	0.38	Non-stationary
Kota	-1.62	0.46	Non-stationary	-2.28	0.18	Non-stationary
Bidar	-2.03	0.27	Non-stationary	-2.04	0.26	Non-stationary
Nizamabad	-1.86	0.34	Non-stationary	-1.86	0.34	Non-stationary
Augmented Dickey-Fuller test results after differencing				Phillips-Perron test results after differencing		
Δ Indore	-8.96*	0.00	Stationary	-9.08*	0.00	Stationary
Δ Nagpur	-9.36*	0.00	Stationary	-9.4*	0.01	Stationary
Δ Kota	-10.45*	0.00	Stationary	-10.96*	0.00	Stationary
Δ Bidar	-8.33*	0.00	Stationary	-8.22*	0.00	Stationary
Δ Nizamabad	-6.57*	0.00	Stationary	-10.71*	0.00	Stationary

Notes: * denote significance at 1% levels of significance and Δ denote the first difference of the time series.

Short run and long run behavior of market prices: Since the Johansen's multiple co-integration test results showed that the selected Soybean markets were having long run equilibrium relationship and presence of co-integration between them, the Vector Error Correction model (VECM) among the selected markets of Soybean was employed to know the speed of adjustments for the prices of Soybean among selected markets, for short run and long run equilibrium of prices. The results of VECM are presented in Table 5.

The estimates of VECM revealed that co-integration equation value of Bidar market attained short run equilibrium rapidly. One month lag price of Indore market was affecting current prices of Bidar. One month lag price of Nagpur market was affecting current prices of Bidar market. Two month lag price of Nagpur market was affecting current prices of Bidar market. One month lag price of Kota market was affecting current prices of Bidar market and two months lag price was affecting current prices of Bidar market. One month lag price of Nizamabad market was affecting current prices of Bidar market.

Table 3 Johansen's Co-integration Test Results of five major Soybean Market prices in India

Hypothesized No. of CE(s)	H0	H1	Eigen value	Trace Statistics results			Max-Eigen Statistics results		
				Trace statistics	0.05 Critical Value	P-Value	Max-Eigen Statistic	0.05 Critical Value	P-Value
None *	r =0	r≥1	0.68	227.74	69.81	0.000*	65.41	33.87	0.002*
At most 1*	r≤1	r≥2	0.63	162.33	47.85	0.012*	57.70	27.584	0.01*
At most 2 *	r≤2	r≥3	0.50	104.62	29.7	0.000*	40.43	21.131	0.000*
At most 3 *	r≤3	r≥4	0.45	64.18	15.49	0.001*	34.24	14.2646	0.008*
At most 4 *	r≤4	r=5	0.40	29.94	3.84	0.002*	29.94	3.8415	0.001*

Notes: in represent the natural logarithm and * denote the rejection of null hypothesis at 5% level of significance

Tables 4 Market pair wise results of the Granger Casualty test

Lagged Periods	Markets Pairs	F-Statistic	P-Value	Decision of null hypothesis	Remarks
1	Indore - Bidar	1.16	0.31	Reject	No causality
	Bidar - Indore	1.61	0.2	Reject	No causality
2	Kota - Bidar	0.57	0.56	Reject	No causality
	Bidar - Kota	2.15	0.12	Reject	No causality
3	Nagpur - Bidar	0.65	0.52	Reject	No causality
	Bidar - Nagpur*	3.38*	0.04*	Do not reject	Unidirectional
4	Nizamabad - Bidar	1.51	0.22	Reject	No causality
	Bidar - Nizamabad	0.37	0.69	Reject	No causality
5	Kota - Indore	1.09	0.34	Reject	No causality
	Indore - Kota	1.83	0.16	Reject	No causality
6	Nagpur - Indore*	2.95*	0.01*	Do not reject	Bi-directional
	Indore - Nagpur*	1.52*	0.03*	Do not reject	
7	Nizamabad - Indore	0.65	0.52	Reject	No causality
	Indore - Nizamabad	0.15	0.85	Reject	No causality
8	Nagpur - Kota	0.59	0.55	Reject	No causality
	Kota - Nagpur	0.03	0.96	Reject	No causality
9	Nizamabad - Kota	2.35	0.10	Reject	No causality
	Kota - Nizamabad	0.14	0.86	Reject	No causality
10	Nizamabad - Nagpur	0.69	0.50	Reject	No causality
	Nagpur - Nizamabad*	2.2*	0.02*	Do not reject	Unidirectional

Note: * represents the level of significance at 5% level

Table 5 Vector Error Correction Model for soybean prices for major five selected markets in India

Error Correction:	Indore	Nagpur	Kota	Bidar	Nizamabad
CointEq1	-0.601045	0.031001	-0.737060	-0.759347*	0.310252
	(0.48892)	(0.49547)	(0.57801)	(0.50942)	(0.34662)
Indore(-1))	0.061365	0.345848	0.746428	0.711105*	-0.662966
	(0.57649)	(0.58422)	(0.68154)	(0.60067)	(0.40870)
Indore (-2))	-0.088184	0.181514	0.308851	0.465131	-0.012166
	(0.51935)	(0.52631)	(0.61398)	(0.54113)	(0.36819)
Nagpur(-1))	-0.668659	-0.680695	-1.235764	-1.200146*	0.670448
	(0.74628)	(0.75628)	(0.88227)	(0.77758)	(0.52908)
Nagpur(-2))	0.217793	0.158641	0.043890	-0.253243*	0.486758
	(0.51758)	(0.52452)	(0.61190)	(0.53929)	(0.36694)
Kota(-1))	-0.194730	-0.165616	-0.734812	0.036009*	0.132978
	(0.30903)	(0.31317)	(0.36534)	(0.32199)	(0.21909)
Kota(-2))	-0.094219	-0.116660	-0.367837	-0.023530*	-0.118620
	(0.29584)	(0.29981)	(0.34975)	(0.30825)	(0.20974)
Bidar(-1))	0.623529	0.330286	0.933078	0.404943	-0.145646
	(0.47410)	(0.48046)	(0.56050)	(0.49399)	(0.33612)
Bidar(-2))	-0.187762	-0.298583	-0.092643	-0.144124	-0.378966
	(0.35558)	(0.36035)	(0.42038)	(0.37050)	(0.25209)
Nizamabad(-1))	0.270816	0.244795	0.555623	0.272560*	-0.278897
	(0.24068)	(0.24390)	(0.28454)	(0.25077)	(0.17063)
Nizamabad(-2))	-0.003571	-0.122810	0.119094	-0.368294	-0.241753
	(0.24618)	(0.24948)	(0.29104)	(0.25650)	(0.17453)
C	9.932049	7.797923	10.29133	6.924391	16.31526
	(31.2345)	(31.6531)	(36.9261)	(32.5446)	(22.1438)

This study investigated the spatial market integration and price behavior of Soybean markets through co integration analysis in India using January, 2016 to December, 2020 modal monthly price data. All major markets of Soybean in the India were found to be highly integrated with regard to price movement. Agricultural markets play an important role in agricultural marketing and production efficiency. A fundamental issue when analyzing policy reform with regard to national agricultural markets is the extent to which domestic agricultural commodity markets respond to price changes. The overall performance of agriculture depends, not only on efficiency of production or supply, but also on marketing efficiency, particularly the agricultural markets and price signal. Spatial market integration measures the extent to which markets at geographically distant locations (such as between regions) share common long-run price or trade information for a homogenous commodity. The results of ADF unit root test indicated that price series are stationary in first differencing logarithm i.e., Indore, Nagpur, Kota, Bidar and Nizamabad markets were found to be integrated zero order I. Results of Johansen's co integration test showed the price series as co integrated. The result of the Granger causality analysis explicated that bidirectional causality market pair was Indore-Nagpur. Two unidirectional causality market pairs were Bidar-Nagpur and Nagpur- Nizamabad. Results of Vector Error Correction Model (VECM) showed that Bidar market attained short run equilibrium rapidly. One month lag price of Indore market was affecting current prices of Bidar. One month lag price of Nagpur market was affecting current prices of Bidar market. Two month lag price of Nagpur market was affecting Bidar market current prices. One and two month lag price of Kota market was affecting current prices of Bidar market. One month lag price of Nizamabad market was affecting current prices of Bidar market. It clearly showed that there was scope for increasing Soybean prices in the India and Telangana State.

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Genetic variability, heritability and genetic advance studies for economically important traits in sunflower (*Helianthus annuus* L.)

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ABSTRACT

The present investigation was carried out to study genetic parameters for eight different traits *viz.,* days to 50 per cent flowering, days to maturity, plant height, head diameter, 100 seed weight, volume weight, seed yield/plot and oil content at ICAR-Indian Institute of Oilseeds Research during *rabi* 2019-2020. The study included a total of 67 genotypes including 5 CMS lines and 10 newly developed restorer lines and their 50 F_1 hybrids along with two checks (KBSH-44 and DRSH-1). Analysis of variance revealed significant differences for all the traits. High variation was observed for plant height and seed yield/plant and lowest was observed for 100 seed weight, oil content and head diameter. The difference between GCV and PCV was low for all the characters indicating less influence of environmental factors on the expression of these traits. High heritability with high genetic advance was observed for plant height, head diameter, 100 seed weight and seed yield/plant indicating additive gene action in the expression of these traits. Simple phenotypic selection may be effective for improving these characters. High heritability coupled with low genetic advance was observed for oil content suggesting involvement of non-additive gene action in the expression of this trait indicating little scope for further improvement through individual plant selection.

Keywords: Genetic advance, GCV, Heritability, PCV, Sunflower

Oilseed crops occupy a prime position in agricultural economy after food grains, and among them sunflower (*Helianthus annuus* L.) is one of the prominent oilseed crop grown in world as well as in India. It is the fourth most important oilseed crop next to soybean, groundnut and rapeseed (Shamshad *et al.,* 2016; Yamgar *et al.,* 2018) which is originated from North America. The crop has much importance especially for its oil content due to presence of high concentration of polyunsaturated fatty acids (PUFA) with 55 to 60% of linoleic acid and 25 to 30% of oleic acid, which reduces the risk of coronary diseases by reducing blood cholesterol levels (Joksimovic *et al.,* 2006). In India, sunflower is cultivated over an area of 2.5 lakh ha with a production of 2.2 lakh tonnes and productivity of 886 kg/ha (Directorate of Economics and Statistics, 2018-19). The requirement of high yield and quality edible oil is raising day by day and therefore, there is a need to increase the area, production and productivity of the crop which is possible through crop improvement strategies. Success of any crop improvement programme depends upon the genetic variability present in the material. Sometimes phenotypic selection based on their performance may not be sufficient because these genotypes may perform poor in further segregating generations, so it is essential to select the genotypes based on genetic worth of the genotypes i.e., based on heritability and genetic advance (Hamouda *et al*., 2016). Genetic variability along with heritability estimates would provide the amount of genetic gain expected out of selection (Burton, 1952; Swarup and Chaugle, 1962). Information on variability and heritability is useful to formulate selection criteria for improvement of seed yield and its component traits. Heritability estimates along with genetic advance are normally more helpful in predicting the gain under selection than heritability estimates alone (Paul *et al.,* 2006). So, taking all these aspects into consideration, the present study was conducted to evaluate the extent of genetic variability, heritability and genetic advance over mean for seed yield and its component traits in sunflower.

The present investigation was carried out during *rabi,* 2019-20 at ICAR-Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad. Study material consisted of 67 genotypes (Table 1). Each genotype was sown in two rows of 3.0 m length following a spacing of 60 cm between the rows and 30 cm between the plants in randomised block design (RBD) with three replications. Standard agronomic practices were performed uniformly for all the experimental units. At maturity five plants from each accession were selected randomly for recording data on days to 50% flowering, days to maturity, plant height (cm), head diameter (cm), 100 seed weight (g), volume weight (g/100 ml), seed yield/plant (g) and oil content (%). Mean performance of the genotypes were calculated and the genotypic coefficient (GCV) and phenotypic coefficient of variation (PCV) was estimated by using the formula given by Burton (1952). The estimates of PCV and GCV were classified as low (0-10%),

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moderate (10-20%) and high (>20%) according to Sivasubramanian and Madhavamenon (1973). Heritability in broad sense (h^2 b) was estimated according to the formula suggested by (Johnson *et al.*, 1955) and (Hanson *et al.,* 1956). Estimation of genetic advance was done following the formula given by Johnson *et al.,* (1955) and Allard (1960).

Table 1 List of genotypes used in the present study in sunflower

S. No.	Experimental Material	Source
	CMS Lines (Lines)	
1.	CMS-234A	UAS, GKVK, Bengaluru
2.	ARM-243A	ICAR-IIOR, Hyderabad
3.	CMS-335A	UAS, GKVK, Bengaluru
4.	HA-430A	ICAR-IIOR, Hyderabad
5.	CMS-1010A	ICAR-IIOR, Hyderabad
	Testers	
6.	PM-81	UAS, Raichur
7.	RHA-6D1	ICAR-IIOR, Hyderabad
8.	RGP-21-P2-S2	ICAR-IIOR, Hyderabad
9.	RGP-28	ICAR-IIOR, Hyderabad
10.	RGP-30-P3-S1	ICAR-IIOR, Hyderabad
11.	RGP-46-P2	ICAR-IIOR, Hyderabad
12.	RGP-49-P4	ICAR-IIOR, Hyderabad
13.	RGP-50-P1-S4	ICAR-IIOR, Hyderabad
14.	RGP-50-P2-S1	ICAR-IIOR, Hyderabad
15.	RGP-58-P4-S2	ICAR-IIOR, Hyderabad
	Crosses	
16.	CMS-234A x PM-81	
17.	CMS-234A x RHA-6D1	
18	CMS-234A x RGP-21-P2-S2	
19.	CMS-234A x RGP-28	
20.	CMS-234A x RGP-30-P3-S1	
21.	CMS-234A x RGP-46-P2	
22.	CMS-234A x RGP-49-P4	
23.	CMS-234A x RGP-50-P1-S4	
24.	CMS-234A x RGP-50-P2-S1	
25.	CMS-234A x RGP-58-P4-S2	
26.	ARM-243A x PM-81	
27.	ARM-243A x RHA-6D1	
28.	ARM-243A x RGP-21-P2-S2	
29.	ARM-243A x RGP-28	
30.	ARM-243A x RGP-30-P3-S1	
31.	ARM-243A x RGP-46-P2	
32.	ARM-243A x RGP-49-P4	
33.	ARM-243A x RGP-50-P1-S4	
34.	ARM-243A x RGP-50-P2-S1	
35.	ARM-243A x RGP-58-P4-S2	
36.	CMS-335A x PM-81	
37.	CMS-335A x RHA-6D1	
38.	CMS-335A x RGP-21-P2-S2	
39.	CMS-335A x RGP-28	
40.	CMS-335A x RGP-30-P3-S1	
41.	CMS-335A x RGP-46-P2	
42.	CMS-335A x RGP-49-P4	
43.	CMS-335A x RGP-50-P1-S4	
44.	CMS-335A x RGP-50-P2-S1	
45.	CMS-335A x RGP-58-P4-S2	
46.	HA-430A x PM-81	
47.	HA-430A x RHA-6D1	
48.	HA-430A x RGP-21-P2-S2	
49.	HA-430A x RGP-28	
50.	HA-430A x RGP-30-P3-S1	
51.	HA-430A x RGP-46-P2	
52.	HA-430A x RGP-49-P4	
53.	HA-430A x RGP-50-P1-S4	
54.	HA-430A x RGP-50-P2-S1	
55.	HA-430A x RGP-58-P4-S2	
56.	CMS-1010A x PM-81	
57.	CMS-1010A x RHA-6D1	
58.	CMS-1010A x RGP-21-P2-S2	
59.	CMS-1010A x RGP-28	
60.	CMS-1010A x RGP-30-P3-S1	
61.	CMS-1010A x RGP-46-P2	
62.	CMS-1010A x RGP-49-P4	
63.	CMS-1010A x RGP-50-P1-S4	
64.	CMS-1010A x RGP-50-P2-S1	
65.	CMS-1010A x RGP-58-P4-S2	
	Checks	
66.	KBSH-44	UAS, GKVK, Bengaluru
67.	DRSH-1	ICAR-IIOR, Hyderabad

The analysis of variance exhibited a significant difference for all the traits considered in the study indicating sufficient amount of variation present in the material utilised. The results pertaining to analysis of variance are presented in Table 2. The results pertaining to mean, variability, heritability and genetic advance of each trait in the present study is represented in Table 3. Wide range of variation was observed for plant height (85.8-206.4 cm) followed by seed yield/plant (5.9-68.5 g) and lowest for 100 seed weight (2.4-7.1g) followed by oil content (32.5-40.3%) and head diameter (7.4-16.6 cm). Highest variation for plant height was also reported by Sutar *et al.* (2010) and Reena *et al.* (2017).

Table 2 Analysis of variance for different characters in sunflower

Source of variation	d.f.	DF	DM	PH	HD	SW	VW	SY/Plant	OC
Mean of sum of squares									
Replication	2	52.93	58.85	6,691.90	0.09	1.29	68.01	183.52	1.72
Treatment	66	70.79**	71.35**	1,505.9**	14.79**	2.96**	25.99**	621.57**	7.44**
Error	132	1.92	2.09	105.1	1.05	0.22	3.45	31.34	0.65
Total	201	125.64	132.3	8302.9	15.93	4.48	97.45	836.43	9.81

**- Significant at 1% level; *- significant at 5% level; d.f. - Degrees of freedom; DF - Days to 50 per cent flowering (days); DM - days to maturity (days); PH - Plant height (cm); HD-Head diameter (cm); SW-100 Seed weight (g); VW-Volume weight (g/100 ml); SY/ Plant-Seed yield/plant (g); OC-Oil content (%)

Table 3 Mean, range, coefficient of variation, heritability and genetic advance as per cent of mean for different traits in sunflower

Character	Mean	Range		Coefficient of Variation		Heritability (%)	Genetic advance as per cent of mean
		Minimum	Maximum	GCV (%)	PCV (%)		
Days to 50 % flowering	65.0	52.0	76.0	7.41	7.72	92.28	14.67
Days to maturity	95.0	82.0	106.0	5.07	5.30	91.69	10.01
Plant height (cm)	154.0	85.8	206.4	14.04	15.53	81.63	26.12
Head diameter (cm)	13.5	07.4	16.6	15.83	17.55	81.30	29.40
100 seed weight (g)	4.98	02.4	7.1	19.21	21.43	80.32	35.46
Volume weight (g/100 ml)	41.4	32.2	46.8	6.62	8.00	68.56	11.30
Seed yield per plant (g)	36.5	05.9	68.5	38.42	41.37	86.26	73.51
Oil content (%)	36.6	32.5	40.3	4.11	4.66	77.60	7.45

The PCV ranged from 5.30 (days to maturity) to 41.37 (seed yield/plant); whereas, GCV ranged from 5.07 (days to maturity) to 38.42 (seed yield/plant). High GCV and PCV was recorded for seed yield/plant (38.42, 41.37). Further, moderate GCV and PCV was recorded for plant height (14.04, 15.53) and head diameter (15.83, 17.55). The character 100 seed weight recorded high PCV (21.43) coupled with moderate GCV (19.21). Low GCV and PCV were recorded for the trait days to maturity (5.07, 5.30); days to 50 per cent flowering (7.41, 7.72); volume weight (6.62, 8.00) and oil content (4.11, 4.66). In the present study values of PCV were higher for all characters than corresponding GCV and the difference between PCV and GCV was narrow indicating less influence of environment over the expression of these characters. Similar reports of high PCV and GCV for seed yield/plant was reported by Dudhe *et al.* (2019); moderate PCV for head diameter by Reena *et al.* (2017) and moderate GCV for plant height, head diameter and 100 seed weight by Kumar *et al.* (2014) and Neelima *et al.* (2016). Further, low PCV for the characters volume weight, days to 50 per cent flowering, days to maturity and oil content was also reported by Kalukhe *et al.* (2010) and Makane *et al.* (2011).

The estimates of heritability ranged from 68.56 (volume weight) to 92.28% (days to 50 per cent flowering) whereas, genetic advance as percentage of mean ranged from 7.45 (oil content) to 73.51% (seed yield/plant). Heritability and genetic advance are important selection parameters. Heritability estimates are more useful when combined with the genetic advance of corresponding trait. Hence, high heritability estimates along with high genetic advance is more useful in predicting genetic gain under selection than heritability estimates alone. High heritability coupled with high genetic advance as percent of mean was observed for the characters seed yield/ plant, 100 seed weight, plant height and head diameter indicating that these characters are governed by additive gene action. Hence, good response to selection can be attained for improvement of these traits. Similar reports of high heritability along with high genetic advance for seed yield/plant, 100-seed weight, plant height was reported by Neelima *et al.* (2016). High heritability estimates coupled with moderate genetic advance was manifested by the traits *viz.,* days to 50 per cent flowering, volume weight and days to maturity indicating involvement of both additive and non-additive gene action in the inheritance of these traits. Similar results were reported by Madhavi Latha *et al.* (2017) for days to 50 per cent flowering, days to maturity and plant height and Supriya *et al.* (2016) for days to 50 per cent flowering. Further, oil content exhibited high heritability coupled with low genetic advance suggesting non-additive gene action in inheritance of this trait. Hence, this trait can be further improved through heterosis breeding.

From the present study, it could be concluded that the traits like seed yield/plant, plant height, 100 seed weight and head diameter are controlled by additive gene action suggesting that these traits can be improved by simple selection. The character oil content was under the influence of non-additive gene action and can be improved through heterosis breeding.

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Effect of phosphorus fertilization and molybdenum seed treatment on yield and economics of soybean

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ABSTRACT

A field experiment was carried out on Alfisols during *rainy* season 2015 at College Farm, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad, Telangana to find the effect of soil application of phosphorus fertilizer and molybdenum seed treatment on soybean. Results revealed that soil application of 60 kg P_2O_5 recorded significantly higher yield attributes (seeds/pod), N uptake by seed (117.0 kg/ha), protein content (41.0 %), seed yield (1784 kg/ha) besides higher gross (₹ 59,220/ha), net returns (₹ 39,520/ha) and B:C ratio (3.0). Similarly seed treatment with molybdenum @ 6 g/kg registered higher yield attributes (seeds/pod), N uptake by seed (101.6 kg/ha), protein content (40.2 %), seed yield (1572 kg/ha) apart from gross, net returns and B:C ratio (₹ 49,872/ha, ₹ 31,892/ha and 2.78) respectively.

Keywords: Molybdenum, Monetary returns, Phosphorus, Soybean, Yield

Soybean (*Glycine max* L.) is one of the most valuable crops in the world, not only for oil (20%), starch content (21%) and feed for livestock and aquaculture, but also, as a good source of protein (42-45%) for the human diet and biofuel feedstock. Further, being a leguminous crop it enriches soil fertility when roots, leaves and stems are in-situ incorporated. It is popularly known as "Golden bean or miracle bean". In India, it is grown in an area of 10.47 m ha with a production of 10.98 m t and productivity of 1049 kg/ha (Directorate of Economics and Statistics, 2018).

Optimum phosphorus nutrition is a key to the sustained higher legume productivity. Indian soils are beset with a higher degree of variability in crop response to different doses and sources of phosphatic fertilizers in different agro-climatic zones due to wide variations in fixation of applied fertilizer material owing to variations in soil pH, organic matter and calcium status and a complex chain of processes and factors that govern the ultimate phosphorus availability to crop plants. Phosphorus plays a vital role as a structural component of cell constituent and metabolically active compounds *i.e*., chloroplasts, mitochondria, phytin, nucleic acid, protein, flavo nucleotides and several enzymes. Besides, it also plays a crucial role in growth and development of root, seed and energy transformations (Raghuveer and Hosmath, 2018). Among the micronutrients molybdenum is one of the important nutrients particularly for legumes which is crucial for nitrogen fixing microorganisms. It is a co-factor for enzymes like nitrogenase, nitrate reductase, xanthine oxidase / dehydrogenase and sulphite reductase. It is needed by *Rhizobium*, the nodule forming bacteria, during the process of atmospheric nitrogen fixation for the conversion of the atmospheric inorganic nitrate form into organic (amino acid) form and is involved in the synthesis of ascorbic acid (Laltlamawia *et al.,* 2004).

Since, molybdenum is required in small quantity, application of this nutrient through seed treatment particularly at optimum concentration would increase root elongation with greater root proliferation and nodulation. Keeping these points in view, an experiment was initiated to find the response of soybean to phosphorus application and molybdenum seed treatment during the rainy season, 2015 at College Farm, College of Agriculture, Professor Jayashankar Telangana State Agricultural University (PJTSAU), Rajendranagar, Hyderabad. The soil of the experimental site was sandy loam with a pH of 7.4, electrical conductivity 0.23 dS/m, low in organic carbon (0.39 %), low in available N (218.0 kg/ha) and available P (33.3 kg P_2O_5/ha), high in available K (410.0 kg/ha) and available Mo (0.28 ppm) was above critical level. The experiment consisted of 12 treatment combinations *viz.,* three levels of phosphorus (0, 30 and 60 kg P_2O_5/ha) and four levels of seed treatment with molybdenum (0, 2, 4 and 6 g/kg seed) laid out in a randomized block design with factorial concept and replicated thrice.

Soybean crop (variety JS-335) was sown on 6th July adopting a spacing of 45.0 cm x 5.0 cm with a recommended dose of 30 kg N and 40 kg K_2O/ha. Phosphorus (soil application) and Molybdenum (seed treatment) were applied as per treatments (Table 1). The gross and net plot size were 5.85 m x 3.0 m and 4.95 m x 2.9 m, respectively. Pre-emergence herbicide pendimethalin 30% EC @ 1 kg a.i./ha was sprayed on next day after sowing under optimum soil moisture condition. At later stages of crop, weeds were controlled by manual weeding at 20-25 DAS. Bio-metric observations on the morpho-physiological parameters were

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taken on five representative plants selected randomly treatment wise from net plot and the mean values were presented. The data recorded on various parameters were statistically analyzed duly following the analysis of variance technique for randomized block design with factorial concept as suggested by Gomez and Gomez (1984). The oil content of seed for each treatment was determined by using continuous type Pulsed Nuclear Magnetic Resonance (NMR-oxford MQC). Gross returns were worked out by multiplying the economic yield with prevailing market price of seed and net returns were calculated for each treatment after deducting the corresponding cost of cultivation from gross returns. Benefit-cost ratio was worked out by dividing gross returns with cost of cultivation.

An overview of the data revealed that graded levels of Phosphorus and molybdenum seed treatment in soybean exerted significant influence on yield attributes, quality parameters, N uptake, seed, haulm yield and monetary returns (Table 1). Among the phosphorus treatments, application of 60 kg P_2O_5/ha recorded significantly higher number of seeds/pod (2.8), shelling percentage (73.9 %) and seed (1784 kg/ha) and haulm yield (2794 kg/ha) over 30 and 0 kg P_2O_5/ha. Graded levels of phosphorus significantly improved the seed yield with each increment from 30 (2125 kg/ha) to 60 kg (2794 kg/ha) over 0 kg (1588 kg/ha). The improvement in seed yield was to the extent of 22.68 and 47.19 % respectively over no 'P' application. With respect to molybdenum seed treatment, 6 g/kg registered maximum number of seeds/pod (2.7), shelling percentage (68.5 %) and haulm yield (2365 kg/ha). Seed treatment with molybdenum significantly improved seed yield with 2 g/kg (1467 kg/ha), 4 g/kg (1521 kg/ha), 6 g/kg (1572 kg/ha) over no seed treatment (1418 kg/ha). The extent of increase in yield was to the tune of 3.45, 7.26 and 10.86 % respectively over 'no' seed treatment with molybdenum.

The interaction effect of graded levels of P application and Mo seed treatment was found to be significant on number of pods/plant (Table 2), seed yield/plant (Table 3) and oil content (Table 4). Among the treatment combinations, application of P @ 60 kg P_2O_5/ha along with molybdenum @ 6 g seed treatment recorded significantly higher pods/plant (42.4), seed yield/plant (8.16 g/plant) and oil content (19.43%) over rest of the treatment combinations. Similarly, N uptake by the seed and protein content were found to be highest with the application of 60 kg P_2O_5/ha (117.0 kg/ha and 41.0%) and molybdenum seed treatment @ 6 g/kg (101.6 kg/ha and 40.2 %).

Table 1 Yield attributes, yield, N uptake and monetary returns of soybean as influenced by phosphorus levels and molybdenum seed treatment

Treatment	No. of pods/ plant	Seeds/ pod	Shelling (%)	Seed yield/ plant (g)	Seed yield (kg/ha)	Haulm yield (kg/ha)	Oil content (%)	N uptake by seed (kg/ha)	Protein content (%)	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
Phosphorus level (kg/ha)													
P_1-0	20.0	2.3	59.3	.5.12	1212	1588	18.0	75.2	39.0	17530	43200	25670	2.46
P_2-30	28.0	2.6	64.0	6.15	1487	2125	18.4	95.0	40.0	18615	50532	31917	2.71
P_3-60	38.0	2.8	73.9	7.48	1784	2794	18.9	117.0	41.0	19700	59220	39520	3.00
S.Em±	0.3	0.03	1.13	0.12	11	23	0.10	0.6	0.08	-	-	254	0.01
CD (p=0.05)	6.0	0.10	3.00	0.30	31	68	0.30	1.8	0.24	-	-	747	0.03
M_o seed treatment (g /kg seed)													
M_{o1}-0	24.9	2.0	62.8	5.81	1418	1992	18.0	90.0	39.5	17530	43200	25670	2.46
M_{o2}-2	27.2	2.6	64.6	6.06	1467	2095	18.4	93.7	39.8	17680	46056	28376	2.60
M_{o3}-4	29.6	2.6	67.0	6.40	1521	2224	18.5	97.7	39.5	17830	48360	30530	2.71
M_{o4}-6	31.9	2.7	68.5	6.73	1572	2365	18.7	101.6	40.2	17980	49872	31892	2.78
SEm±	0.4	0.04	0.41	0.04	12	27	0.04	0.7	0.10	-	-	294	0.02
CD (p=0.05)	1.2	0.12	1.23	0.12	36	79	0.12	2.1	0.25	-	-	862	0.06
Interaction (P x Mo)													
SEm±	3.0	0.07	1.80	0.19	22	47	0.07	1.3	0.18	-	-	509	0.03
CD (p=0.05)	7.8	NS	NS	0.47	NS	NS	0.21	NS	NS	-	-	NS	NS

Higher seed and haulm yield registered with the application of 60 P_2O_5/ha and seed treatment with Mo @ 6g/kg was perhaps due to the adequate nutrient availability and uptake by the crop that reflected in higher yield attributes (pods/plant, seeds/pod, seed yield/plant, test weight, and shelling per cent). Similar results of improved seed yield due to phosphorus application in soybean were earlier reported by Thanki *et al.* (2005) and Rupendra and

Sharma (2002) and molybdenum in lentil by Togay *et al.* (2014). Improved protein content was due to the improved nodulation coupled with the positive role of Mo on nitrogenase activity thereby improving biological N fixation and N uptake. These results are in accordance with Sharma *et al.* (2011) and Alben Awomi *et al.* (2012). Improved oil content under adequate P could be due to the fact that it helps in synthesis of fatty acids and their esterification by acceleration of biochemical reactions in glyoxalate cycle and P is a constituent of phospholipids that is highly essential for their synthesis (Singh and Singh, 2013).

Highest gross, net returns and B:C were accrued with 60 kg P_2O_5/ha (₹59,220/ha, ₹39,520/ha and 3.0) and molybdenum seed treatment, @6 g/kg (₹49,872/ha, ₹31,892/ha and 2.78 respectively) on account of higher seed yield in comparison to rest of the treatments. These findings are in line with those of Karpagam and Girishchander (2014).

Table 2 Number of pods/plant as influenced by interaction of phosphorus levels and molybdenum seed treatment

Factor -A Phosphorus levels (kg/ha)	Factor – B Molybdenum seed treatment (g/kg)				
	M_{o1}-0	M_{o2}-2	M_{o3}-4	M_{o4}-6	Mean (P)
P_1-0	16.8	18.6	20.8	22.2	20.0
P_2-30	24.5	26.7	28.6	31.0	28.0
P_3-60	33.5	36.4	39.4	42.4	38.0
Mean (M_o)	24.9	27.2	29.6	31.9	
P x M_o	S.Em±	3.0			
	CD (P=0.05)	7.8			

Table 3 Seed yield (g/plant) as influenced by interaction of phosphorus levels and molybdenum seed treatment

Factor -A Phosphorus levels (kg/ha)	Factor – B Molybdenum seed treatment (g/kg)				
	M_{o1}-0	M_{o2}-2	M_{o3}-4	M_{o4}-6	Mean (P)
P_1-0	4.80	5.00	5.23	5.46	5.12
P_2-30	5.73	6.00	6.30	6.56	6.15
P_3-60	6.90	7.11	7.66	8.16	7.48
Mean (M_o)	5.81	6.06	6.40	6.73	
P x M_o	S.Em±	0.19			
	CD (p=0.05)	0.47			

Table 4 Oil content (%) as influenced by interaction of phosphorus levels and molybdenum seed treatment

Factor -A Phosphorus levels (kg/ha)	Factor – B Molybdenum seed treatment (g/kg)				
	M_{o1}-0	M_{o2}-2	M_{o3}-4	M_{o4}-6	Mean (P)
P_1-0	18.03	18.16	18.21	18.26	18.00
P_2-30	18.00	18.33	18.41	18.56	18.40
P_3-60	18.00	18.85	19.03	19.43	18.99
Mean (M_o)	18.00	18.44	18.55	18.75	
P x M_o	S.Em±	0.07			
	CD (P=0.05)	0.21			

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Plant density and nitrogen interaction on productivity of summer sesame (*Sesamum indicum* L.)

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ABSTRACT

Plant spacing manipulations affect the quality and quantity of sunlight for photosynthesis and the branching *vis-à-vis* crop productivity. Field experiment was conducted to study the effect of different plant spacings (broadcasting, 30 x 30 cm, 45 x 30 cm and 45 x 45 cm and solid rows of 45 cm apart) in conjunction with nitrogen doses (0, 30 and 45 kg/ha) on growth rate of branches and capsules, and seed yield of sesame (Variety Sweta). Branching, a significant plant phenotypic plasticity in sesame was the main attribute affected by plant spacing and N doses. Solid rows of 45 cm apart sowing (2.2 lakh plants/ha) recorded significantly the highest seed yield (8.0 q/ha) among different plant spacing treatments. Crop raised with broadcasting method (approx 2.8 lakh plants/ha) yielded 7.4 q/ha which was significantly higher than other plant spacings of 30×30 cm (1.11 lakh plants/ha), 45×30 cm (0.74 lakh plants/ha) and 45×45 cm (0.49 lakh plants/ha). Application of 45 kg N/ha recorded significantly higher seed yield than 30 kg N/ha and no N across different plant spacings. Except 45×30 cm and 45×45 cm spacings, all other spacings recorded significantly higher seed yield for each increment in N dose.

Keywords: Nitrogen doses, Phenotypic plasticity, Plant density, Sesame

A coherent plant population is a prime agronomical prerequisite for higher seed yield of sesame, if nutrient resources are unlimited in the soil environment with a cap on brink plant density, which can provide a beneficial micro-environment within the canopy for optimum yields. Therefore, agronomical management to achieve optimal crop production targets optimal plant density for stabilizing yield in crop species (Donald, 1963). It was clear from surveys of different species and populations that plasticity can (i) be a complex character, and (ii) be selected to fit species to the particular demands of different environments (Bradshaw, 2006). The magnitude of the response of the planting spacing is expressed in terms of branching potential of specific cultivar and seed yield in soybean (Agudamua *et al*., 2016). However, in case of sesame a reduction in plant density might aid in more branches, since the density may alter plant architecture (Procópio *et al*., 2013). Balanced fertilization (Ramesh *et al*., 2017; Patel *et al*., 2020) is one of the soil and crop management practices and sesame demands all essential nutrients (Ramesh *et al*., 2019) which exert a great influence on seed yield (Patel *et al.,* 2020) under optimum plant population conditions. Further an increment in N improved maize yields at high planting densities (Ladha *et al*., 2016) as N optimized grain-filling parameters (Wei *et al*., 2019) through high N use efficiency (Ma, 2020), which might apply to sesame too, offsetting the resource competition. Plasticity in rapeseed after flowering was related to floral branching, which was strongly promoted by low plant density (Rondanini *et al*., 2017) could be analogous to sesame too.

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Despite some research efforts elsewhere in the world, for the most part these factors *viz.,* plant density and N have been overlooked for sesame production over the years.

Manipulating population density with optimum fertilizer schedule for a given sesame production system, results in more branches with a greater level of productivity through capsule production and seed yield rather than broadcasting that is commonly followed in rainfed production systems. Therefore, the triple alliance of an optimum population, geometry and nutrient schedule framework is practically preferred. With this backdrop, a study was conducted with the following objectives *viz*., i) to analyse the branching behaviour and capsule formation of sesame (Variety Shweta) under varying plant densities, and ii) whether incremental doses of N can offset plant density effect on sesame yield.

An experiment was conducted at Narkhoda research farm of ICAR-Indian Institute of Oilseeds Research, Hyderabad during summer season of 2018. The research farm is geographically located at a latitude of 17°15'16" N and longitude 78°18'30" E at an altitude of 542 m above sea level. The crop was grown in red sandy soils belonging to chalka soil series of Alfisols order. The soil was poor in nutrients (OC: 0.4%; N: 235 kg/ha (low), P: 9.5 kg/ha (low), K: 280 kg/ha (high). Need based irrigations were provided.

The experimental field was prepared following the primary tillage practices. The land was leveled using mould board plough followed by rotavator to obtain fine soil tilth. The experiment was conducted in split-plot design with three replications. Five plant spacings were arranged in main-plots (broadcasting, 30×30 cm, 45×30 cm, 45×45 cm and solid rows 45 cm apart to accommodate 28, 11, 7, 5 and 22 plants/m^2) and three N doses in sub-plots (0, 30, and 45 kg/ha). Following the specifications of the design, a field layout was prepared and each treatment was assigned randomly to experimental plots within the main and sub-plots. The blocks and plots within each block were separated by a 0.5 m wide-open space. A plot size of 5.4 m × 4.5 m was adopted to accommodate all the treatments. Two border rows and two plants on either side of the row were left while harvesting to avoid border effects. Sesame (Variety Sweta) was used for the study. Sowing was done on 19th January 2018 and harvested on 13th April 2018. The seed rate used for broadcasting and solid rows of 45 cm apart was 5 kg and 3.96 kg/ha respectively. The recommended seed rate for sesame is 5 kg/ha. Three to five seeds were sown as per the treatments except in broadcasting and solid-row method of sowing. At 15 days after sowing (DAS), the seedlings were thinned to achieve the desired plant population (one plant/hill) for each plot except in solid row planting and broadcasting. Basal application of 30 kg P_2O_5 and 20 kg K_2O/ha was carried out at sowing. Half the dose of N was applied at sowing and the remaining half was applied at 25 DAS as per the treatment. Urea, SSP, and muriate of potash were used as sources of N, P_2O_5 and K_2O respectively. Hand weeding was carried out to keep the plots free from weeds and to provide better aeration. Recommended standard location specific package of practices and prophylactic measures were followed to raise a healthy crop. Five plants randomly selected from each plot were tagged and data on number of branches/plant and capsules/plant were recorded at periodic intervals. At the end of cropping season, yield was recorded from net plot area and computed to q/ha. All the data were subjected to two-way analysis of variance (ANOVA) using the Statistical Analysis System (SAS Institute, Cary, NC). The F-test was used to determine the significance of the treatments and least significant difference (LSD) was used to compare the means.

Branch/capsule growth rates were calculated from the formula.

Branch/capsule growth rate = $(W_2-W_1)/(t_2-t_1)$, where W_1 and W_2 are branch/capsule number at times t_1 and t_2.

Our experimental results showed that sesame at all densities produced branches but the higher the density, the fewer the number of branches were produced. Number of branches/plant varied which was in the range of 1.58-3.16, 2.07-4.37 and 2.82-4.74/plant at 30, 60 and 90 DAS respectively and that a large proportion of this variation was noticed due to a variation in plant-plant and row-row spacing, confirming previous observations (Langham, 2007) on sesame that wide row spacing with intense light a "few branch" line may have 6 or more branches, and under low fertility and moisture, a "many branch" line may have 4 branches or less. Further the views of Chapin (1980) that plants from high-resource environments are generally more plastic than their counterparts from low-resource environments were applicable in the present study wherein the sesame crop is raised under irrigated ecology with varying space availability. The results presented in Table 1 indicated that the number of branches/plant was governed by the plant density. This corroborates the views of Ashri (1998). In sesame, branching is a complex character predominantly decided by the environment *i.e.*, spacing, availability of sun light and soil fertility rather than the genotype *per se.* Foregoing plant-plant spacing as in 45 cm solid row spacing and/or neither side spacing as in broadcasting had deleterious effects on branching behaviour of sesame since direct sunlight has to strike the leaf axil for branch initiation (Langham, 2007). The data presented for branch growth rates were significantly different either with plant spacing or nitrogen doses, albeit, have provided some clues on their effect on branching. Branch growth rate was higher at 30-60 DAS for 45 ×45 cm than 30×30 cm, but the reverse at 60-90 DAS possibly the close plant-plant spacing at 30×30 cm might have modified the microclimate at the plant level to induce the branching. The beneficial effect of plant microclimate on sesame growth and yield was also confirmed by Swami *et al*. (2017). If the branch has to grow continuously, it essentially requires light at the tip. However, the amount of light that reaches the branches at the bottom is dependent on the population size. This corroborates the views of Langham (2007). Application of N fertilizer invariably facilitated in branching due to the availability of sufficient nutrients in the soil from time to time. This also corroborated with the findings of Haruna (2011).

Sesame yield is primarily dictated by the capsule number/plant and its weight. Results (Table 2) indicated that sesame produces capsules continuously from 50-90 DAS as an indeterminate plant, as conformed by Ashri (1998) and have a direct bearing on the seed yield/plant including the number of primary and secondary branches (Aristya and Taryono, 2016). However, capsule number/plant decreased due to the intensified competition for space and light, if not nutrients, under crowded plant densities viz., broadcasting as well as 45 cm solid row spacing from 30 DAS to harvest with an average reduction in capsule number/plant of 72-82% and 52-62% respectively over average of square (30×30 cm and 45×45 cm) and rectangular plant geometry (45×30 cm). The capsule growth rate was the lowest for broadcasting due to intense competition for space at 50-70 DAS. At this stage, capsule growth rate of each spacing significantly differed over other spacings suggesting the efficient utilisation of the space available in two-dimensions (plant-plant and row-row). Even the availability of distinct row-row spacing under 45 cm solid row too had a clear advantage over other spacings. However, at 60-70 DAS, the capsule growth rate under rectangular geometry (45×30 cm) registered significantly the lowest capsule growth rate over other spacings. Hence, it is clear that improving capsule number/plant under rectangular geometry remains a challenging issue for further enhancements in capsule production.

As the plant density increased, the capsule number/plant decreased, so that the total number of capsules harvested per unit area remained in the range of 635-948/m^2 over varied plant densities. However, all the capsules formed may not directly contribute to the final yield since 86 to 91% of the reproductive potential was reported to be lost during development and while capsule formation is rapid in the early reproductive phase, shedding follows at the later stages as opined by Saha and Bhargava (1982). Trends in capsule number/plant were balanced by the opposite effects on seed yield per unit area.

Application of N either at 30 or 45 kg/ha was equally effective in significantly influencing the capsule number/plant and capsule growth rate and over no N at 70 and 90 DAS. The interaction effect between plant spacing and N significantly influenced the capsule growth rate during 50-70 DAS.

Table 1 Effect of plant spacing and N on branching pattern in sesame

Treatment	Branches (No./plant)			Branch growth rate ($\times 10^{-2}$/day)		
	30 DAS	60 DAS	90 DAS	30-60 DAS	60-90 DAS	30-90 DAS
Plant spacing (S)						
Broadcasting	1.6^{c}	2.1^{c}	2.8^{b}	1.6	2.5	2.1
30 × 30 cm	2.9^{a}	3.6^{ab}	4.2^{a}	2.4	1.9	2.2
45 × 30 cm	2.6^{ab}	3.7^{ab}	4.3^{a}	3.5	2.2	2.8
45 × 45 cm	3.2^{a}	4.4^{a}	4.7^{a}	4.0	1.1	2.7
Solid rows 45 cm apart	2.1^{bc}	3.1^{b}	3.8^{ab}	3.3	2.6	2.9
SEm±	0.2	0.2	0.2	0.4	0.3	0.2
CD (P=0.05)	0.6	0.9	0.8	NS	NS	NS
CV (%)	21.9	24.9	17.5			
Nitrogen (N) kg/ha						
0	2.2^{b}	3.0^{b}	3.5^{b}	2.7	1.8	2.2
30	2.6^{a}	3.5^{a}	4.1^{ab}	2.9	1.9	2.4
45	2.7^{a}	3.6^{a}	4.4^{a}	3.3	2.4	2.9
SEm±	0.1	0.1	0.1	0.3	0.2	0.2
CD (P=0.05)	0.3	0.4	0.4	NS	NS	NS
CV (%)	16.2	15.2	14.0			
Interaction (S×N)						
CD (P=0.05)	NS	NS	NS	NS	NS	NS

The seed, stalk and biological yield (Table 3) was significantly influenced by plant spacings. Significantly, the highest seed yield was recorded in 45 cm solid row spacing (8.0 q/ha). The next best treatment was broadcasting method (7.36 q/ha). And significantly the lowest seed yield was recorded (5.7 q/ha) with 30×30 cm. As stated by Aristya and Taryono (2016) from factor wise analysis that, the number of branches (primary and secondary), the number of capsules/plant, and biomass yield/plant were considered as appropriate traits for sesame improvement, and for maximising sesame productivity. The main reasons for this were that 1) an optimum population canopy structure and/or branching pattern is closely related to proper plant density, and 2) the full yield potential supported by sufficient fertilization for the given plant density structure. Planting density has proven to be a very effective agronomic strategy to improve sesame seed yield. Indeed, a plant spacing of 45 x 45 cm was found to be beneficial only in terms of branching and capsule number but not on seed yield/ha. Intermediate spacing aimed at increasing the plant population have response with varying degrees of branching and capsule number, but yield is subjected to strong trade-offs. This study indicated that the importance of the higher row-row spacing rather than plant-plant spacing. The plant densities were actually established at 45 cm solid row spacing, it is obvious that (a) all capsules might be filled as productive capsules, and (b) single capsule weight might also be sufficiently high. When the biomass yields of sesame are compared, the most striking difference between the seed and stalk yields of broadcasting and 45 cm solid row spacing could be seen. Hence, it appeared that for sesame the seed drill sowing of 45 cm of solid rows could maintain the optimum plant density in the range of 2.2 lakh plants/ha. A comparison of row sowing (30×30 cm, 45×30 cm, 45×45 cm and solid row 45 cm apart) over broadcasting on seed yield (6.51 q/ha over 7.35 q/ha) could not prove beneficial in the present study apparently due to a change in the population size *i.e*., 1.14 lakhs (0.49-2.2 lakhs/ha) for row spacing while 2.8 lakhs/ha for broadcasting. This is contrary to the finding of Kumar *et al.* (2015) quoting an average 16% yield increment with row sowing. Stem dry matter production was much lower in the latter spacing, apparently due to more resource allocation to the seed and vice-versa for broadcasting. The higher densities allocated more vegetative dry matter to stem but less seed than the lower densities. Plant densities might have positively influenced canopy microenvironment such as light, temperature, and relative humidity. This corroborates the opinion of Yang *et al*. (2014). Further the light quantity and/or quality available from the spacing might have served as a sensory cue for the adjustment of plant growth and development. This conforms to the views of Rondanini *et al.* (2017). Except 45 × 30 cm and 45 × 45 cm spacing, all other spacings yielded significantly higher yield for each increment with nitrogen dose, while in the former 45 kg/ha recorded significantly higher seed yield over other N doses (Table 4). Oil content was not influenced significantly either by the plant spacings or by N.

Table 2 Effect of plant spacing and N on capsule formation pattern in sesame

Treatment	Capsules (No./plant)			Capsule growth rate (No./day)	
	50 DAS	70 DAS	90 DAS	50-70 DAS	70-90 DAS
Plant spacing (S)					
Broadcasting	10.3^{d}	16.6^{e}	28.9^{c}	0.3^{e}	0.6^{a}
30 × 30 cm	36.7^{b}	72.0^{c}	85.3^{b}	1.7^{c}	0.7^{a}
45 × 30 cm	48.0^{a}	90.6^{b}	97.5^{b}	2.1^{b}	0.3^{b}
45 × 45 cm	51.8^{a}	114.9^{a}	128.5^{a}	3.2^{a}	0.7^{a}
Solid rows 45 cm apart	21.6^{c}	36.3^{d}	42.1^{c}	0.8^{d}	0.3^{b}
SEm±	2.5	3.5	3.3	0.1	0.1
CD (P=0.05)	9.9	14.1	13.3	0.3	0.3
CV (%)	27.1	19.7	15.9		
Nitrogen (N) kg/ha					
0	31.2	58.5^{b}	66.1^{b}	1.4	0.4^{b}
30	32.5	66.5^{ab}	82.1^{a}	1.8	0.5^{ab}
45	37.4	73.5^{a}	80.6^{a}	1.8	0.7^{a}
SEm±	1.5	2.6	2.4	0.1	0.1
CD (P=0.05)	NS	9.3	8.6	NS	0.2
CV (%)	21.6	18.4	14.7		
Interaction					
S at N					
SEm±	3.4	5.7	5.3	0.2	0.2
CD (P=0.05)	NS	NS	NS	0.9	0.5
N at S					
SEm±	3.7	5.8	5.5	0.3	0.1
CD (P=0.05)	NS	NS	NS	0.8	0.5

Large scale row cropping of sesame is preferred to facilitate intercultural operations through seed drill sowing under rainfed environments. Notwithstanding to this fact, the resource poor farmers prefer broadcasting. Enhancing sesame productivity has become entrenched in a single tactic-population management under a specific nitrogen regime which is an effective measure to pursue in order to achieve high yield in sesame. Optimal yield can only be obtained through proper coordination of branching and capsule number by modification of plant density. The underlying mechanism for the enhanced reproductive allocation must be through, but the study reinforced the importance of optimum plant density and/or row sowing in question, for maximising the sesame yield.

From our experimental results, it could be concluded that solid row sowing at 45 cm apart rows (seed rate of 3.96 kg/ha) mimicking seed drill sowing provided significantly the highest seed yield across different nitrogen doses. Among other plant spacing treatments, sowing by broadcasting (seed rate of 5 kg/ha) provided significantly higher seed yield than 30 x 30 cm, 45 x 30 cm and 45 x 45 cm plant spacings.

Table 3 Effect of plant spacing and N on yield and seed oil content of sesame

Treatment	Yield (q/ha)			Oil content (%)
	Seed	Stalk	Biological	
Plant spacing (S)				
Broadcasting	7.4[b]	18.6[a]	25.9[a]	41.4
30 × 30 cm	5.7[d]	8.5[bc]	14.2[c]	40.4
45 × 30 cm	6.7[c]	8.6[bc]	15.4[bc]	40.8
45 × 45 cm	5.7[d]	6.5[c]	12.2[c]	40.9
Solid rows 45 cm apart	8.0[a]	12.1[b]	20.1[b]	40.4
SEm±	0.1	1.0	1.2	0.3
CD (P=0.05)	0.2	3.8	5.0	NS
CV (%)	11.2	32.2	26.2	3.07
Nitrogen (N) kg/ha				
0	5.5[c]	10.6	16.1	41.0
30	6.5[b]	10.5	16.9	40.5
45	8.1[a]	11.5	19.6	40.7
SEm±	0.1	0.7	0.8	0.1
CD (P=0.05)	0.3	NS	NS	NS
CV (%)	13.6	31.57	21.6	1.56
Interaction (S×N)	Significant	NS	NS	NS

Table 4 Interaction effect of plant spacing and N on seed yield of sesame (q/ha)

Treatment	Nitrogen (N) (kg/ha)		
Plant spacing (S)	0	30	45
Broadcasting	5.8	6.7	9.6
30 × 30 cm	4.8	5.8	6.5
45 × 30 cm	5.6	6.2	8.1
45 × 45 cm	5.1	5.7	6.4
Solid rows 45 cm apart	6.2	7.9	9.8
	S at same N		N at same S
SEm±	0.3	SEm±	0.3
CD (P=0.05)	0.6	CD (P=0.05)	0.7

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Productivity and profitability of summer sunflower (*Helianthus annuus* L.) with integrated nutrient management

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ABSTRACT

A field experiment was conducted at College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar on sandy loam soils during summer season of 2018-19 with an objective of evaluating nutrient management for enhancing sunflower productivity under eastern Indian conditions. The experiment was laid out in a randomized block design with three replications. There were twelve treatment combinations *viz.,* 1. Control; 2. Recommended dose of fertilizers (RDF @ 60:80:60 kg N: P_2O_5: K_2O/ha); 3. RDF + S @ 40 kg/ha; 4. RDF + B @ 0.02%; 5. RDF + S @ 40 kg/ha + B @ 0.02%; 6. STBFR (60:100:60 kg N: P_2O_5: K_2O/ha + S @ 40 kg/ha + B @ 0.02%); 7. FYM @ 5 t/ha; 8. RDF + FYM @ 5 t/ha; 9. RDF + FYM @ 5 t/ha + S @ 40 kg/ha; 10. RDF + FYM @ 5 t/ha + B @ 0.02%; 11. RDF + FYM @ 5 t/ha + S @ 40 kg/ha + B @ 0.02%; 12. STBFR + FYM @ 5 t/ha. The results of the study indicated that integrated nutrient management exhibited significant effect on growth, seed and oil yield of sunflower. Application of STBFR + FYM @ 5 t/ha recorded significantly highest growth parameters, seed (2.59 t/ha) and oil yield (1114 kg/ha) of sunflower which remained at par with RDF + FYM @ 5 t/ha + S @ 40 kg/ha + B @ 0.02%. Highest gross (₹141084/ha) and net returns (₹85406/ha) were recorded with STBFR + FYM @ 5 t/ha.

Keywords: Boron, FYM, Nutrient management, Ray floret stage, RDF, Sunflower, STBFR

Oilseeds are important for human diet as well as industrial sector. India ranks fourth in oilseed production in the world, next only to the USA, China and Brazil, harvesting about 29 mt of oilseeds per annum, grown in an area of nearly 27 m ha with an annual average yield of 1058 kg/ha (Reddy and Immanuelraj, 2017). Sunflower is one of the most important high quality oilseed crops which is widely cultivated in different parts of the world and is emerging as an important oilseed crop of Odisha state.

Sunflower oil is generally considered as premium oil and fetches premium value in the market because of its light colour and high level of poly unsaturated fatty acids (PUFA).The productivity is affected by various factors like rainfed cultivation, quality seed, improper nutrient management, bird damage and insect pest and disease incidences. Continuous and indiscriminate use of chemical fertilizers containing the only major nutrients has led to secondary and micronutrient deficiencies (Sudhakar *et al.*, 2020) and hence balanced fertilization (Ramesh *et al.*, 2017) is recommended which exerts a greater influence on seed yield (Patel *et al.*, 2020). Therefore, in the coming decades, integrated nutrient management is expected to play a significant role in improving the crop yield as well as designing sustainable agriculture systems. In this context, an attempt has been made to evaluate the impact of integrated nutrient management on growth, yield and profitability of sunflower during the summer season.

A field experiment was conducted at Main Research Farm, OUAT, Bhubaneswar on sunflower during summer, 2019. The station is geographically located at 20° 12'N latitude and 85°52' E longitude with an altitude of 25.9 m above mean sea level. The soil of experimental field was sandy loam having 295 kg/ha available N, 10.7 kg/ha available P, 147.8 kg/ha exchangeable K and 0.62% organic carbon. The pH of the soil was 5.3.The experiment was laid out in a randomized block design, replicated thrice with twelve treatments: 1. Control, 2. RDF (60:80:60 kg N: P_2O_5: K_2O/ha), 3. RDF + S @ 40 kg/ha, 4. RDF + B @ 0.02%, 5. RDF + S @ 40 kg/ha + B @ 0.02% (at ray floret opening stage), 6. Soil test based fertiliser recommendation (STBFR 60:100:60 kg N: P_2O_5: K_2O/ha + S @ 40 kg/ha + B @ 0.02%), 7. FYM @ 5 t/ha, 8. RDF + FYM @ 5 t/ha, 9. RDF + FYM @ 5 t/ha + S @ 40 kg/ha, 10. RDF + FYM @ 5 t/ha + B @ 0.02%, 11. RDF + FYM @ 5 t/ha + S @ 40 kg/ha + B @ 0.02%, 12. STBFR + FYM @ 5 t/ha. KBSH-53 was sown at a spacing of 60 x 30 cm and a plot size of 5.5 m ×3.2 m (17.6 m^2) was maintained for each replication. Well decomposed FYM (0.52% N, 0.24% P_2O_5, 0.49% K_2O, 0.021% S, 23 ppm Zn and 18 ppm B), full dose of phosphorus, potassium, sulphur and half of nitrogen was applied as basal dose while remaining nitrogen was applied in two equal splits at knee-high stage and at 50-55 DAS. The source of N, P and K, S and B were Urea, Diammonium phosphate, Muriate of potash, Gypsum, and Borax respectively. All the cultural operations were performed as per the standard package of practices of sunflower. Pre-emergence application of pendimethalin @ 1.0 kg a.i./ha

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was done uniformly followed by hand weeding at 40 DAS. During the experimental period, a total of five irrigations were given uniformly to all plots and irrigation was stopped 25 days before harvesting. Need-based plant protection measures were taken up. Observations on morphological parameters were recorded from ten randomly selected plants while yield was recorded on net plot (3.0×3.0 m^2) basis. The raw data was subjected to statistical analysis (Gomez and Gomez, 1984). The gross plot size was 5.5m×3.2m (17.6 m^2).

For most of the parameters studied [plant height, total dry matter (TDM), leaf number, leaf area index (LAI)], the two treatments *viz.,* STBFR + FYM @ 5 t/ha and RDF + FYM @ 5 t/ha + S @ 40 kg/ha + B @ 0.02% were at par. The treatment with STBFR + FYM @ 5 t/ha registered taller plants (207 cm) at harvest and was at par with RDF + FYM @ 5 t/ha + S @ 40 kg/ha + B @ 0.02%. An increase in plant height might be attributed to the positive effect of FYM, soil test based fertilizer application coupled with FYM assured the availability of Sulphur and Boron besides other nutrients at an optimum rate at all growth stages. The results are in conformity with the findings of by Rasool *et al.* (2013). The number of leaves/plant and LAI were significantly different with nutrient management options following similar trend. The nutrient management options caused a significant variation in the dry matter accumulation too. The maximum dry matter accumulation/plant was observed with STBFR + FYM @ 5 t/ha at harvest (145.7 g) which remained at par with RDF + FYM @ 5 t/ha + S @ 40 kg/ha + B @ 0.02%. This might be due to an improvement in soil physical, chemical and biological properties as conformed by Ahmad and Jabeen (2009). Sulphur plays an important role in the nutrition of oilseed crops and it acts as a constituent of sulphur containing amino acids like cystine, cysteine and methionine (Gangadhara, 1990; Parmar *et al.*, 2018). Sulphur is required for the synthesis of oil while boron for pollen germination and pollen tube growth (Duggar, 1983), and boron deficiency at flowering can affect pollen viability and abortion of stamens and pistils (Dell and Longbin, 1997; Chitralekha and Nirmala, 2000) which contributes to low seed set.

Table 1 Growth parameters and yield of sunflower as influenced by nutrient management

Treatment	Plant height (cm) at harvest	Drymatter at harvest (g/plant)	No of functional leaves/plant (75 DAS)	Leaf area index (LAI) (75 DAS)	Seed yield (t/ha)	Oil yield (kg/ha)
T_1- Control	161.0	100.71	20.20	3.10	0.84	297
T_2- RDF (60:80:60 kg N: P_2O_5: K_2O /ha)	178.0	112.29	27.98	3.16	1.52	592
T_3- RDF + S @ 40 kg/ha	181.2	115.87	28.13	3.18	1.69	679
T_4-RDF + B @ 0.02%	184.6	118.17	28.80	3.21	1.72	684
T_5-RDF + S @ 40 kg/ha + B @ 0.02%	188.3	127.79	30.17	3.27	1.99	819
T_6- STBFR (60:100:60 kg N: P_2O_5: K_2O /ha + S @ 40 kg/ha + B @ 0.02%)	198.0	137.55	31.23	3.32	2.18	917
T_7- FYM @ 5 t/ha	169.4	106.48	24.27	3.12	1.24	448
T_8- RDF + FYM @ 5 t/ha	187.7	122.10	29.44	3.24	1.83	738
T_9- RDF + FYM@5 t/ha + S @ 40 kg/ha	194.3	131.08	30.47	3.28	2.01	838
T_{10}- RDF + FYM @ 5 t/ha + B @ 0.02%	196.2	133.11	31.03	3.30	2.09	865
T_{11} - RDF + FYM @ 5 t/ha + S @ 40 kg/ha + B @ 0.02%	202.6	142.12	31.62	3.35	2.37	1000
T_{12}- STBFR + FYM @ 5 t/ha	207.3	145.69	33.11	3.39	2.59	1114
SEm ±	2.66	1.66	0.62	0.02	0.11	44.9
CD (p=0.05)	7.8	4.96	1.82	0.07	0.33	132.0
CV(%)	10.2	9.8	9.5	9.0	10.68	10.2

*RDF- 60: 80: 60 kg N: P_2O_5: K_2O/ha

Significantly highest seed (2.59 t/ha) and oil yield (1114 kg/ha) was recorded with STBFR + FYM @ 5t/ha which remained at par with RDF + FYM @ 5 t/ha + S @ 40 kg/ha + B @ 0.02% (2.37 t/ha and 1000 kg/ha respectively). STBFR with FYM directly increased crop yields either by acceleration of respiratory process, by increasing cell permeability, hormone growth action or combination of all the processes *viz*., release of nutrients, increasing availability of nutrients and improving soil physical, chemical and biological properties. The beneficial effect of FYM on sunflower yield is well documented by Rasool *et al.* (2013) and Sheotran *et al.* (2017). Most of the pathways are dependent on enzyme and co-enzymes, which are synthesized by these mineral nutrients such as sulphur, boron, major nutrients (NPK) and FYM. Better translocation of photosynthates from source to sink enabled better growth and yield attributing parameters and finally the seed yield of crop. This corroborates the findings of Rasool *et al.* (2013). Highest oil yield might be due to better synthesis of sulphur containing amino acids and fatty acid biosynthesis (especially the step of conversion of Acetyl CO-A to Melonyl CO-A) resulting from increased activity of thiokinase enzyme which depends upon sulphur supply. Similar results were reported by Akbari *et al.* (2011) and Rasool *et al.* (2013). B application might have increased the oil content due to better pollination and seed set leading to formation of protein and oil synthesis thereafter (Tahir *et al.,* 2014).

Economics of sunflower crop varied significantly due to different nutrient management options (Table 2). Significantly highest gross return (₹1,41,084/ha) and net return (₹ 85,406/ha) were recorded with STBFR + FYM @ 5 t/ha. Application of STBFR + FYM @ 5 t/ha recorded 70.3% and 112.5% increased gross return and net return over RDF respectively. Application of STBFR + FYM @ 5 t/ha recorded highest B: C ratio of 2.56 apparently due to high seed yield.

Application of STBFR + FYM @ 5 t/ha enhances sunflower growth, yield attributes, seed yield, oil yield, and economic indices which remained at par with RDF + FYM @ 5 t/ha + S @ 40 kg/ha + B @ 0.02%. Thus integrated and balanced application of organic and inorganic sources of nutrients (along with micronutrients) has resulted in high monetary returns of sunflower and is necessary for sustaining sunflower yields in sandy loam soils of eastern India in the summer season that is emerging as a profitable crop.

Table 2 Economics of sunflower as influenced by different nutrient management options

Treatment	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
T_1- Control	31470	45468	13998	1.44
T_2- RDF (60:80:60 kg N: P_2O_5: K_2O /ha)	42111	82296	40185	1.95
T_3- RDF + S @ 40 kg/ha	44701	91476	46775	2.05
T_4 RDF + B @ 0.02%	43021	92934	49913	2.16
T_5 RDF + S @ 40 kg/ha + B @ 0.02%	45331	107828	70950	2.51
T_6 -STBFR (60:100:60 kg N: P_2O_5: K_2O /ha + S @ 40 kg/ha + B @ 0.02%)	46878	117828	70950	2.51
T_7- FYM @ 5 t/ha	39470	66960	27490	1.70
T_8- RDF + FYM @ 5 t/ha	50111	99306	49195	1.98
T_9- RDF + FYM @ 5 t/ha + S @ 40 kg/ha	52701	108864	56163	2.07
T_{10}- RDF + FYM @ 5 t/ha + B @ 0.02%	51021	113292	62271	2.22
T_{11} - RDF + FYM @ 5 t/ha + S @ 40 kg/ha + B @ 0.02%	53331	128304	74973	2.41
T_{12}- STBFR + FYM @ 5 t/ha	54778	140184	85406	2.56
SEm ±	-	3105.3	3465.6	-
CD (P=0.05)	-	9107	10097	-

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Nutrient uptake, post-harvest soil nutrient status and economic returns from sunflower (*Helianthus annuus* L.) hybrids under different tillage and nutrient levels on lowland rice fallow environments of Odisha

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ABSTRACT

A field experiment was conducted at College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar on sandy loam soils during summer season of 2019 to study the effect of varied nutrient doses and tillage on the nutrient uptake and economics of sunflower (*Helianthus annuus* L.) hybrids under lowland rice fallow environments. Three sunflower hybrids *viz.,* DRSH-1, KBSH-44 and MSFH-17 were tested under three graded fertility levels RDF (recommended dose of fertilizers), 50% RDF (30: 40: 30 kg N: P_2O_5: K_2O /ha), 100% RDF (60: 80: 60 kg N: P_2O_5: K_2O /ha) and 150% RDF (90:120:90 kg N: P_2O_5: K_2O/ha) and four tillage practices *viz.,* reduced, minimum, zero tillage and conventional tillage practice. Sunflower under zero tillage recorded the highest uptake of N (52.65 kg /ha), P (21.87 kg/ha) and K (76.03 kg/ha) besides highest seed yield (1.91 t/ha). On the other hand, conventional tillage recorded the highest post-harvest soil available nitrogen (216.6 kg /ha), phosphorous (12.9 kg/ha) and potassium (214.4 kg/ha). Among the hybrids, KBSH-44 recorded significantly higher seed yield (1.81 t/ha) besides highest nutrient uptake. Raising sunflower hybrid KBSH-44 under rice fallow zero tillage conditions and fertilized with 150% RDF (90:120:90 kg N: P_2O_5: K_2O/ha) was found economically superior in terms of gross returns, net returns and B: C ratio (2.34).

Keywords: Nutrient uptake, RDF, Rice fallow, Sunflower hybrid

Oilseeds play an important role in agricultural economy of India. Oilseeds are important next only to food grains in terms of area, production and value. Sunflower ranks third in total area and fourth in the total production among major oilseed crops in the world i.e. soybean, *Brassica*, sunflower and groundnut. Its oil is of premium quality with high level of poly unsaturated fatty acids (PUFA) which is good for heart patients. Presently sunflower is cultivated worldwide on an area of 27.3 m ha with a productivity of 1.82 t/ha. In India, area under sunflower is 3.81 lakh ha with a production of 2.51 lakh tonnes. In Odisha, it is cultivated in an area of 24.88 thousand hectares with production and productivity of 29.69 thousand metric tonnes and 1193 kg/ha, respectively. Rice fallow areas are the potential regions for horizontal expansion of oilseeds to utilize the residual soil moisture and nutrients (Ramesh *et al*., 2020). Sunflower can serve as an ideal catch crop during the period when land is left fallow after *kharif* rice with 150 days duration which is harvested during November-December (Ramesh *et al.,* 2019). In Odisha, rice fallow includes all the three rice ecosystems *viz.,* upland, medium as well as low lands, which are kept fallow during *rabi* season after harvest of *kharif* paddy to the tune of 12.2 lakh ha spread over all the thirty districts due to multitude of reasons. Although sunflower is cultivated in few pockets with supplemental irrigation, improved package of practices are needed to boost the productivity.

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Tillage plays a major role under rice fallow environments. While conservation agriculture is a cultivation practice encompassing nil disturbances to the land (Ramesh *et al*., 2021) through conservation tillage to control erosion, reduce soil compaction, improve soil physical properties and retention of moisture and thereby improve land productivity. Nutrient supply has a great influence on crop grain yield (Mohammadi *et al.,* 2011) and the yields of hybrids are better than varieties due to high nutrient uptake (Sheoran *et al*., 2016). Sunflower crop responds to nutrients because of its deep root system. Balanced fertilization favourably influences seed yield (Ramesh *et al.,* 2017; Patel *et al.,* 2020). Conservation tillage places greater emphasis on environment, soil organic carbon storage, minimizing tillage expenses and so on. Understanding the best tillage practice, fertilizer management for a particular hybrid is a critical component of such rice fallow situations. Appropriate tillage practices with balanced application of fertilizers for a suitable hybrid would result in a greater level of productivity, nutrient uptake and a higher economic benefit than if management practices were solely based on the non-rice fallow systems. Keeping these points in view, the present experiment was conducted to examine the effect of different tillage practices and fertility management on productivity and nutrient uptake of summer sunflower hybrids in rice fallow environments of Odisha.

The experiment was conducted at Agronomy Main Research Farm, OUAT, Bhubaneswar during the summer, 2019. The research farm is geographically located at 200

12'N latitude and 850 52' E longitudes at an altitude of 25.9 m above mean sea level. The soil of the experimental field was sandy loamy, slightly acidic (pH =5.5), low in organic carbon (0.34%), available N (200.0 kg/ha) and P_2O_5 (11.7 kg/ha) and medium in exchangeable K_2O content (210.0 kg/ha). The experiment was laid out in a split-split plot design, replicated thrice with four tillage management practices (M_1- Conventional, M_2 - Reduced, M_3 - Minimum and M_4 - Zero), in main plots, three genotypes (G_1- DRSH-1, G_2- KBSH-44 and G_3-MSFH-17 as (local check) in sub plots and three fertility levels F_1- 50% RDF (30 : 40 : 30 kg N : P_2O_5: K_2O/ha), F_2-100% RDF (60:80:60 kg N:P_2O_5:K_2O/ha), F_3-150% RDF (90:120:90 kg N:P_2O_5:K_2O/ha) in sub-sub plots. The gross plot size was 5.4 m×3.3 m (17.82 m^2) with a spacing of 60 cm x 30 cm. The land was prepared as per the tillage treatments, conventional tillage (2 plough fb 2 cultivator and 1 rotavator), reduced tillage (1 plough fb 1 cultivator and 1 rotavator), Minimum tillage (1 cultivator fb 1 rotavator) and zero tillage (Herbicide spray + seed dibbling) after harvest of the preceding rice crop. Well decomposed FYM @ 5t/ha was applied uniformly at the time of final land preparation. The fertilizer was applied as per the treatment i.e. 50% RDF (30: 40: 30 kg N: P_2O_5: K_2O/ha), 100% RDF (60: 80:60 kg N: P_2O_5: K_2O/ha) and 150% RDF (90: 120: 90 kg N: P_2O_5: K_2O/ha) through urea, single super phosphate and muriate of potash. Entire quantity of P was applied as basal whereas N was applied in three splits and K in two splits. Full dose of P + 50% N + 50% K was applied at the time of sowing. First topdressing was done at 30 DAS with 25% N + 50% K while the balance 25% N was top dressed at 45 DAS. Three Sunflower hybrids *viz*., DRSH -1, KBSH-44 and MSFH-17 (DRSH-1:100-105 days duration, yield potential 20-25 q/ha, oil content of 40-44%; KBSH-44: 95-100 days duration, yield potential 17.5-28 q/ha, oil content 36-38 %; MSFH-17 :85-88 days duration, yield potential 13-16 q /ha, oil content 35-37%) were sown @ 5 kg/ha in line by maintaining 60 cm row to row and 30 cm plant to plant distance, at a depth of 3-4 cm on 31.12.2018. For weed management in zero tillage plots, glyphosate @1.0 kg a.i./ha was sprayed after harvest of rice followed by pre-emergence spray of pendimethalin @ 1.0 kg/ha. For other tillage practices two hand weeding were done at 20 and 40 DAS. During experimental period, a total of five irrigations were given uniformly. The crop was kept free from pests and diseases by taking up the need-based plant protection measures. The crop was harvested when back of the head (capitulum) turned to lemon yellow colour. Standard soil and plant nutrient analysis procedures were followed for nutrient uptake calculations and post-harvest nutrient status. Data were analysed statistically using the F-test (Gomez and Gomez, 1984). Critical difference (CD) values at 5% probability level were used for determining the significance of differences between the means.

Our experimental results, with respect to yield and economics of different treatments, indicated that zero tillage recorded significantly highest seed yield (1.91 t/ha) while conventional tillage gave the least seed yield of 1.63 t/ha. Significant increase of seed yield in no tillage over conventional tillage was also reported earlier by Sapkota *et al*. (2014). Enhanced yield in conservation tillage was because of the associated factors like residual nutrients from the preceding rice crop, resistance against soil degradation, soil moisture and fertility improvements, reduced evaporation loss and improved water infiltration as well as less soil and wind erosion as reported by Govaerts *et al.* (2011). Among the hybrids, KBSH-44 recorded significantly highest seed yield (1.81 t/ha) which was at par with DRSH-1 (1.73 t/ha). MSFH-17 gave least seed yield of 1.65 t/ha (Patel *et al.,* 2020). This might be due to the genetic potential of KBSH-44 to utilize the resources properly, translocate the photosynthates from source to sink and adaptability to agro-climatic condition. Pattanayak (2015) and Sheoran *et al*. (2016) observed similar findings. 150% RDF produced significantly higher seed yield of 2.09 t/ha followed by 100% RDF (1.75 t/ha). The treatment 50% RDF gave least seed yield (1.35 t/ha). The seed yield increased progressively with increasing level of fertilizer in all the hybrids as reported by Nasim *et al.* (2017). All the economic indices, gross return, net return and B:C ratio were influenced by tillage management, hybrids and fertility levels (Table 1). Maximum gross returns (₹1,02,709/ha), net returns (₹61,172/ha) and highest benefit- cost ratio of 2.48 were obtained under zero tillage. The lowest economic returns were obtained with conventional tillage. Out of three hybrids, KBSH-44 recorded the maximum gross return of ₹97,604/ha, higher net return of ₹55,720/ha and B:C ratio of 2.32 followed by DRSH-1. The hybrid MSFH-17 recorded significantly lowest gross return, net return and B:C ratio. Gross income, net income and B:C ratio continued to increase till 150% RDF.150% RDF registered the highest gross return of ₹1,12,786/ha, net return of ₹64,439/ha and benefit-cost ratio of 2.34 followed by 100% RDF (2.24), whereas 50% RDF recorded least gross return of ₹72,630/ha, net return of ₹36,233/ha and B: C ratio (2.01).

In terms of nutrient uptake, analysis of the results (Table 2) indicated significantly higher uptake of primary nutrients (52.65, 21.87 and 76.03 kg NPK/ha respectively) under zero tillage practice and lowest under conventional tillage (44.41, 17.79 and 64.03 kg/ha NPK respectively) apparently due to high seed yield (Patel *et al*., 2020). More N, P and K content and corresponding dry matter contributed for higher nitrogen uptake in zero tillage (Sridhar *et al*., 2012). Enhanced drymatter cum yield in conservation tillage may be because of the associated factors like resistance against soil degradation, soil moisture and fertility improvements, reduced evaporation loss as well as less soil and wind erosion as reported by Govaerts *et al.* (2011). Enhanced nutrient uptake in zero tillage in comparison to conventional tillage might be due to enhanced soil moisture which facilitate better nutrient uptake by increasing biomass as reported by Sobhana (2017). The competitive ability of rice fallow crop systems is enhanced through readily available transformed nutrients from the carry over effect of rice fertilization is the key to success of rice fallow sunflower. Relative time of nutrient release and availability from the previous rice crop, for instance, is an important determinant of competitive ability, as an early acquisition of nutrients enhances growth and productivity from rice fallow crops. Among the hybrids, KBSH-44 resulted in the highest nitrogen and potassium uptake due to its high dry matter production and higher nutrient content in its dry matter and was followed by DRSH-1. Similar findings were reported by Kailash (2015) and Pattanayak (2015). Accumulation of total nitrogen (59.92 kg/ha), phosphorous (24.1 kg/ha) and potassium (85.56 kg/ha) in sunflower was highest under 150% RDF whereas lowest accumulation of 35.30, 14.5 and 53.36 kg/ha nitrogen, phosphorous and potassium respectively was recorded under 50% RDF. Increased total biomass with increasing nutrient application might be the reason for greater absorption of all the nutrients from the soil, which resulted in higher total uptake of various nutrients. This corroborated the findings of Dutta and Enghipi (2016) and Adhikary *et al*. (2018). The on par nutrient uptake between DRSH-1 and KBSH-44 might be due to on par dry matter accumulation.

Table 1 Influence of tillage, hybrid and fertility level on yield and economics of sunflower grown in paddy fallows

Treatment		Seed yield (t/ha)	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
	Tillage management					
M_1	Conventional	1.63	44729	87617	42889	1.93
M_2	Reduced	1.66	42238	89594	47356	2.10
M_3	Minimum	1.73	40710	93067	52357	2.27
M_4	Zero	1.91	41538	102709	61172	2.48
	SEm ±	0.035	-	-	-	-
	CD (0.05)	0.12	-	-	-	-
	Hybrid					
G_1	DRSH-1	1.73	42383	93292	50908	2.19
G_2	KBSH-44	1.81	41883	97604	55720	2.32
G_3	MSFH-17	1.65	42643	88845	46202	2.07
	SEm ±	0.035	-	-	-	-
	CD (0.05)	0.11	-	-	-	-
	Fertility level					
F_1	50% RDF	1.35	36397	72630	36233	2.01
F_2	100% RDF	1.75	42167	94325	52158	2.24
F_3	150% RDF	2.09	48347	112786	64439	2.34
	SEm ±	0.024	-	-	-	-
	CD (0.05)	0.07	-	-	-	-

The post-harvest soil status analysis indicated that the soil was more acidic (pH of 5.1) under zero tillage which remained at par with minimum tillage (Table 3). A soil pH of 5.7 was observed under conventional tillage. It has been observed earlier that surface soil becomes more acidic under conservation agriculture than conventional tillage (Sobhana, 2017). The lowering of pH under conservation agriculture has been attributed to build up of soil organic matter and release of organic acids upon decomposition in the surface layer (Singh *et al*., 2014). There was no significant difference in electrical conductivity of soil due to tillage practices (Sridhar *et al*., 2012). Significantly higher soil organic carbon of 0.40% was seen with zero tillage whereas the lowest organic carbon of 0.35% was found under conventional tillage. The results are in accordance with the findings of Meena (2010). Restriction of tillage under zero tillage condition improves the structure of the soil, especially micro aggregates, which is active site of holding labile C for longer periods. This led to higher labile C formation in soil. Highest soil available nitrogen (216.6 kg/ha) and phosphorous (12.9 kg/ha) was observed under conventional tillage (Table 3). Tillage practices could not influence the available soil potassium significantly. Similar results were reported by Gupta *et al.* (2011) and Sridhar *et al.* (2012). Minimum soil available nitrogen (204.8 kg/ha) and potassium (212.6 kg /ha) was where KBSH-44 was grown, whereas maximum soil available nitrogen (211.7 kg/ha), and potassium (214.6 kg/ha) was observed where MSFH-17 hybrid had been grown (Table 3). No significant difference was seen in available phosphorous status in soil, as uptake of nutrients by KBSH-44 was more as sunflower is a voracious feeder. Difference in available soil nutrients were also reported by Kailash (2015). As anticipated, maximum soil available nitrogen (219.5 kg/ha), phosphorus (13.7 kg/ha) and potassium (218.0 kg/ha) were observed under 150% RDF (Table 3), whereas minimum soil available nitrogen, phosphorus and potassium were observed under 50% RDF. These observations were as repored earlier by Dutta *et al.* (2016) and Kalaiyarasan *et al.* (2017).

Table 2 Total nutrient uptake of sunflower as influenced by tillage practices, genotype and fertility levels

Treatments		Nutrient uptake (kg/ha)		
		Nitrogen	Phosphorus	Potassium
	Main Plot (Tillage)			
M_1	Conventional	44.41	17.79	64.03
M_2	Reduced	45.55	18.40	69.00
M_3	Minimum	47.63	19.08	70.62
M_4	Zero	52.65	21.87	76.03
	S.Em. ±	1.03	0.56	1.21
	CD(p=0.05)	3.44	1.87	4.04
	Sub Plot (Hybrid)			
G_1	DRSH-1	47.59	18.92	70.69
G_2	KBSH-44	50.37	19.79	72.72
G_3	MSFH-17	44.71	19.15	66.37
	S.Em. ±	0.56	0.54	0.73
	CD (p=0.05)	1.85	NS	2.40
	Sub-Sub Plot (Fertility Levels)			
F_1	50% RDF	35.30	14.5	53.36
F_2	100% RDF	47.46	19.2	70.86
F_3	150%RDF	59.92	24.1	85.56
	S.Em. ±	0.68	0.30	0.80
	CD (p=0.05)	2.00	0.90	2.35

* RDF- 60: 80: 60 kg N: P_2O_5: K_2O/ha

Table 3 Post-harvest soil pH, EC, Organic carbon and soil available nutrients as influenced by tillage practice, hybrid and fertility levels

Treatment		pH	Electrical conductivity (d/Sm)	Organic Carbon (%)	Soil available nutrients (k /ha)		
					Nitrogen	Phosphorus	Potassium
	Tillage management						
M_1	Conventional	5.7	0.25	0.35	216.6	12.9	214.4
M_2	Reduced	5.6	0.21	0.36	209.6	12.0	212.6
M_3	Minimum	5.3	0.20	0.37	204.7	12.3	211.5
M_4	Zero	5.2	0.23	0.40	202.1	11.8	211.3
	SEm ±	0.08	0.01	0.01	1.35	0.15	1.63
	CD (p=0.05)	0.3	NS	0.02	4.5	0.5	NS
	Hybrid						
G_1	DRSH-1	5.6	0.24	0.36	208.3	12.1	212.6
G_2	KBSH-44	5.4	0.23	0.41	204.8	12.1	210.2
G_3	MSFH-17	5.5	0.20	0.34	211.7	12.5	214.6
	SEm ±	0.07	0.01	0.004	1.34	0.16	0.84
	CD (p=0.05)	NS	NS	0.01	4.4	NS	2.7
	Fertility Level						
F_1	50% RDF	5.4	0.20	0.34	194.4	10.4	206.2
F_2	100% RDF	5.5	0.22	0.36	210.8	12.5	213.1
F_3	150%RDF	5.6	0.25	0.41	219.5	13.7	218.0
	SEm ±	0.06	0.01	0.003	1.44	0.14	1.58
	CD (p=0.05)	NS	0.01	0.01	4.2	0.4	4.6

* RDF- 60:80: 60 kg N: P_2O_5: K_2O/ha; Initial soil fertility: 200: 11.7: 210 kg N: P_2O_5: K_2O/ha

Zero tillage, the extreme form of conservation tillage during summer in rice fallows was found to be the optimum tillage practice for getting higher productivity of sunflower on sandy loam soils under the agro-climatic conditions of Bhubaneswar, Odisha. To no small extent, the success and sustainability of conservation tillage coupled with appropriate nutrient scheduling shapes the success and sustainability of rice fallow systems. Among the hybrids, KBSH-44 performed significantly better than existing hybrid MSFH-17 with high nutrient uptake.150% recommended dose of fertilizer gave highest nutrient uptake by the plants, gross return, net return and B:C ratio in sunflower. Growing of summer sunflower hybrids under zero tillage fertilized with 150% RDF (90:120:90 kg $N:P_2O_5:K_2O$/ha) could maximize the productivity under lowland rice fallow environments of Odisha.

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Assessment of genetic variability and resistance against stem and root rot caused by *Macrophomina phaseolina* in segregating generations of sesame (*Sesamum indicum* L.)

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ABSTRACT

An investigation was carried out to assess the genetic variability and disease resistance against stem and root rot caused by *Macrophomina phaseolina* in sesame. Segregating generations of ten cross combinations involving the sesame varieties *viz.,* VRI 1, TMV 3, TMV 4, TMV 6 as female parents and ORM 7, ORM 14, ORM 17 as male parents were used. The genetic variability parameters *viz.,* GCV (%), PCV (%), heritability (h^2) and Genetic Advance (GA) were estimated in F_2 generation for the traits plant height, number of primary branches/plant, number of capsules/plant, number of leaves/plant, capsule leaf ratio and single plant yield. High GCV(%) and PCV (%) were recorded for the traits number of primary branches/panicle, number of capsules/plant and number of leaves/plant in F_2s of all the ten cross combinations revealed the presence of enough genetic variability for these traits. High heritability coupled with high genetic advance were recorded for the traits *viz.,* plant height, number of primary branches/plant, number of capsules/plant, number of leaves/plant and single plant yield unveiled that these traits are governed by additive gene action. Hence, hybridization followed by simple recurrent selection based on the progeny testing could be useful for improving these traits. Disease reaction studies of F_3 generation in sick plot concluded that three crosses *viz.,* Cross IV (TMV 3 X ORM 7), Cross VII (TMV 4 X ORM 7) and Cross X (TMV 6 X ORM 7) are moderately resistant for stem and root rot disease and Cross IV (TMV 3 X ORM 7) recorded highest mean single plant yield of 15.6 g/plant. Hence, Cross IV (TMV 3 X ORM 7) may be utilised for improving the yield and root rot resistance in sesame.

Keywords: Genetic variability parameters, Sesame, Stem and root rot resistance

Sesame (*Sesamum indicum* L.) is an important oilseed crop, belonging to the family Pedaliaceae. It is one of the oldest crops brought to cultivation by the mankind. Sesame is being cultivated for its oil (46-50 %), protein (18 %), and medicinal properties. The productivity of the sesame crop is one of the lowest and the national average productivity is 431 kg/ha (Jayaramachandran *et al*., 2020). When comparing the other oilseed crops the productivity is significantly low because of its inherent genetic potential, susceptibility to biotic and abiotic stresses. To improve the yield potential of any crop, knowledge about the genetic variability and inheritance pattern of the yield contributing characters is a prerequisite. Estimating the genotypic coefficient of variation (GCV%) and phenotypic coefficient of variation (PCV%) for yield contributing characters of sesame will give enough understanding about the presence of genetic variability among the traits. Heritability (h^2) and genetic advance as percent of mean (GA %) are the two important estimates which will give us thorough knowledge about the potential of selected parents to inherit its genetic information to subsequent generations.

In addition to low productivity potential of sesame crop, susceptibility of sesame to biotic and abiotic stresses also affecting the yield significantly. Throughout the world, the yield losses of sesame due to stem and root rot caused by *Macrophomina phaseolina* (Tassi) Goid (MP) were reported as 57 % (Meena *et al*., 2018). *Macrophomina phaseolina* is a soil borne pathogen which can affect the roots and lower parts of the stem during seedling stage and cause damping off. During flowering to maturity stage, it can also infect the whole plant and cause rotting of entire plant especially in dry and hot conditions (Abawi and Corrales 1989; Shabana *et al*., 2014). As this pathogen is a soil borne (Maiti *et al*., 1988), management for this disease includes soil solarisation, application of systemic fungicides (Mahdy *et al*., 2005) using biocontrol agents such as bacteria and fungi (Abdul Sattar *et al*., 2006) and finally cultivating resistant genotypes (Pereira *et al*., 1996). However, due to harmful deleterious consequences of systemic fungicides and low efficacy of bio control agents the host plant resistance (HPR) is the only viable alternate (Mahdy *et al*., 2005). Hybridising distinct genotypes followed by pedigree selection is a successful breeding methodology for any crop improvement programme. Hence, in order to evolve a high yielding sesame variety with root rot resistance and to study the genetic architecture of yield the present investigation was carried out involving ten different cross combinations.

The popular sesame varieties *viz*., VRI 1, TMV 3, TMV 4 and TMV 6 were used as female parents whereas the sesame varieties moderately resistant to stem and root rot *viz*., ORM 7, ORM 14 and ORM 17 were used as male parents for our hybridisation programme. The special characters of these parents are given in the Table 1. The F_2 generation of ten cross combinations *viz*., VRI 1 X ORM 7 (Cross I), VRI 1 X ORM 14 (Cross II), VRI 1 x ORM 17 (Cross III), TMV 3 X ORM 7 (Cross IV), TMV 3 X ORM 14 (Cross V), TMV 3 X ORM 17 (Cross VI), TMV 4 X ORM 7 (Cross VII), TMV 4 X ORM 14 (Cross VIII), TMV 4 X ORM 17 (Cross IX) and TMV 6 X ORM 7 (Cross X) were raised in the field along with the parents without replication at Oilseeds Research Station, Tindivanam. Each F_2s were raised in the plot size of 4 X 3 m with a spacing of 30 X 30 cm. Observations on yield contributing traits *viz*., plant height, number of primary branches per plant, number of capsules per plant, number of leaves per plant, capsule leaf ratio (number of capsules per plant/number of leaves per plant) and single plant yield were recorded from thirty randomly selected plants in each cross combination. Selfing has been carried out before anthesis in order to avoid cross pollination. Data on all the seven characters were subjected to statistical analysis to estimate the genetic parameters like genotypic coefficient of variation (GCV %), phenotypic coefficient of variation (PCV %), heritability (h^2), genetic advance as percent of mean (GA%) by following TNAUSTAT.

The F_3 generation of the 10 cross combinations were raised along with the parents in the sick plot as well as in normal field at Regional Research Station, Vriddhachalam (Fig. 1). The plot size was 4 x 3 m. The incidence of root rot disease was recorded in the plots on 40 DAS and 70 DAS. Stem and root rot disease severity in percent was calculated based on Bedawy and Mohamed (2018) method as follows:

Disease Incidence =
(No of plants affected/Total number of plants) X 100

The levels of disease resistance were scored by following the scale described by Thiyagu *et al*. (2007) as given below (Table 2).

In addition to the stem and root rot resistance, single plant yield was also recorded in both the sick plot and normal conditions. The yield loss for the F_3 generation in sick plot was determined from the mean of single plant yield data as follows (Bedawy and Mohammed, 2018).

Yield loss % =
100 - (Seed yield in sick plot condition/Seed yield in normal condition) X 100

In present study high GCV (%) and PCV (%) estimates were recorded for the characters number of primary branches per panicle, number of capsules per plant and number of leaves per plant in F_2s of all the ten cross combinations, revealed that for all these three characters had enough variability created through hybridization followed by segregation. Similar findings of high GCV (%) and PCV (%) for the traits number of capsules per plant, number of leaves per plant and single plant yield were reported earlier by Narayana and Murugan (2013), Parameshwarappa *et al.* (2009) and Gangadhara (2012). In F_2s of all the ten crosses, the GCV (%) and PCV (%) estimates are moderate for the plant height and single plant yield. Bharathi *et al*. (2014) also reported the moderate GCV (%) and PCV (%) estimates for plant height and single plant yield in sesame and hence these traits can be improved through pedigree selection in latter generations. Low estimate of GCV (%) and PCV (%) were observed for the trait capsule leaf ratio. It indicates the presence of narrow genetic base for this trait. If single plant yield is positively correlated with the capsule leaf ratio, creation of genetic variation for capsule leaf ratio will increases scope towards yield improvement. In general, the differences between GCV (%) and PCV (%) were very small for all the seven characters in F_2 of all the ten cross combinations indicating that for all these traits the variability are mostly governed by genetic factors.

Fig. 1..Screening for stem and root rot resistance caused by *Macrophomina phaseolina* in F_3 generation under sick plot condition

High heritability coupled with high genetic advance was recorded for all the traits except capsule leaf ratio in the F_2s of ten cross combinations. This indicated that the traits *viz.,* plant height, number of primary branches per plant, number of capsules per plant, number of leaves per plant and single plant yield are governed by additive gene action. So, hybridization followed by simple recurrent selection based on the progeny testing could be useful for improving these traits. Gangadhara *et al.* (2012) and Thirumal Rao *et al.* (2013) reported the similar results of high heritability and high genetic advance for the traits number of primary branches per plant and number of capsules per plant. Hence, it has been concluded that yield contributing characters *viz.,* number of primary branches per plant, number of capsules per plant and seed yield per plant are heritable and fixable.

Table 1 Description of sesame varieties used as parents for hybridization

Name of the variety	Source	Parentage	Special features
VRI 1	Released from TNAU	Pure line selection from Tirukattupalli local	Short duration crop, 4 loculed, suited specially for rice fallows
TMV 3	Released from TNAU	Derivative of South Arcot local X Malabar	Bushy with profuse branching, 4 loculed, brown to black seeds
TMV 4	Released from TNAU	Pure line selection from Sattur local	Bushy with profuse branching, 4 loculed, brown seeds
TMV 6	Released from TNAU	Pure line selection from Andhra Pradesh variety	Erect with moderate branching 4 loculed, brown seeds, Oil content – 54 %
ORM 7	Released from OAU	Mutant of Tillotama (B 67) Followed by pedigree method of selection	Tolerant to phllody, stem and root rot, Alternaria leafspot
ORM 14	Released from OAU	Mutant of Tillotama (B 67) Followed by pedigree method of selection	Tolerant to *Macrophomina,* wilt, phyllody. Resistant to *Phytopthora, Alternaria,* Bacterial leaf spot
ORM 17	Released from OAU	Mutant of Tillotama (B 67) Followed by pedigree method of selection	Tolerant to major sesame diseases like *Cercospora,* blight, powdery mildew, *Macrophomina* & pest like *Antigastra*

Table 2 Scale used for screening for stem and root rot resistance caused by *Macrophomina phaseolina* in F_3 generation under sick plot condition

Disease Incidence (%)	Category
1-10	Resistant (R)
11-20	Moderately Resistant (MR)
21-30	Moderately Susceptible (MS)
31-50	Susceptible (S)
51-100	Highly Susceptible (HS)

The reaction of F_3 generation of 10 crosses and its parents against *Macrophomina phaseolina* under sick plot condition is furnished in the Table 3. Among the F_3 generation the stem and root rot incidence (%) on 40 DAS was lowest (0.92 %) in Cross VII (TMV 4 X ORM 7) and highest (14.47 %) in Cross II (VRI 1 X ORM 14). Among the parents ORM 17 recorded lowest (1.17%) incidence, whereas TMV 3 recorded highest (26.96 %) incidence on 40 DAS. The wide range of disease incidence (%) both in F_3 generation and its parents on 40 DAS confirmed the persistence of genotypic differences for root rot resistance in the early stage. These results are also coincided with the earlier reports of Thiyagu *et al.* (2007) and Shabana *et al.* (2014).

The results of root rot incidence (%) on 70 DAS in F_3 generation of 10 crosses ranged from 14.8 % (Cross VII - TMV 4 X ORM 7) to 70.71 % (Cross IX - TMV 4 X ORM 17). Among the parents, the stem and root rot incidence on 70 DAS ranged from 13.33 % (ORM 7) to 53.3 % (VRI 1). Observations on stem and root rot incidence (%) on 40 DAS and 70 DAS stated that, the severity of the pathogen may get intensified irrespective of the crop stages. Based on the estimates of level of resistance the crosses *viz.,* Cross I (VRI 1 X ORM 7), Cross II (VRI 1 X ORM 14) and Cross V (TMV 3 X ORM 14), Cross IX (TMV 4 X ORM 17) were classified as highly susceptible. Highly susceptible nature in the first two crosses *i.e*. Cross I & Cross II may be due to highly susceptible parent VRI 1 (53.3%) and in the Cross V and IX may be due to transgressive segregation. Hence, VRI 1 may be used as a susceptible check for root rot resistance screening. The crosses *viz*., Cross III (VRI 1 X ORM 17), Cross VIII (TMV 4 X ORM 14) are classified as moderately susceptible whereas the Cross VI (TMV 3 X ORM 17) was grouped as susceptible. Cross IV (TMV 3 X ORM 7 , Cross VII (TMV 4 X ORM 7) and Cross X (TMV 6 X ORM 7) were grouped as moderately resistant for stem and root rot stated that ORM 7 is a good source for stem and root rot resistance . Among the moderately resistant crosses Cross IV (TMV 3 X ORM 7) (Fig 2.) recorded highest mean single plant yield (15.6g) with the yield loss of 12.5 per cent while Cross VII (TMV 4 X ORM 7) and Cross X (TMV 6 X ORM 7) recorded mean single plant yield of 14.3 g and 10.25 g with the yield loss of 16.8 and 14.35 percent respectively. Hence, Cross IV (TMV 3 X ORM 7) may be utilised for improving the yield, stem and root rot resistance in sesame.

Table 3 Mean, range, genotypic (GCV %) and phenotypic (PCV %) coefficients of variability, broad sense heritability (h^2) and genetic advance as % of mean (GA) for different characters in F_2 generation of 10 cross combinations of sesame

Character	Cross	Parameters					
		Mean	Range	GCV (%)	PCV (%)	(h2)	GA as % of mean
PH	Cross I	102.27	90-130	9.27	10.40	79.50	17.03
	Cross II	107.30	65-173	16.47	17.07	93.10	32.70
	Cross III	101.30	67-133	11.94	12.85	86.30	22.85
	Cross IV	100.70	80-125	11.69	12.63	85.70	22.29
	Cross V	101.70	70-140	15.93	16.62	91.90	31.46
	Cross VI	101.10	68-120	12.85	13.21	87.90	24.83
	Cross VII	107.70	72-140	14.51	15.19	91.20	28.56
	Cross VIII	93.17	63-122	18.42	19.14	92.70	36.54
	Cross IX	95.60	65-124	18.32	19.00	93.00	36.38
	Cross X	103.13	67-126	14.19	14.94	90.20	27.77
NPBPP	Cross I	3.57	2-5	23.07	10.40	71.70	40.25
	Cross II	3.40	2-8	39.76	42.67	86.80	76.31
	Cross III	4.63	2-8	25.74	12.85	84.20	48.65
	Cross IV	4.97	2-8	43.16	44.39	94.50	86.43
	Cross V	3.47	2-6	28.21	16.62	78.20	51.39
	Cross VI	4.17	2-6	19.13	22.80	70.40	33.08
	Cross VII	4.27	2-6	20.48	15.59	74.10	36.31
	Cross VIII	4.30	2-6	17.58	21.29	68.20	29.90
	Cross IX	4.27	2-6	21.38	19.00	75.70	38.33
	Cross X	4.33	2-8	35.58	37.52	89.90	69.50
NCPP	Cross I	41.67	23-88	37.19	38.63	92.70	73.76
	Cross II	36.40	18-73	34.89	36.92	89.30	67.94
	Cross III	39.47	16-97	39.57	41.08	92.80	78.52
	Cross IV	52.07	20-115	45.13	45.90	96.70	74.25
	Cross V	46.27	20-80	37.81	38.97	94.20	75.60
	Cross VI	53.97	38-80	25.37	26.62	90.80	49.81
	Cross VII	54.00	20-95	33.56	34.51	94.50	67.22
	Cross VIII	45.90	25-72	29.61	31.09	90.70	58.09
	Cross IX	50.63	30-70	19.29	21.12	83.40	36.31
	Cross X	34.87	10-70	40.44	42.32	91.30	75.59
NLPP	Cross I	45.23	25-90	33.24	35.73	86.60	63.70
	Cross II	46.17	25-82	26.31	29.27	80.80	48.70
	Cross III	49.30	27-107	30.93	33.18	86.90	59.40
	Cross IV	61.07	26-122	37.25	38.49	93.60	74.25
	Cross V	54.90	23-87	31.32	33.12	89.40	61.00
	Cross VI	67.40	47-104	23.32	24.92	87.60	44.95
	Cross VII	65.50	32-102	27.70	29.21	90.40	54.40
	Cross VIII	58.60	29-94	27.75	29.54	88.30	53.72
	Cross IX	64.40	34-94	19.77	21.81	82.20	36.93
	Cross X	41.80	16-76	33.65	36.52	84.90	63.89
CLR	Cross I	0.81	0.45-0.94	22.85	23.99	90.70	44.84
	Cross II	0.77	0.56-0.88	7.03	10.47	45.10	9.73
	Cross III	0.78	0.59-0.90	6.37	9.95	41.00	8.40
	Cross IV	0.83	0.67-0.94	3.84	8.15	22.20	3.73
	Cross V	0.82	0.65-0.93	4.97	8.76	32.20	5.81
	Cross VI	0.80	0.61-0.94	6.82	10.11	45.50	9.47
	Cross VII	0.81	0.58-0.93	10.71	12.98	68.10	18.20
	Cross VIII	0.78	0.60 -0.91	8.37	11.3	54.90	12.78
	Cross IX	0.79	0.64-0.92	8.30	11.21	54.80	12.64
	Cross X	0.81	0.55-0.92	7.38	10.41	50.20	10.77
SPY	Cross I	4.73	3.7-5.7	10.30	14.58	50.00	15.01
	Cross II	4.73	3.5-6.8	18.02	20.75	75.40	32.22
	Cross III	4.50	3.0-6.3	17.74	20.78	72.10	31.19
	Cross IV	5.16	3.2-6.5	20.22	22.32	82.10	37.74
	Cross V	5.06	2.8-6.5	19.68	21.91	80.70	36.41
	Cross VI	5.40	2.7-8.1	25.38	26.93	88.80	49.25
	Cross VII	5.29	3.7-7.8	16.16	18.22	78.70	29.53
	Cross VIII	5.28	3.0-7.2	23.72	25.46	86.90	45.55
	Cross IX	5.39	3.2-6.8	17.26	19.48	78.50	31.49
	Cross X	5.54	3.2-6.4	12.41	15.21	66.50	20.85

PH- Plant height, NPBPP- Number of primary branches per plant, NCPP- Number of capsules per plant, NLPP- Number of leaves per plant, CLR- Capsule leaf ratio and SPY- Single plant yield

Table 4 Screening for stem and root rot resistance caused by *Macrophomina phaseolina* in F_3 generation under sick plot condition

Crosses/Parents	Initial plant stand	Stem and Root rot incidence				Disease Reaction	Single Plant Yield (g)	Yield loss (%)
		Number of plants affected on 40 DAS	Disease Incidence (%)	Number of plants affected on 70 DAS	Disease Incidence (%)			
VRI 1X ORM 7	96	6	6.25 (0.253)	59	61.45 (0.901)	HS	11.20	48.50
VRI 1 X ORM 14	152	22	14.47 (0.390)	96	63.10 (0.919)	HS	11.50	53.40
VRI 1 X ORM 17	52	3	5.70 (0.241)	12	23.07 (0.501)	MS	16.80	39.50
TMV 3 X ORM 7	234	33	14.10 (0.385)	43	18.3 (0.442)	MR	15.60	12.50
TMV 3 X ORM 14	163	7	4.29 (0.209)	84	51.5 (0.800)	HS	14.00	41.20
TMV 3 X ORM 17	104	6	5.70 (0.241)	39	37.50 (0.659)	S	12.80	48.70
TMV 4 X ORM 7	108	1	0.92 (0.030)	16	14.80 (0.395)	MR	14.30	16.80
TMV 4 X ORM 14	168	18	10.71 (0.333)	50	29.76 (0.577)	MS	12.00	28.40
TMV 4 X ORM 17	140	14	10.00 (0.322)	99	70.71 (0.999)	HS	11.75	56.40
TMV 6 X ORM 7	152	9	5.92 (0.246)	28	18.4 (0.443)	MR	10.25	14.35
VRI 1	135	11	8.10 (0.289)	72	53.30 (1.01)	HS	7.80	69.50
TMV 3	89	24	26.96 (0.546)	41	46.06 (0.745)	S	8.25	52.56
TMV 4	103	4	3.88 (0.198)	38	36.89 (0.652)	S	14.60	44.50
TMV 6	111	20	18.01 (0.438)	38	34.23 (0.624)	S	11.20	42.30
ORM 7	135	3	2.22 (0.150)	18	13.33 (0.373)	MR	7.25	18.60
ORM 14	129	3	2.32 (0.153)	19	14.7 (0.393)	MR	9.56	20.40
ORM 17	117	2	1.17 (0.108)	16	13.6 (0.377)	MR	7.86	14.60
Mean	128	10.76	8.15	45.17	35.33		11.57	36.60
SE	9.73	2.31	1.69	6.80	4.68		0.69	4.30
CD at 5 %		3.58		10.43			1.46	9.11

Values in parenthesis are arcsine transformed values, DAS - Days after sowing, HS - Highly Susceptible, MS - Moderately Susceptible, S - Susceptible, MR- Moderately Resistant

Fig. 2. Stem and root rot resistant plants identified in F_3 generation of Cross IV (TMV 3 X ORM 7) under sick plot condition

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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.
Kanwar J S and Raychaudhuri S P 1971. *Review of Soil Research in India*, pp 30-36. Indian Society of Soil Science, New Delhi.
Mukherjee J N 1953. The need for delineating the basic soil and climatic regions of importance to the plant industry. *Journal of the Indian Society of Soil Science*, **1** : 1-6.
Khan S K, Mohanty S K and Chalam A B, 1986. Integrated management of organic manure and fertilizer nitrogen for rice. *Journal of the Indian Society of Soil Science*, **34** : 505-509.
Bijay-Singh and Yadvinder-Singh 1997. Green manuring and biological N fixation: North Indian perspective. In: Kanwar J S and Katyal J C (Ed.) *Plant Nutrient Needs, Supply, Efficiency and Policy Issues 2000-2025.* National Academy of Agricultural Sciences, New Delhi, India, pp.29-44.
Singh S, Pahuja S S and Malik R K 1992. Herbicidal control of water hyacinth and its effect on chemical composition of water *(in) Proceedings of Annual Weed Science Conference*, held during 3-4 March 1992 by the Indian Society of Weed Science, at Chaurdhary Charan Singh Haryana Agricultural University, Hisar, 127p.
AICRP on Soybean 1992. *Proceedings of 23rd Annual Workshop of All-India Co-ordinated Research Project on Soybean*, held during 7-9 May 1992 at University of Agricultural Sciences, Bangalore, Karnataka, National Research Centre for Soybean, Indore, pp.48.
Devakumar C. 1986. Identification of nitrification retarding principles in neem (*Azadirachta indica* A.Juss.) seeds. Ph D Thesis, Indian Agricultural Research Institute, New Delhi.

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$\pm$, NS (not C.D., S.E.m$\pm$, 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^3$$m^2$s (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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