THE INDIAN SOCIETY OF OILSEEDS RESEARCH

(Founded in 1983, Registration Number ISSN 0970-2776)

MEMBERSHIP TARIFF

(w.e.f. 01.06.2014)

Life Membership		**Annual Subscription**		**India**	**Abroad**
Individual :	Rs.3000/- + Admn. Fee Rs.50/-	Individual	:	Rs. 400/- + Admn. Fee Rs.50/-	US$ 100 Ordinary
		Institutions	:	Rs. 3000/-	US$ 200 Institutions
		Students	:	Rs. 300/- + Admn. Fee Rs.50/-	

For subscription, please contact ☛ The General Secretary, Indian Society of Oilseeds Research, ICAR-Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad-500 030, India

Payment can be made online by fund transfer to account No. **52032213529** with IFSC Code: **SBIN 0020074.** After payment, the UTR No. and payment details may be sent by e-mail (oilseedsociety@gmail.com) / post to the General Secretary, ISOR, ICAR-IIOR, Rajendranagar, Hyderabad-500 030. For further details please visit: http://www.isor.in.

ANNOUNCEMENT

The Journal of Oilseeds Research has been rated at **5.02** by National Academy of Agricultural Sciences (NAAS) from January 1, 2017

Journal of Oilseeds Research is published quarterly by the Indian Society of Oilseeds Research

JOURNAL OF OILSEEDS RESEARCH

Previous Issue : Vol. **36**, No. 4, pp. 203-264

Vol. **37**, No. 1 Mar., 2020

CONTENTS

Review

Short Communications

Review

Sulphur fertilization in groundnut crop in India: A review

A SOLAIMALAI*, M JAYAKUMAR[1], K BASKAR AND M SENTHILKUMAR[2]

Agricultural Research Station, Tamil Nadu Agricultural University, Kovilpatti-628 501, Tamil Nadu

ABSTRACT

Balanced nutrition is considered as one of the basic needs to achieve the potential yield. Sulphur is one of the major plant nutrients for that is deficient in most of the Indian soils. Sulphur is now recognized as the fourth major plant nutrient after N, P and K and is also an integral part of the balanced fertilization and nutrition for oilseed crops in general and groundnut in particular. Optimization of mineral nutrition is also a key factor to enhance productivity of groundnut. Oilseeds are energy rich crops and hence the requirement of major as well as secondary and micro nutrients is high. Sulphur is an essential plants nutrient with a specific role in the synthesis of sulphur containing amino acids like methionine and cysteine and synthesis of proteins, chlorophyll besides oil. It promotes proper filling of grains in oilseeds and thus enhances market quality. Sulphur is also known to promote nodulation in legumes thereby N fixation. Global reports of sulphur deficiency and consequent crop response, particularly in an oilseed crop like groundnut are quite ostensible. Literature with respect to the effect of sulphur application in groundnut cultivation in India has been reviewed here.

Keywords: Biochemistry, Groundnut, Growth, Nutrient uptake, Physiology, Sulphur, Yield

Groundnut (*Arachis hypogaea* L.) is one of the most important among edible oilseed crops in the world and belongs to Leguminoceae (Fabaceae) family. It is also known as earthnuts, peanuts, goobers, goober peas, pindas, jack nuts, pinders, manila nuts, and monkey nuts. Groundnut is believed to have originated in Central American region from where they spread to other parts of the world. They are widely cultivated in India, Africa, South America, United States (Tom, 2007), China (Yao, 2004) and a few other countries. Its seed contain 43-55% oil content (Din *et al.,* 2009), 24-26% protein, 45-48% fat, 3% fiber and 15-18% carbohydrate (Shokunbi *et al.,* 2012). It is a dietary source of calcium, magnesium, iron, zinc, phosphorus, vitamin E, riboflavin, thiamine and potash. This crop is also used in the form of fodder, seeds, straw and hay (Smith, 2002). Groundnut serves as an important source of food and energy. It can be used as food (cooking oil, raw, roasted) feed (green material, straw, seed pressings) and used in industry as a raw material (Onyeike, 2003). Use of groundnut reduces the risk of cardiovascular disease (Etherton *et al*., 1999), breast cancer, colon and prostate (Awad *et al*., 2000). It may also reduce osteoporosis (Messina, 1999), and diabetes (Jiang *et al*., 2000). Groundnut was introduced in India in the middle of nineteenth century on east coast of the South Arcot district in Tamil Nadu. Groundnut is self-pollinated, allotetraploid legume with the chromosome number (2n=40). The name *Arachis hypogaea* L. is derived from the Greek word Arachis which means the legume and hypogaea means below ground. In India about, 90 per cent of area under groundnut, with 84 per cent of the production is confined to six states *viz.,* Gujarat, Andhra Pradesh, Rajasthan, Tamil Nadu, Karnataka and Maharashtra. Among these, Gujarat ranks first in both area and production, while Tamil Nadu ranks first in productivity.

Sulphur is one of the secondary essential plant nutrients required for different growth functions of groundnut. Besides, sulphur is involved in the formation of S containing amino acids, vitamins and has direct role in root growth and nodulation (Jat and Ahlawat, 2009). Sulphur in the form of sulphate is involved in various metabolic and enzymatic activities of plants. It is also a constituent of glutathione, a compound supposed to play part in plant respiration. Further, sulphur also plays a vital role in chlorophyll formation as it constitutes succynyl Co-A. It engages in activation of a number of enzymes participating in the dark- reaction of photosynthesis via improvement in general and their activation at cellular level by promoting greater photosynthesis and meristematic activity. Sulphur nutrition stimulates vegetative growth of crops in terms of dry matter accumulation, number and weight of nodules/plant. Having realized the importance of sulphur nutrition, several researchers have carried out experiments to determine the quantity and source, time of application, and the effects of applied sulphur on the yield as well as quality of oil in groundnut. We have tried providing an updated review on these aspects.

Effect of sulphur on growth, yield attributes and yield of groundnut

The optimum amount of sulphur is determined by the soil type and the available sulphur. Positive responses in terms of pod and haulm yield have been observed with increasing levels of sulphur. In most of the cases, the optimum has been found to be around 30-40 kg/ha. As the studies have been

[1]Central Coffee Research Institute, Coffee Research Station, Chikmagaluru-577 117, Karnataka, E-mail: agrokumar2013@gmail.com; [2]Forest College and Research Institute, TNAU, Mettupalayam-641 301, Tamil Nadu; *Corresponding author's E-mail: solaiagronkpt@gmail.com

carried out in different soil types and with different practices, it is not possible to compare the results across the experiments.

Many studies have shown that application of 20-25 kg S/ha increased the production of both pod and haulm yield. At Junagadh (Gujarat), in calcareous soils, application of 20 kg S/ha as elemental sulphur to the soil before sowing produced 25% more pods and 16% more fodder (Singh *et al.,* 1990b) while, Vaghasia *et al.* (2007) revealed that growth, yield, quality, returns as well as B:C ratio were significantly enhanced with the sulphur fertilization at 50 and 25 kg/ha over the control. However, these two levels were found at par with each other. At Dharwad (Karnataka), application of sulphur at 20 kg/ha, as well as application of 10 kg S/ha during *kharif* season, gave significantly more number of pods/plant, pod yield and oil content in kernels than the control (Agasimani *et al.,* 1993). Battacharya *et al.* (1997) reported that application of 20 kg S/ha significantly increased the plant height, dry matter and nodulation in groundnut than control. Results of the field experiment carried out by Patil *et al.* (2003) during *kharif* season at PDKV, Akola with red sandy loam soil revealed that application of sulphur @ 20 kg/ha as elemental sulphur along with recommended dose of N, P provided significantly higher kernel and haulm yield of groundnut as compared to control. In Tap Dong (South Korea), significant enhancement of seed yield, oil yield and seed protein content were observed with application of sulphur 20 kg/ha than control (0 kg S/ha) in cultivar Ambar and Kaushal (Arshad *et al.,* 2006). Giri *et al.* (2011) found that application of sulphur @ 15 kg/ha significantly enhanced all the yield attributing characters *viz.,* number of pods/plant, number of kernels/pod, 100-kernel weight and kernel yield over control. The increase in kernel yield due to this level of sulphur was to the tune of 73.11 per cent over control and 30 kg/ha. Dash *et al.* (2013) found that application of sulphur at 20 kg/ha significantly increased the pods/plant, 100-kernel weight, shelling per cent, pod and haulm yields of groundnut. From the response quadratic curve, the economic highest pod yield of 1.82 t/ha was obtained with 34 kg S/ha.

There are quite a few reports where application of sulphur between 25 and 40 kg/ha have been reported to enhance the yield. Shivraj and Gowda (1993) reported that shelling percentage, 100-kernel weight, pod yield, haulm yield and oil yield of groundnut were higher with the application of 30 kg S/ha. Similar results have been reported by Panda *et al.* (1997) have reported that application of 30 kg S/ha in groundnut enhanced the pod yield significantly over control. In alluvial zone of Mohanpur (West Bengal), Dutta *et al.* (2015) reported that sulphur fertilization at 30 kg/ha gave significantly higher number of pods/plant, shelling percentage, 100-kernels weight as well as pod yield, haulm and kernel yield over 0 and 15 kg S/ha. However, it remained at par with 45 kg/ha. Higher gross returns, net returns, B:C ratio were found with application of 30 kg S/ha. Sulphur use efficiency also showed increasing trend up to 30 kg S/ha. Similar results were reported with *kharif* groundnut over control (Bandopadhyay and Samui, 2000; Dutta and Patra, 2005). At Rahuri (Maharashtra), Kadam *et al.* (2000) observed that every increase in level of sulphur up to 40 kg/ha recorded significant improvement in yield attributes, dry pod, haulm yield and protein content followed by 20 kg/ha and compared with control (no application) during summer season. Maity *et al.* (2003) at IARI, New Delhi noted higher yield attributes and pod yield of groundnut when the crop was applied with sulphur at 30 kg/ha. Bandopadhyay *et al.* (2002) reported that number of pods/plant, kernels/ pod, 100-kernels weight, oil and protein content, pod and haulm yields were recorded maximum under 30 kg S/ha during summer season. In sulphur deficient soil during *kharif* season, yield of groundnut crop increased significantly with increasing levels of sulphur up to 40 kg S/ha (Prasad, 2003). At Nadia (West Bengal), Patel *et al.* (2009) noted that sulphur fertilization at 40 kg/ha gave significantly higher number of pods/plant, shelling percentage, 100 kernels weight, weight of pods/plant as well as pod yield over 0 and 20 kg S/ha.

In some of the studies, sulphur application at rates of more than 40 kg/ha have proved better for increasing the yield in groundnut. Dimree *et al.* (1993) found that every increase in levels of elemental sulphur up to 45 kg/ha in groundnut produced significantly more number of pods/plant, kernels/pod, pod weight/plant, kernel size and shell yield over application of 15 and 30 kg of S/ha and control. Increasing the sulphur level to 60 kg/ha rather decreased the yield as compared to proceeding level of 45 kg/ha. Sahu *et al.* (1999) showed that sulphur application significantly increased the pod yield, shelling percentage and uptake of S (0, 15, 30 and 45 kg/ha). Higher yield, shelling percentage and uptake of rainfed groundnut genotypes were recorded when sulphur was applied at 45 kg/ha on lateritic sandy loam soil. At Ujhani (Uttar Pradesh), Chaubey *et al.* (2000) observed that number of pods/plant, shelling percentage, 100-kernel weight and pod yield increased significantly with increasing levels of sulphur up to the 45 kg/ha over 15 and 30 kg/ha and control. Further increase in it level to 60 kg/ha did not have beneficial effect during rainy season. Singh *et al.* (2003) reported that sulphur fertilization at 60 kg/ha registered significant improvement in plant height and dry matter production at 30, 60, and 90 DAS and at harvest stages over 20 and 40 kg S/ha and control during summer season on sandy loam soil of Rajasthan. At Navsari (Gujarat), Hadavani *et al.* (1993) observed that application of sulphur at 60 kg/ha registered higher concentration and uptake of S in kernels and haulm by summer groundnut that was significantly more than 0, 20 and 40 kg/ha in clay soil.

At New Delhi, Noman *et al.* (2015) observed that application of sulphur @ 40 kg/ha significantly improved the yield attributes *viz.,* pods/plant, kernels/pod and shelling percentage as well as pod yield, kernel yield, haulm yields, net returns and B:C of groundnut over 0 and 20 kg S/ha. This level of sulphur fertilization resulted in 31.4 per cent increase in pod yield, 52.7 per cent in haulm yield and 56.7 per cent in net return over control on sandy loam soil low in available sulphur during *kharif* season. At Anand (Gujarat), application of sulphur @ 40 kg S/ha produced higher dry matter content at 45 DAS, branches per plant, pod per plant, shelling percentage, seed index, pod yield, haulm yield, oil content and protein content (Patel *et al.,* 2018) (Table 1).

Table 1 Effect of levels of sulphur on yield of summer groundnut

Sulphur (kg/ha)	Pod yield (kg /ha)	Haulm yield (kg/ ha)
0	1745	3704
20	1956	4141
40	2083	4349
CD (P=0.05%)	109	200

Kumpawat and Rathore (1994) observed significant increase in pod yield of groundnut with the application of sulphur up to 150 kg/ha at Bhilwara in Rajasthan (sandy soils). At Udaipur (Rajasthan), Tiwari *et al.* (1994) revealed that pod yield increased progressively with increasing levels of sulphur up to 100 kg/ha on summer groundnut. At Chintamani (Karnataka), higher number of pods/plant, shelling percentage, oil yield and haulm yield were recorded when the crop was applied with 50 kg S/ha through gypsum which was found significantly superior to 25 kg/ha and control on sandy loam soil (Wali *et al.,* 1994).

Thus, depending on the type of soil and available sulphur at that site, different quantities of sulphur have given positive results. In general, in sandy loam and alluvial soils, it has been observed that higher doses of sulphur are required.

Physiological and biochemical parameters

Sulphur is one of the essential plant nutrients which is best known for its important and specific role in the synthesis of sulphur containing amino acids like methionine (20%) and cysteine (27%) and synthesis of proteins, chlorophyll and oil. Moreover, it is also associated with the synthesis of vitamins (biotine, thiamine), co-enzyme-A metabolism of carbohydrates, proteins and fats. Sulphur is also known to promote nodulation in legumes thereby N fixation and associated with the crops of spurious nutrition and market quality (Khan and Mazid, 2011). Its application increases drought and cold tolerance in plant by process of disulphide linkage (Schonhof *et al.,* 2007). Its deficiency results in poor flowering, fruiting, cupping of leaves, reddening of stem and petiole and stunted growth. Global reports of sulphur deficiency and consequent crop response, particularly in oilseed crops like groundnut are quite ostensible (Schonhof *et al.,* 2007). The groundnut oil is considered safe from both nutritive and culinary points of view as it contains good quantities of MUFA (40-50%) and PUFA (25-35%) that attribute to its relatively longer shelf-life (Nagesh yadav *et al.,* 2017). Groundnut oil is a rich source of vitamin A, B and E and also contain high content of tocopherol (0.9 mg/g oil), an antioxidant which prevents development of rancidity (Das, 1997). Its kernel on an average contains 25.3 per cent easily digestible protein which is about 1.3 times higher than meat, 2.5 times higher than eggs, and also rich in carbohydrates (6.0 to 24.9 %), minerals and vitamins (Das,1997).

Sulphur plays an important role in plant growth and development processes (Chaubey *et al.,* 2000). With increased supply of sulphur, the process of tissue differentiation from somatic to reproductive, meristematic activity and development might increase resulting in higher plant height and number of leaves (Nabi *et al.,* 1990). It is known to be involved in maintaining the cell integrity and membrane permeability, activation of many enzymes, cell division and positive effect on protein synthesis and carbohydrate transfer (Singh *et al.,* 2012).The higher crude protein content in kernals of groundnut could be attributed to the fact that optimum levels of sulphur in the plants are known to enhance nitrogen uptake which might improve protein synthesis (Meena and Shivay, 2010).

At Junagadh (Gujarat), sulphur fertilization up to 40 kg S/ha significantly increased plant height, dry-matter accumulation [60 days after sowing (DAS)], total chlorophyll content (55 DAS) and mature pods/plant, whereas, dry-matter accumulation at 90 DAS and at harvesting, immature pods/plant, weight of mature and immature pods/plant, and 100-kernel weight increased significantly up to 20 kg S/ha. Significantly higher number of total and effective root nodules/plant (60 DAS), and shelling outturn were recorded at 40 kg S/ha over the control (Saini *et al.,* 2016). At Coimbatore (Tamil Nadu), application of nano-sulphur @ 30 kg/ha was recorded higher root, shoot, kernel and shell dry matter while compared to conventional sulphur @ 40 kg/ha. The percent increase in chlorophyll a and b and soluble protein contents of nano-sulphur over conventional sulphur at 30 kg S/ha were 6.8%, 4.3% and 9.4% respectively at harvest stage. The nano-sulphur fertilization @ 30 kg S/ha had registered significantly higher per cent increase over conventional sulphur fertilization at 25, 13.8 and 1.8% for number of pod, hundred kernel weights and shelling percentage, respectively (Thirunavukkarasu and Subramanian, 2016). Nagesh Yadav *et al.* (2018) found that the maximum CGR at all the stages of crop was recorded when sulphur was applied through gypsum. Sulphur application through SSP registered 13.9, 9.8 and 21.4% increase in CGR over elemental sulphur at these stages, respectively. On the other hand, SSP and gypsum increased the RGR by 7.2 and 6.3%, respectively over elemental sulphur.

Different sources of sulphur

Different sources of sulphur are known to have differential effect on the growth and yield of groundnut. The source also decides the method of application - whether soil based or foliar spray based and the interaction effect between source and method is also established. Researchers have tried different sources of sulphur such as elemental sulphur, gypsum, phospho-gypsum, wettable sulphur, iron sulphate, zinc sulphate, sulphate of potash, etc along with different quantities so that the interaction effect of the source and quantity could be studied. Gypsum, which supplies both calcium and sulphur, is a by-product of many industries, is the most commonly used source of sulphur as it is a cheaper source compared to elemental sulphur. Application of gypsum could also take care of the deficiency of both calcium and sulphur especially in crops like groundnut for which calcium nutrition is also important. Here we are providing a summary of the results obtained in reports when different sources of sulphur were tried in groundnut.

Among the various sources tested, gypsum was the best with respect to yield, followed by single super phosphate and ammonium sulphate in sulphur deficient soil during *kharif* season (Prasad, 2003). Poonia *et al.* (2006) reported that application of sulphur and phosphorus solubilising micro-organism significantly increased the yield attributes (pods/plant, pod weight/plant and seed index) and yields of groundnut (pod yield, haulm yield and harvest index) except the number of kernels/pod. At Tirupati (Andhra Pradesh), application of 20:10:25 kg NPK/ha + gypsum @ 250 kg/ha + $ZnSO_4$ 25 kg/ha recorded higher 100 pod weight (77 g), test weight (28.3 g), shelling percentage (69.3 %) and pod yield (1712 kg/ha) of rainfed groundnut in sandy clay loam soil over other INM practices in a long term fertilizer experiment from 1988 (Kishore babu *et al.,* 2007). In some cases, phosphogypsum has been tried as the source. Kalaiyarasan *et al.* (2002) reported that yield and yield attributing characters of groundnut *viz.,* number of pods/plant, shelling percentage, pod and kernel yields were significantly improved due to increasing sulphur levels and maximum values were noticed at 45 kg/ha through gypsum and was closely followed by SSP at 30 kg S/ha in red laterite soil.

Other versions of gypsum like phosphogypsum and ferrogypsum have also been tired as sources of sulphur and positive effects have been reported. Naresha *et al.* (2018) have reported that among phosphogypsum levels, 500 kg/ha applied at flower initiation recorded the highest yield (2.1 ton) and B:C ratio (2.1) over control (2.0), Application of sulphur through phosphogypsum significantly increased the groundnut pod yield and shelling percentage up to 40 kg S/ha as compared to control and 20 kg/ha and other sources on lateritic soils during post rainy season at Bhubaneswar (Sahu and Das, 1997). Application of Ferro gypsum in amounts equivalent to recommend dose of 400 kg gypsum/ha is reported to have significantly increased the pod yield, haulm yield, shelling per cent and kernel yield of groundnut (Jagadeeswaran *et al.,* 2001).

At Junagadh (Gujarat), application of sulphur in the form of iron sulphate, zinc sulphate, iron pyrite, gypsum, phospho-gypsum, elemental sulphur, wettable sulphur and Fe-EDTA decreased chlorosis and increased chlorophyll and carotenoid contents of leaves, uptake of Fe, S and Zn and pod yield of groundnut significantly. The foliar spray of 0.5% aqueous solution of iron sulphate, zinc sulphate and Fe-EDTA at 20, 35, 50 and 65 days after emergence (DAE) was more effective than their soil applications. The Fe-EDTA corrected only iron chlorosis, while gypsum, phosphogypsum and elemental sulphur only sulphur chlorosis. However, iron sulphate and iron pyrite corrected iron and sulphur and zinc sulphate corrected zinc and sulphur chlorosis. Among the soil amendments, application of iron sulphate and iron pyrite showed better responses to groundnut and showed higher Fe and S uptake than other treatments. The responses of gypsum, phosphogypsum and elemental sulphur were at par. The correlation study showed that pod yield of groundnut was negatively correlated with chlorosis and positively correlated with the chlorophyll and carotenoid contents in groundnut leaves (Singh *et al.*, 1990a). In another experiment at Junagadh, elemental S, pyrite, and $FeSO_4$ @ 20 kg/ha ere more effective than gypsum and phosphogypsum, with $FeSO_4$ being the most effective source of S for improving plant growth traits, yield, and nutrient uptake. The most effective method of $FeSO_4$ application was half to the soil at planting time (basal) followed by the remainder in three equal foliar sprays at 30, 50 and 70 days after plant emergence (DAE). Pyrite and elemental S were most effective when applied to the soil only, half as a basal soil dressing, and the remainder in two equal doses at 25 and 50 DAE. Plant concentrations of S, P, and potassium (K) were similar for each source of S, but elemental S, pyrite, and $FeSO_4$ enhanced N, Fe, manganese (Mn), and Zn uptake. Gypsum and phosphogypsum enhanced calcium (Ca) uptake (Singh and Vidya, 1995).

In a pot experiment, Tathe (2008) reported that sulphur fertilization at 120 kg/ha as elemental sulphur significantly increased the yield, uptake of N, P, K, Ca and Mg as well as seed oil content and protein than lower levels and control.

In some of the reports, significant differences were not noticed with different source of sulphur. In Chintapalle (Andhra Pradesh), Sulphur application significantly influenced the growth, yield attributing characters, yield and oil content over control regardless of the sources [(elemental sulphur, sulphur bentonite and gypsum)] and levels of sulphur (15, 30 and 45 kg/ha). Addition of sulphur at 45 kg/ha through gypsum recorded highest plant height, number of filled pods per plant, 100-pod weight, 100-kernel weight, pod yield, haulm yield and oil content of the kernels (variety K6) during rabi season. Application of gypsum at 45 kg/ha has increased the pod yield to the tune of 52.2% and 50.3%. Oil content in the kernels was found to be 7.5% and 8.8% during 2010 and 2011, respectively over control (Tejeswara Rao *et al.,* 2013). Similarly, at Sardar Krushinagar (Gujarat), source of sulphur had no-significant effect on yield, quality and nitrogen, phosphorus and sulphur uptake in summer irrigated groundnut. However, a linear increase in pod and haulm yields were recorded up to 40 kg S/ha. It increased the pod yield over 0 and 20 kg S/ha to the tune of 19.90 and 8.34% respectively (Patel *et al.,* 2008; Patel *et al.,* 2009). At Dhari (Gujarat) Ramdevputra *et al.* (2010) recorded the highest pod yield and net realization with the application of sulphur at 18.75 kg/ha through gypsum + 18.75 kg/ha through SOP than application of 18.75 kg S/ha alone through gypsum under rainfed conditions. However, it showed statistical similarity with the treatment involving 18.75 kg S/ha through gypsum + 18.75 kg S/ha through SOP.

In a recent report, sulphur application through gypsum recorded the highest pod yield (1872 kg/ha) at Jobner (Rajasthan). Among the different sources of sulphur tried, gypsum showed 13.1 and 32.0% more yield than that obtained under SSP and elemental sulphur treatment, respectively (Nagesh *et al.,* 2019) (Table 2).

Thus, a perusal of literature indicates that gypsum, a cheaper source of sulphur has shown better results in many studies. However, in case there are calcareous soils where calcium levels are high, elemental sulphur could be the choice as source of sulphur.

Nutrient uptake by groundnut

Sulphur application is also known to influence the uptake and utility of other plant nutrients from the soil. Many studies have indicated the positive effect of application of sulphur as it ensures more balanced nutrient availability to the plant and is also known to have a positive effect on nodulation.

At Junagadh (Gujarat), plants grown with sulphur @ 20 kg/ha compared to those without S had increased tissue concentrations of nitrogen, phosphorus, S, iron and zinc as well as higher total uptake of mineral nutrients (Singh and Vidya, 1995). Application of sulphur significantly increased the nutrient uptake over the control. Application of 45 kg S/ha by SSP registered the maximum uptake of N, P, K and S being at par with 30 kg S/ha (Kalaiyarasan *et al.,* 2003; Kalaiyarasan *et al.,* 2007). Higher uptake of nutrients (N, P and K) by summer groundnut was observed when 100% RDF or 125% RDF was applied along with gypsum @ 500 kg/ha (Dutta and Mondal, 2006). Increased N, P and S concentrations and uptake were observed due to S application (Kumar *et al.,* 2008). Higher N and P content in groundnut plant and kernel were recorded due to application of 30: 50: 50 kg/ha of N, P and K though Urea, Single super phosphate and Muriate of potash as source when they were applied along with gypsum @ 500 kg/ha (Salke *et al.,* 2011). Poonia *et al.* (2013) found that application of sulphur at 40 kg/ha through gypsum significantly increased the nitrogen, phosphorus, potash and sulphur uptake by groundnut crop over control and 20 kg S/ha.

Increase in application of sulphur led to an increase in uptake of N, P, K and S by groundnut crop was observed when sulphur was applied up to 45 kg/ha at Navsari, Gujarat (Table 3). However, the increase in nutrient uptake parameters with the increase in sulphur level from 30 kg/ha to 45 kg/ha showed no significant differences (Patel and Zinzala, 2018).

Table 2 Effect of sulphur sources on yields, shelling and harvesting index of groundnut

Sulphur source	Pod yield (kg/ha)	Haulm yield (kg/ha)	Kernel yield (kg/ha)	Shelling (%)	HI (%)
Sulphur levels (kg/ha)					
15	1148	1991	748	65.04	36.45
30	1547	2682	1045	67.40	36.60
45	1752	3146	1237	70.46	35.74
60	1892	3469	1364	71.95	35.30
75	1903	3579	1376	72.13	34.95
SEm (±)	44.34	102.51	38.28	1.42	0.88
CD (P =0.05)	128.44	296.96	110.90	4.10	NS
Source of sulphur					
Gypsum	1872	3332	1334	70.80	36.29
Elemental sulphur	1418	2521	965	67.57	35.90
SSP	1655	3067	1163	69.82	35.24
CD (P=0.05)	99	230	85.91	3.18	NS

Table 3 Effect of sulphur levels on sulphur content and uptake by groundnut

Sulphur levels (kg/ha)	Nutrient uptake (kg/ha)			
	Nitrogen	Phosphorus	Potassium	Sulphur
0	81.35	13.91	27.60	6.36
15	99.61	17.70	32.62	8.67
30	120.31	22.69	38.27	10.57
45	129.44	26.60	41.02	11.67
CD (P=0.05)	13.30	2.51	3.52	0.65

Effect of sulphur on kernel quality

Application of sulphur is known to affect the quality of groundnut in terms of increased shelling percentage, protein and oil content in the seeds. Even the source of sulphur supplement is known to influence the oil content in the seeds. Favourable effect of sulphur application was noticed on shelling percent sulphur was supplied at 15 kg or more/ha (Chitkala and Reddy, 1991). Dimree and Dwivedi (1994) found that application of sulphur at 45 kg/ha along with 40 kg P/ha increased the protein and oil content in groundnut kernels over the treatments where sulphur was applied at 15 and 30 kg S/ha. Application of 25 kg S/ha along with 500 kg calcium gave higher oil and protein content in kernel (Thakare *et al.,* 1998). Sahu *et al.* (2001) noted that the application of sulphur at 40 kg/ha through phosphogypsum produced significantly higher oil content and oil yield of groundnut kernels than 20 kg/ha and control. Application of sulphur at 45 kg/ha through gypsum recorded higher oil content in kernels of groundnut. Oil content in the kernels was found to be 7.5 and 8.8% higher during 2010 and 2011, respectively over control (Rao *et al.,* 2013). Veeranagappa *et al.* (2015) reported that significantly higher oil content (45.57 per cent) was recorded in application of recommended dose of NPK (40:40:90) + FYM (12.5 t/ha) + 45 kg/ha S through gypsum compared with other treatments. Oil yield was significantly higher in same treatment (618.8 kg/ha) and was superior over all the other treatments. This could be due to application of S through gypsum which provided S and Ca. Sulphur the integral part of amino acids like cysteine, cystine and methionone recorded higher oil content over no application of sulphur. Highest oil content (44.67%) was obtained with the application of sulphur at 75 kg/ha (Nagesh *et al.,* 2019). Application of S @ 45 and 60 kg/ha resulted in 6.4 and 14.2% and 9.5 and 17.5% more oil content than 30 and 15 kg S/ha, respectively. However, it was found at par with 60 and 75 kg S/ha. It could be inferred from the data presented here that oil content in kernel was significantly affected due to different sources of sulphur.

Residual effect

Application of sulphur is known to influence the succeeding crop positively due to the residual effect. The residual effect of different sulphur sources on wheat (*Triticum aestivum*) grain yield has been observed (Prasad, 2003). In Tonk district of Rajasthan, residual effect of sulphur @ 20, 40 and 60 kg/ha applied to groundnut crop increased the grain yield of succeeding wheat crop by 10.4, 20.7 and 22.4%, respectively, over the control. Similar trend was found in straw yield of wheat. Residual effect of sulphur also increased the S uptake by wheat significantly (Singh *et al.,* 2005).

Groundnut based cropping systems

Gypsum gives significant effect on groundnut grown in rice based cropping system (Ghosh, 1995). In groundnut-mustard rotation total grain yield was 13% more when S was applied to groundnut and mustard was raised on residual fertility (Singh *et al.,* 1991). Benefit: cost ratio in wheat also exhibited significant improvement due to marked residual effect of 40 kg S/ha over control and 20 kg S/ha (Singh and Saha, 1995). The variation in system productivity, production efficiency and economic efficiency were attributable to direct and residual effects of sulphur on productivity of respective component crops in groundnut - wheat cropping system (Gupta and Jain, 2009). In a recent cropping system based study at New Delhi, it was observed that direct application of S @ 40 kg/ha led to significant enhancement in groundnut pod yield, wheat grain yield, system productivity, system production efficiency and system economic efficiency in groundnut - wheat cropping system (Heba *et al.,* 2016) (Table 4).

Groundnut based intercropping systems

Intercropping is one of the attempts for optimizing resource utilization for achieving maximum production per unit area and time. Though the potentiality exists, presently about 20 - 30 % of the total groundnut area is covered under intercropping (Singh *et al.,* 1997).

Jat and Ahlawat (2010) have reported higher system productivity, net return and B: C ratios were higher in pigeon pea + groundnut intercropping (Table 5). Application of sulphur (at either 35 or 70 kg/ha), recorded significant increase in yield. Among the sources of sulphur, cosavet recorded higher yield and yield attributes, nutrient uptake and S use efficiency.

Table 4 Effect of sulphur application to groundnut on groundnut pod yield, wheat grain yield, system productivity [(groundnut pod equivalent yield (GPEY)], production efficiency and economic efficiency under groundnut - wheat cropping system

Sulphur levels (kg/ha)	Wheat grain yield (t/ha)	Groundnut pod yield (t/ha)	GPEY (t/ha)	Production efficiency (kg/ha/day)	Economic efficiency (₹/ha/day)
0	5.42	1.63	3.53	9.7	240.8
20	5.48	2.00	3.92	10.7	281.1
40	5.67	2.13	4.11	11.3	299.2
CD (P=0.05)	0.63	0.04	0.09	0.10	7.1

Table 5 Effect of source and levels of sulphur on system productivity and economics of pigeon pea + groundnut intercropping system

Cropping system	Pigeon pea equivalent yield (t/ha)	Net return (₹/ha)	B:C ratio
Sole pigeon pea	1.51	14,939	1.22
Pigeon pea + groundnut	1.76	23,148	1.75
CD (P=0.05%)	0.03	-	-
Source and level of S (kg/ha)			
Control	1.50	15,620	1.72
Elemental sulphur @ 35	1.65	20,808	2.02
Elemental sulphur @ 70	1.72	20,464	1.81
Gypsum @ 35	1.67	21,365	2.12
Gypsum @ 70	1.81	21,229	1.96
Cosavet @ 35	1.89	19,447	1.24
Cosavet @ 70	1.96	14,225	0.65
CD (P=0.05)	0.08	-	-

To conclude, from the published literature on the effect of sulphur application to groundnut crop it could be inferred that sulphur fertilization at 20-60 kg/ha was found most suitable for obtaining higher productivity and profitability of groundnut. Similarly, gypsum was observed as the most effective source of sulphur for enhancing growth, nutrient use efficiencies, yield attributes, quality parameters, yield and profitability of groundnut with a positive residual effect on succeeding crops.

REFERENCES

Agasimani C A, Babalad H B and Patil P L 1993. Response of groundnut to sulphur and boron. *Journal of Maharashtra Agriculture Universities*, **18**(2): 318-319.

Arshad J, Inayat S F, Saif A and Malik Z A 2006. Interactive effect of nitrogen and sulphur on yield and quality of groundnut *Arachis hypogaea* L. *Korea Journal Crop Science*, **51**(6): 519-522.

Awad A, Chan K, Downie A and Fink C 2000. Peanut as a source of beta-sitosterol, a sterolwith anticancer properties. *Nutrition Cancer*, **36**(2): 238-241.

Bandopadhyay P and Samui R C 2000. Response of groundnut (*Arachis hypogaea*) cultivars to levels and sources of sulphur in West Bengal. *Indian Journal of Agronomy*, **45**(4): 761-764.

Bandopadhyay P, Samui R C, Kundu C K and Rajibnath 2002. Response of summer groundnut to varying levels of phosphorus, potassium and sulphur in West Bengal. *Journal of International Academia*, **6**(4): 462-467.

Battacharya B, Chakraborty A, Bandopadhyay S and Samanta D 1997. Effect of sulphur application and different sowing methods on concentration and uptake of S in summer groundnut (*Arachis hypogaea* L.). *Indian Journal of Agronomy*, **38**(3): 502-503.

Chaubey A K, Singh S B and Kaushik M K 2000. Response of groundnut (*Arachis hypogaea* L.) to sources and levels of sulphur fertilization in mid-western plains of Uttar Pradesh. *Indian Journal of Agronomy*, **45**(1): 166-169.

Das P C 1997. *Oilseeds Crops of India.* Kalyani Publishers, Ludhiana, India, pp. 80-83.

Dash A K, Nayak B R, Panigrahy N, Mohapatra S and Samant P K 2013. Performance of groundnut (*Arachis hypogaea*) under different levels of sulphur and irrigation. *Indian Journal of Agronomy*, **58**(4): 578-582.

Dimree S and Dwivedi K N 1994. Response of sulphur and phosphorus on groundnut. *Journal of Oilseeds Research*, **11**(2): 113-195.

Dimree S, Dwivedi K N and Hariram 1993. Effect of sulphur and phosphorus nutrition on yield and yield attributes of groundnut (*Arachis hypogaea* L). *Indian Journal of Agronomy*, **38**(2): 327-328.

Din U N, Mehmood A, Khattak G S, Saeed I and Hassan M F 2009. High yielding groundnut (*Arachis hypogaea* L.) variety "Golden". *Pakistan Journal of Botany*, **41**(5): 2217-2222.

Dutta D and Mondal S S 2006. Response of summer groundnut (*Arachis hypogaea*) to moisture stress, organic manure and fertilizer with and without gypsum under lateritic soil of West Bengal. *Indian Journal of Agronomy*, **51**(2): 145-148.

Dutta D and Patra B C 2005. Response of summer groundnut (*Arachis hypogaea* L.) to sources and levels of sulphur fertilization in alluvial soils. *Journal of International Academia*, **9**(1): 45-48.

Dutta D, Mudi D D, Murmu P and Thentu T L 2015. Response of groundnut (*Arachis hypogaea* L.) to irrigation schedules, sulphur levels and sources in alluvial zone of West Bengal. *Indian Journal of Agronomy*, **60**(3): 443-449.

Etherton, Kris E P, Pearson T, Wan Y, Hargrove R, Moriarty K, Fishell V and Etherton T 1999. High monounsaturated fatty acid diets lower both plasma cholesterol and triacylglycerol concentrations. *American Journal of Clinical Nutrition*, **70**: 1009-1015.

Ghosh P K 1995. Groundnut in rice - based cropping system: problems and prospects. *Indian Farm*, July, pp. 9-13.

Giri U, Kundu P, Chakraborty A and Bandyopadhyay P 2011. Effect of sulphur and different irrigation regimes on groundnut. *Journal of Crop and Weed*, **7**(2): 80-83.

Gupta H and Jain LG 2009. Effect of sulphur on groundnut - wheat cropping system. *Agriculture Journal*, **8**(2): 55-62.

Hadavani R G, Ahlawat R P S and Trivedi S J 1993. Effect of sulphur application and different sowing methods on concentration and uptake of S in summer groundnut (*Arachis hypogaea* L.). *Indian Journal of Agronomy*, **38**(3): 502-503.

Heba M N, Rana D S, Choudhary A K, Rajpoot S and Paul T 2016. Sulphur and Zn management in groundnut (*Arachis hypogaea*)-wheat (*Triticum aestivum*) cropping system: Direct effects on system productivity and residual effects on yield, energetics and Zn biofortification in wheat. *Indian Journal of Agricultural Sciences*, **86** (4): 441-417.

Jagadeeswaran R, Murugappan V and Singaram P 2001. Effect of ferro gypsum on yield, nutrient uptake and quality in groundnut. *Madras Agricultural Journal*, **88**(4-6): 210-213.

Jat R A and Ahlawat I P S 2009. Effect of farm yard manure, source and level of sulphur on growth attributes, yield, quality and total nutrient uptake in pigeonpea (*Cajanus cajan*) and groundnut (*Arachis hypogaea*) intercropping system. *Indian Journal of Agricultural Science*, **79**(12): 1016-1019.

Jat R A and Ahlawat I P S 2010. Effect of organic manure and sulphur fertilization in pigeonpea (*Cajanus cajan*) + groundnut (*Arachis hypogaea* L.) intercropping system. *Indian Journal of Agronomy*, **55**(4): 276-281.

Jiang R, Manson J, Stampfer M, Liu S, Willett W and Hu F 2000. Nut and peanut butter consumption and risk of type 2 diabetes in women. *Journal of American Medical Association*, **20**: 2554-2560.

Kadam U A, Pawar V S and Pardeshi H P 2000. Influence of planting layouts, organic manures and levels of sulphur on growth and yield of summer groundnut. *Journal of Maharashtra Agriculture Universities*, **25**(2): 211-213.

Kalaiyarasan C, Vaiyapuri V and Chandrasekharan M V S 2002. Effect of sulphur sources and levels on the growth and yield of groundnut in red laterite soil. *Annals of Agricultural Research*, **23**(4): 618-621.

Kalaiyarasan C, Vaiyapuri V and Chandrasekharan M V S 2003. Effect of sulphur sources and levels on the nutrient uptake, crop quality and sulphur use efficiency in groundnut. *Annals of Agricultural Research*, **24**(3): 478-480

Kalaiyarasan C, Vaiyapuri V and Chandrasekharan M V S 2007. Effect of sulphur sources and levels on nutrient uptake, crop quality and use in groundnut. *Journal of International Academia*, **11**(1): 55-58.

Khan T A and Mazid M. 2011. Nutritional significance of sulphur in pulse cropping system. *Biology and Medicine*, **3**(2): 114-133.

Kishore babu G, Munaswamy V, John K and Padma Raju A 2007. Effect of long term application of manure and fertilizers on yield and yield attributes of rainfed groundnut, *Arachis hypogaea* L. *Journal of Oilseeds Research*, **26**(2): 119-122.

Kumar A, Sharma M and Mehra R K 2008. Effect of phosphorus and sulphur on yield and nutrient uptake by groundnut in inceptisols. *Asian Journal of Soil Science*, **3**(1): 139-141.

Kumpawat B S and Rathore S S 1994. Effect of FYM and Sulphur on yield of groundnut (*Arachis hypogaea* L.). XIIth National Symposium on Integrated Input Management for Efficient Crop Production, 2-5 February 1994, Coimbatore, Tamil Nadu, pp. 107.

Maity S K, Giri G and Deshmukh P S 2003. Effect of phosphorus, sulphur and planting methods on parameters and total yield of groundnut (*Arachis hypogaea* L.) and sunflower (*Helianthus annuus* L.). *Indian Journal of Plant Physiology*, **8**(4): 377-382.

Meena H N and Shivay Y 2010. Productivity of short-duration summer forage crops and their effect on succeeding aromatic rice in conjunction with gypsum-enriched urea. *Indian Journal of Agronomy*, **55**(1):11-15.

Messina M 1999. Legumes and soybeans: overview of their nutritional profiles and health effects. *American Journal of Clinical Nutrition*, **70**: 439-450.

Nabi G and Salim R S 1990. Utilization of added sulphur by groundnut on two uduli haplustalf. *Journal of Indian Society of Soil Science*, **12**: 151-155.

Nagesh Y, Yadav S S, Neelam Y, Yadav M R, Rakesh Kumar and Yadav L R 2019. Sulphur management in groundnut for higher productivity and profitability under semi-arid condition of Rajasthan, India. *Legume Research*, **42**(4): 512-517

Nagesh Yadav, Yadav S S, Neelam Yadav, Yadav M R, Rakesh Kumar, Yadav L R, Yadav V K and Sharma O P 2018. Sulphur management in groundnut for higher productivity and profitability under semi-arid condition of Rajasthan, India. *Legume Research*, **41**(2): 293-298.

Naresha R, Laxminarayana P, Suneetha Devi K B and Sailaja V 2018. Quality, yield and economics of rabi groundnut as influenced by irrigation scheduling and phosphogypsum levels. *International Journal of Current Microbiology and Applied Science*, **7**(3): 3292-3303.

Noman H M, Rana D S and Rana K S 2015. Influence of sulphur and zinc levels and zinc solubilises on productivity, economics and nutrient uptake in groundnut (*Arachis hypogaea* L.). *Indian Journal of Agronomy*, **60**(2): 301-306.

Onyeike E N and Oguike J U 2003. Influence of heat processing methods on the nutrient composition and lipid characterization of groundnut seed pastes. *Nigerian Society of Experimental Biology*, **15**(1): 34-43.

Panda S C, Nanda S S and Mishra R C 1997. Response of winter groundnut (*Arachis hypogaea* L.) to methods of sowing and sources of sulphur. *Indian Journal of Agronomy*, **42**(4): 680-685.

Patel A R and Zinzala V J 2018. Effect of sulphur and boron on nutrient content and uptake by summer groundnut (*Arachis hypogaea* L.). *The Pharma Innovation Journal*, **7**(4): 47-50.

Patel G N, Patel P T, Patel P H and Patel R M 2008. Yield attributes, yield, quality and uptake of nutrients by summer groundnut as under North Gujarat condition. *Journal of Oilseeds Research*, **25**(1): 35-37.

Patel G N, Patel P T, Patel P H, Patel D M, Patel D K and Patel R M 2009. Irrigation and sulphur management in summer irrigated yield attributes, yield, quality and uptake of nutrients by summer irrigated groundnut as influenced by source and levels of sulphur under different irrigation schedules. *Journal of Oilseeds Research*, **26**(2): 119-122.

Patel P K, Viradiya M B, Kadivala V H and Shinde R D 2018. Effect of potassium and sulphur on yield attributes, yield and quality of summer groundnut (*Arachis hypogaea* L.) under middle Gujarat condition. *International Journal of Current Microbiology and Applied Science*, **7**(9): 2268-2273.

Patil S S, Ruat P D, Ingole G L and Dangore S T 2003. Effect of sulphur and magnesium on yield, nutrient uptake and quality of groundnut. *New Agriculture*, **14**(1-2): 49-52.

Poonia B S, Shanwal A V, Rajput O P, Singh J and Dharmveer 2006. Effect of sulphur fertilization, phosphorus solubilizing micro-organism (PSM) and growth regulators on groundnut (*Arachis hypogaea* L.). *Annals of Biology*, **22**(1): 19-22.

Poonia B S, Singh P, Rajput O P and Sumeriya H K 2013. Response of groundnut (*Arachis hypogaea* L.) in rainfed condition under the influence of sulphur, PSB and growth regulation. *Annals of Biology*, **18**(3): 336-338.

Prasad B 2003. Effect of direct and residual effects of different sulfur fertilizers on groundnut and wheat cropping system on Typic Haplaquent soils. *Journal of Plant Nutrition*, **26**(5): 997-1008.

Ramdevputra M V, Akbari K N, Sataria G S, Vora V D and Padmani D R 2010. Effect of sulphur application on yield of groundnut and soil fertility under rainfed conditions. *Legume Research*, **33**(2): 143-145.

Rao K T, Rao A U and Sekhar D 2013. Effect of sources and levels of sulphur on groundnut. *Journal of Academia and Industrial Research*, **2**(5): 268-270.

Sahu S K and Das B B 1997. Effect of source, dose, time and mode of sulphur application to groundnut on lateritic soils, Orissa, India. *International Arachis Newsletter*, **17**: 62-63

Sahu S K, Nayak S C, Dhal J K and Nayak R K 1999. Response to sulphur of rainfed groundnut genotypes on lateritic sandy loam in Orissa, India. *International Arachis Newsletter*, **19**: 46-47.

Sahu S K, Nayak S C, Nayak R K and Dhal J K 2001. Integrated management of sulphur for groundnut on a lateritic soil in Orissa, India. *International Arachis Newsletter*, **21**: 49-50.

Saini C, Jain N K and Mathukia R K 2016. Effect of sulphur and plant-growth regulators on growth, yield and economics of summer groundnut (*Arachis hypogaea*). *Indian Journal of Agronomy*, **61**(1): 115-118.

Salke S R, Shaikh A A and Dalavi N D 2011. Effect of phosphatic fertilizers, gypsum and sulphur on groundnut (*Arachis hypogaea* L.). *Bioinfolet*, **8**(3): 276-277.

Schonhof I, Blankenburg D, Muller S and Krumbein A 2007. Sulphur and nitrogen supply influence growth, product appearance, and glucosinolate concentration of broccoli. *Journal of Plant Nutrition and Soil Science*, **170**: 65-72.

Shivraj B and Gowda A 1993. Influence of levels and sources of sulphur on yield and quality of groundnut. *Current Research*, **22**(3-5): 45-47.

Shokunbi O S, Fayomi E T, Sonuga O S and Tayo G O 2012. Nutrient composition of five varieties of commonly consumed Nigerian groundnut (*Arachis hypogea* L.) Biochemistry Department, Babcock University, Ilisan Remo, Ogun State, Nigeria. **63**(1): 14- 18.

Singh A L, Ghosh P K and Devi Dayal 1997. Nutrient management in groundnut and groundnut based cropping systems. *In: Nutrient Management Practices in crops and cropping Systems*, Ghonsikar C P and Shinde V S (Eds), Scientific Publishers, Jodhpur. pp. 157-190.

Singh A L, Joshi Y C, Devi Dayal and Misra J B 1991. Application of different sources of sulphur in groundnut. *In: Proceedings of the National Seminar on Sulphur in Agriculture. In*: Siddharmappa R, Vijaya Chaudahry P K and Susheela Devi L (Eds.) University of Agricultural Sciences, Bangalore and Fertilizer and Chemicals Travancore Ltd., Cochin, India. pp. 76-81.

Singh A L, Joshi Y C, Vidya C and Zala P V 1990a. Effect of different sources of iron and sulphur on leaf chlorosis, nutrient uptake and yield of groundnut. *Fertilizer Research*, **24**: 85-96.

Singh A L, Joshi Y C and Koradia V G 1990b. Effect of micronutrients and sulphur on groundnut (*Arachis hypogaea* L.) in calcareous soil. *In: Proceedings of the International Congress of Plant Physiology,* New Delhi, pp. 1236-1240.

Singh A L and Vidya C 1995. Source and mode of sulphur application on groundnut productivity. *Journal of Plant Nutrition*, **18**(12): 2739-2759·

Singh L and Saha J 1995. Direct and residual application of sulphur on groundnut-wheat cropping system. *Agriculture Journal*, **4**(8): 53-59.

Singh R A, Singh P V, Singh J, Singh D P and Khan K 2012. Integrated nutrient management in groundnut (*Arachis hypogaea* L.) for higher production during rainy season. *International Journal of Agricultural Sciences*, **8**(1): 37-40.

Singh S, Kumar Y, Gill O P, Singh S and Kumar Y 2003. Growth characteristics of summer groundnut (*Arachis hypogaea* L.) as influenced by sulphur levels, irrigation schedules and organic manures. *Annals of Agriculture Research*, **19**(2): 135-139.

Singh Y P, Sharma S C and Maan J S 2005. Effect of sulphur on yield and its uptake in groundnut (*Arachis hypogaea*) and their residual effect on succeeding wheat (*Triticum aestivum*). *Indian Journal of Agronomy*, **50**(2): 116-118.

Smith A F 2002. *Peanuts: The Illustrious history of the goober pea.* University of Illinois Press, pp. 234.

Tathe A S 2008. Response of different levels of sulphur and zinc fertilization on yield and uptake of nutrients by groundnut. *Asian Journal of Soil Science*, **3**(1): 133-136.

Tejeswara Rao K, Upendra Rao A and Sekhar D 2013. Effect of sources and levels of sulphur on groundnut. *Journal of Academia and Industrial Research*, **2**(5): 268-270.

Thakare S K, Gowande R P, Selukar S S and Dawane P N 1998. Influence of sulphur and calcium on yield and quality attributes of groundnut. *Journal of Soil and Crops*, **8**(2): 163-164.

Thirunavukkarasu M and Subramanian K S 2016. Nano-sulphur on biomass, yield attributes, soil microbes and physiological parameters of groundnut. *Life Science Leaflet*, **63**: http://petsd.org/ojs/index.php/lifesciencesleaflets/issue/view/65.

Tiwari R C, Chaplot P C and Sharma A 1994. Effect of irrigation schedules and sulphur levels on summer groundnut (*Arachis hypogaea* L.). *Legume Research*, **17**(2): 101-104.

Tom D D 2007. Earliest-known evidence of peanut, cotton and squash farming found. http://www.eurekalert.org/pub_releases/2007-06/vu-eeo0 62507.php.

Tripathi M L, Rajput R L and Chauratia S K 2007. Effect of sources and levels of sulphur on yield and economics of sesame. *Advances in Plant Science*, **20**(11): 501-502.

Vaghasia P M, Khanpara U D and Mathukia R C 2007. Response of groundnut to in-situ moisture conservation and sulphur nutrition under rainfed condition. *Advances in Plant Science*, **20**(1): 177-178.

Veeranagappa P J, Saralakumari V R, Ramakrishna Parama SS, Prakash and Bhaskar S 2015. Growth, yield attributes and yield of groundnut as influenced by the application of varied levels and sources of sulphur. *Trends in Biosciences*, **8**(24): 6796-6799.

Wali S Y, Shivaraj B and Gowda A 1994. Response of groundnut genotypes to graded levels of sulphur in Alfisols of southern Karnataka. *Journal of Oilseeds Research*, **11**(2): 282 - 284.

Yao G 2004. Peanut production and utilization in the People's Republic of China. http://www.caes.uga.edu/commodities/fieldcrops/peanuts/pins/documents/ChinaProduction.pdf.

Heterosis for yield and its component traits in Indian mustard (*Brassica juncea* L., Czern & Coss)

RAJKUMARI BONY DEVI AND AMITAVA DUTTA

Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia-741 252, West Bengal

(Received: December 16, 2019; Revised: February 21, 2020; Accepted: February 24, 2020)

ABSTRACT

Four lines were crossed with eleven testers in line x tester mating design for estimation of combining ability and heterosis for yield and its component characters in mustard (*Brassica juncea*). Lines PM-25 and PM-27 were found to be superior general combiners for length of siliqua and seed yield. PM-25 was also found to be a very good general combiner for number of seeds/siliqua and 1000 seed weight. The cross Varuna x Pusa Tarak showed high *sca* for seed yield followed by Varuna × Pusa LES-39 while for 1000 seed weight trait, Varuna x PM-28 and Varuna x PM-25 were found to be better. Varuna x Pusa Tarak also showed high *sca* for total number of siliqua/plant. Among the 44 hybrids, Varuna × Pusa LES-39 recorded highest heterosis for seed yield /plant over mid parent and better parent followed by Varuna × PM-27, Varuna × PM-26, Kranti× PM-27 and Varuna × Pusa Tarak. The results of this study suggest that the cross Varuna x Pusa Les 39 is best for high seed yield due to high siliqua length, number of siliqua at main axis, total number of siliqua/plant and number of seeds/siliqua.

Keywords: Combining ability, Heterosis, Mustard, Yield

Indian mustard (*Brassica juncea* L., Czern & Coss) is an important oilseed crop of India which plays a crucial role in edible oil economy. The traditionally grown rapeseed mustard species, namely Toria, Yellow sarson, Brown sarson, Indian mustard, Black mustard and Taramira have been grown since about 3500 B.C. along with nontraditional species like Gobhi sarson, white mustard and Ethiopian mustard or Karan rai (Chauhan *et al.,* 2011). In 2016-17, rapeseed-mustard was grown in an area of 63.23 lakh ha with a production of 79.77 lakh tonnes and productivity of 1262 kg/ha (Darekar and Reddy, 2018). Though the nutritional advantages of rapeseed-mustard oil available in India outdo many other edible oils (lowest amount of harmful saturated fatty acids), and contains two essential fatty acids (*viz.,* linoleic and linolenic), the presence of erucic acid and glucosinolates are considered to be undesirable. Indian varieties under cultivation have high erucic acid (about 50%) and high glucosinolates (≥100 μmol/g) defatted seed meal. At present the cultivation of low erucic acid Indian mustard (quality mustard) is done on limited scale in Punjab state only. Since the yield of quality mustard is low as compared to popular mustard varieties, there is a need to improve seed yield of quality mustard under Indian conditions.

For success of any breeding programme the basic need is selecting better parents for hybridization. Combining ability analysis provides information related to gene action involved in the inheritance of quantitative characters and helps the breeder in the choice of suitable parents (Dutta *et al.,* 2011). In rapeseed mustard breeding programme general and specific combining ability effects (GCA and SCA) are hybrid combination. The line x tester analysis is one of the efficient methods of evaluating large number of inbreds as well as providing information on the relative importance of gca and sca effects for interpreting the genetic basis of important plant traits (Singh and Chaudhury, 1977). Mid parent and better parent heterosis (heterobeltiosis) have extensively been explored and utilized for boosting various qualitative and quantitative traits in rapeseed (Nassimi *et al.,* 2006; Chapi *et al.,* 2008). The main aim of present investigation was to determine the combining ability of 15 parents for yield and yield contributing traits and to select parents with good gca and crosses with good sca effects through line x tester mating design.

Corresponding author's E-mail: amitavapors@gmail.com

MATERIALS AND METHODS

Four lines *viz.,* Varuna, Pusa Bold, JD-6 and Kranti were crossed with eleven testers *viz.,* PM-21, PM-22, PM-24, PM-25, PM-26, PM-27, PM-28, PM-29, PM-30, Pusa LES-39 and Pusa Tarak according to line x tester mating design at A-B Block farm, BCKV, Kalyani Nadia West Bengal during *rabi* 2015-16. The research station is located at a height of 9.75 m above mean sea level (23.5° N latitude and 89° E longitudes). The soil of the experimental site is sandy loam in texture with pH 6.7. Forty four F_1 hybrids produced during the winter season of 2015-16 were evaluated during the winter season of 2016-17. The F_1 hybrids along with 15 parents were sown in a randomized block design with three replications. Thirteen phenological and quantitative characters were studied to estimate combining ability effects and heterosis. The mean values were subjected to line x tester analysis (Kempthrone, 1957) to estimate combining ability effects and variances. Mid parent heterosis and better parent heterosis was determined by the procedure of Falconer and Mackey (1980).

Each replication comprising 59 entries (44 F_1s and 15 parents) were sown in 4.8 m × 3.0 m plot maintaining plant to plant distance 10 cm and row to row distance 30 cm with recommended package of practices. Observations were recorded on ten randomly selected plants from each plot of all replications to record data on the following characters plant height (cm), main axis height (cm), days to first flowering, days to 50% flowering, days to maturity, number of primary branches/plant, number of secondary branches/plant, number of siliqua on main axis, total number of siliqua/plant, length of siliqua (cm), number of seeds/siliqua, 1000 seeds weight (g) and seed yield/plant (g).

RESULTS AND DISCUSSION

The analysis of variance of the mean data of lines, testers and their hybrids (Tables 1 and 2) revealed significant differences of mean square for all the characters except number of primary branches per plant, length of siliqua and 1000 seed weight.

Based on *per se* performance and general combining ability effects (Table 3a and 3b) Kranti, PM-21 were superior with respect to early flowering and PM-21, PM-26 were superior with respect to maturity. PM-21 was also a good combiner for higher main axis height and early maturity. PM-25 was a good general combiner for length of siliqua, seeds/siliqua, 1000 seeds weight and seed yield/plant. Character wise performance of entries revealed that lower plant height in PM-22 and PM-28; PM-21 and PM-30 for higher main axis height can be used as parents. Likewise for early flowering Kranti and PM-21; for early maturity PM-21 and PM-26; for number of primary and secondary branches Pusa Tarak, PM-29 and PM-30; for length of silique, PM-24, PM-25 and PM-27; for number of seeds/silique PM-25 and Pusa Bold; for siliqua/plant PM-30 and Pusa Tarak; for higher 1000 seed weight Varuna and PM-25 and for high seed yield/plant PM-25 and PM-27 may be selected as good donor parents. These parents can be considered for crossing for improvement of one or more characters along with high seed yield. The findings were in conformity with the findings of Singh *et al.* (2006).

The *sca* effects and *per se* performance were not always considered together. Top ranking crosses involved high, medium and low combiners as parents (Singh and Lallu, 2004). The cross combinations with good results on account of low x low *gca* effects of their parents may be explained because of the main role in non-additive gene action. High x high general combiners showed additive x additive gene action for these characters and may be exploited through pedigree method of breeding. A perusal of tables 3a and 3b revealed that, character-wise best specific combiners: for lower plant height it was Varuna x PM-22 and JD-6 x PM-28 due to high significant negative effect for dwarfness. For first and 50% flowering (days), JD-6 x PM-21 and JD-6 x PM-26 were good combiners but only JD-6 x PM-26 showed significant effect of *sca.* For days to maturity, Varuna x PM-26 and Pusa Bold x PM-21 were good combiners but only Pusa Bold x PM-21 recorded significant *sca* effects. JD-6 x PM-29 and Pusa Bold x PM-29 were good combiners for primary branches/plant. Pusa Bold x PM-29 and Kranti x PM-30 were good combiners for secondary branches/plant. Pusa Bold x PM-30 and Varuna x Pusa Tarak showed high significant *sca* effect for total siliqua/plant but for 1000 seed weight Varuna x PM-28 and Varuna x PM-25 were found to be good combinations. For length of siliqua, Pusa Bold x PM-24 and Varuna x PM-24; for siliqua/ plant JD-6 x PM-25 and Pusa Bold x PM-28 were superior. Varuna x Pusa Tarak followed by Varuna x Pusa Les-39 had maximum significant effect for seed yield/plant. Ramesh (2012) found similar results for siliqua/plant and seed yield.

Table 1 Analysis of variance for phenological characters of mustard

Source of variation	d.f.	Plant height (cm)	Main axis height (cm)	1st flowering (days)	50% flowering (days)	Maturity (days)
Replications	2	234.55**	473.95**	13.85**	7.73**	3.16*
Genotypes/treatment	58	882.55**	2450.44**	47.16**	45.20**	7.98**
Parents	14	824.25**	753.12**	39.32**	44.13**	15.53**
Parents vs hybrids	1	11801.06**	70913.32**	151.43**	67.79**	1.53ns
Hybrids	43	647.62**	1410.90**	47.29**	45.02**	5.67**
GCA lines	3	272.52**	348.86**	275.73**	247.16**	13.58**
GCA testers	10	684.67**	2033.98**	31.32**	30.17**	8.82**
SCA line x tester	30	672.78**	1309.41**	29.76**	29.75**	3.83**
Error	116	188.64	322.08	4.56	4.18	3.14

* and **significant at 5% and 1% level of significance respectively; ns: non-significant

Table 2 Analysis of variance for yield and its attributing characters of mustard

Source of variation	d.f.	Primary branches/ plant	Secondary branches/plant	Number of siliqua at main axis	Total siliqua/plant	Length of siliqua (cm)	Seeds/ siliqua	1000-seeds weight (g)	Seed yield/plant (g)
Replications	2	0.01ns	9.16	11.40	214.17	0.02ns	0.87	0.78ns	3.91*
Genotypes/treatment	58	3.39	52.09	204.58	6641.43	1.16	12.75	1.25ns	19.88
Parents	14	1.61ns	16.90	103.71	2237.15	0.64ns	6.38	0.99ns	5.85
Parents vs hybrids	1	72.22	1093.82	1953.62	87308.54	0.25ns	20.87	0.24	261.19
Hybrids	43	2.36	39.32	196.74	6199.40	1.35ns	14.63	1.36	18.83
GCA lines	3	0.16	14.32	172.09	6518.04	3.21	23.61	4.19	45.05
GCA testers	10	2.60	35.39	154.91	7477.15	1.29	9.57	1.58	22.97
SCA line x tester	30	2.50	43.13	213.15	5741.62	1.19	15.42	1.01	14.83
Error	116	1.04	5.70	46.30	685.64	0.10	2.01	0.12	0.86

* and unmarked values significant at 5% and 1% level of significance respectively; ns: non- significant

Table 3a Character wise estimates of general combining ability of superior parents and specific combining effects of superior cross combinations

Character	General combining ability effects o f superior parents			Specific combining ability effects of superior cross combinations			
	Parents	*Per se* performance	GCA effects	Crosse combinations	*Per se* performance	SCA effects	GCA effects
Plant height (cm.)	PM-22	193.00	-14.73*	Varuna x PM-22	145	-23.24**	MxL
	PM-28	158.67	-6.02	JD-6 x PM-28	163	-17.01*	MxH
Main axis height (cm)	PM-21	91.00	15.06*	Pusa Bold x PM-26	80.33	-44.66**	MxL
	PM-30	99.67	13.02	JD-6 x PM-28	107	-6.19	MxL
Days to 1st flowering	Kranti	41.67	-3.11**	JD-6 x PM-21	39	-1.26	LxL
	PM-21	48.67	-2.92*	JD-6 x PM-26	39	-3.01*	MxH
Days to 50% flowering	PM-21	54.67	-3.04*	JD-6 x PM-21	45	-0.51	LxL
	Kranti	47.33	-2.89**	JD-6 x PM-26	45	-2.34*	MxH
Days to Maturity	PM-21	110.67	-2.05*	Varuna X PM-26	104.00	-1.74	LxH
	PM-26	105.67	-1.14	Pusa Bold X PM-21	104.00	-1.83*	LxH

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

Table 3b Character wise estimates of general combining ability of superior parents and specific combining effects of superior cross combinations

Character	General combining ability effects of superior parents			Specific combining ability effects of superior cross combinations			
	Parents	*per se* performance	GCA effects	Crosse combinations	*per se* performance	SCA effects	GCA effects
No. of primary branches	PM-29	4.30	0.95*	JD-6 x PM-29	7.67	1.90*	LxH
	Pusa Tarak	2.67	0.49	Pusa Bold x PM-29	6.33	0.48	LxL
No. secondary branches	Pusa Tarak	4.33	2.59	Pusa Bold x PM-29	18.33	7.40**	LxH
	PM-30	1.67	2.42*	Kranti x PM-30	16.67	4.09**	LxM
No. of siliqua at main axis	PM-27	34.33	5.08	JD-6 x PM-27	59.33	10.05**	HxM
	PM-26	27.33	3.83	JD-6 x PM-28	59	14.63**	LxL
Total no. of siliqua	PM-30	95.33	32.89*	Pusa Bold x PM-30	260.33	67.05**	MxH
	Pusa Tarak	83.67	19.06	Varuna x Pusa Tarak	228.67	42.76**	MxH
Length of siliqua(cm)	PM-24	5.56	0.57**	Pusa Bold x PM-24	6.83	0.49	HxL
	PM-25, PM-27	5.91, 5.95	0.29*	Varuna x PM-24 Kranti x PM-29	6.57	0.32* 0.90**	LxM
No. of seeds/ siliqua	PM-25	13.58	1.74*	JD-6 x PM-25	16.67	1.92*	LxM
	Pusa Bold	11.23	0.56	Pusa Bold x PM-28	16.33	3.19**	MxL
1000 seeds weight (g)	Varuna	5.12	0.44**	Varuna x PM-28	5.84	1.16**	MxL
	PM-25	4.07	0.41*	Varuna x PM-25	5.52	0.63**	HxM
Seed yield/plant (g)	PM-25	6.08	1.64**	Varuna x Pusa Tarak	13.20	2.498*	HxL
	PM-27	4.80	1.50**	Varuna x Pusa Les-39	12.88	4.368*	LxL

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

The parents that exhibited maximum heterosis for seed yield over mid parent and better parent are presented in Table 4. The magnitude of heterosis for seed yield/plant ranged from -8.23 to 284.96% over mid parent and -31.39 to 266.00% over better parent. The cross Varuna x Pusa LES-39 showed high *per se* performance along with 284.96% and 266.00% heterosis over mid parent and better parent respectively. This cross also showed significant heterosis for other traits *viz.,* length of siliqua, siliqua on main axis, siliqua/plant and seeds/siliqua. High heterosis for seed yield was also observed for the crosses Varuna x PM-27, Varuna x PM-26, Kranti x PM-27 and Varuna x Pusa Tarak. Therefore, the results revealed superior crosses with high level of heterosis for seed yield. This would enable the breeders to concentrate on few promising cross combinations for further crop improvement.

The information on gca effects of the parents shall be considered along with highly significant sca effect and higher per se performance of hybrids for predicting the value of any hybrid. General combining ability effects revealed that PM-21 might be considered the best general combiner for early flowering and maturity, days to 50% flowering, days to maturity and main axis height. PM-22 followed by PM-28 may be selected as donor for short plant height. Pusa Tarak followed by PM-30, PM-26 and PM-27 were good general combiners for the traits like number of primary and secondary branches and total number of siliqua/plant. PM-27, PM-24, PM-25 was found to be very good general combiners for length of siliqua and seed yield. PM-25 was also found to be a very good general combiner for number of seeds/siliqua and 1000 seed weight. Varuna x PM-22 and JD-6 x PM-28 had negative significant effect for dwarfness. For early flowering, JD-6 x PM-21 and JD-6 x PM-26 hybrid were good combiners. For early maturity, Varuna x PM-26 followed by Pusa Bold x PM-21 were good combinations but only Pusa Bold x PM-21 showed significant effect of *sca.* Pusa Bold x PM-30 and Varuna x Pusa Tarak showed high significant *sca* for total siliqua number/ plant and but for 1000 seed weight Varuna x PM-28 and Varuna x PM-25 were found to be good combinations. Varuna x Pusa Tarak and Varuna x Pusa Les 39 had maximum significant *sca* effect for seed yield/plant.

In present investigation the top ranking hybrid was Varuna x Pusa LES-39 which showed high *per se* performance, high heterosis over mid parent and better parent for seed yield/plant (g). The hybrid Varuna x Pusa LES-39 also showed significant heterosis for the characters length of siliqua, siliqua at main axis, siliqua/plant and seeds/siliqua. The cross combination Varuna x Pusa LES-39 and also Varuna × PM-27, Varuna × PM-30, Varuna× Pusa Tarak, Varuna × PM-26 cross combinations could be further exploited for selection of high yielding pure lines or transgressive segregants with desirable traits during advance generations.

Table 4 Crosses exhibited higher estimates of heterosis (%) over mid parent (MP) and better parent (BP) for seed yield

Crosses	*Per se* performance	Heterosis %		Desirable significant heterosis for other traits
		Over MP	Over BP	
Varuna x Pusa LES-39	12.88	284.96**	266.00**	LS, SAMA, SPP,SPS
Varuna x PM-27	10.47	151.66**	118.04**	SPP, SPS
Varuna x PM-26	8.86	145.18**	138.90**	DTM, PB, SB, SPP
Kranti x PM-27	11.59	111.69**	88.61**	MAH, DTM, 1000-SW
Varuna x Pusa Tarak	13.20	149.12**	86.49**	SPS, PB

* and **significant at 5% and 1% level of significance respectively
LS: Length of siliqua, SAMA: Siliqua at main axis, SPP: Siliqua/plant,SPS: Seeds/siliqua,
MAH: Main axis height, DTM: Days to maturity, SB: Secondary branch,
PB: Primary branch, 1000 SW:1000-seed weight (g)

REFERENCES

Chapi O G, Hashemi A S, Yasari E and Nematzadeh G A 2008. Diallel analysis of seedling traits in canola. *International Journal of Plant Breeding and Genetics*, **2**: 28-34.

Chauhan J S, Singh K H, Singh V V and Kumar Rao 2011. Hundred years of rapeseed-mustard breeding in India: accomplishments and future strategies. *Indian Journal of Agricultural Sciences*, **81**(12): 1093-1109.

Darekar A and Reddy A A 2018. Oilseed price forecasting: case of mustard in India. *Agricultural Situation in India*, February, 2018: 31-37.

Dutta A, Ghosh P D, Sadhukhan R, Hossain M and Hossain F 2011. Combining ability and heterosis for seed yield and its component characters in sunflower (*H. annuus* L.). *Journal of Oilseed Research*, **28**(1): 33-39.

Falconer D S and Mackey 1980. *Introduction to Quantitative Genetics.* Oliver and Boyd Ltd., London.

Kempthrone O 1957. *An Introduction to Genetic Statistics.* John Wiley and Sons, Inc., New York, 545 pp.

Nassimi A W, Sardar A R and Naushad A 2006. Study on heterosis in agronomic characters of rapeseed (*Brassica napus* L.) using diallel. *Journal of Agronomy*, **5**: 505-508.

Ramesh V 2012. Combining ability of plant height and yield components in spring type of rapeseed varieties (*Brassica napus* L.) using Line x Tester analysis. *International Journal of Agriculture and Forestry*, **2**(1): 58-62.

Singh R K and Chaudhury B D 1977. *Biometrical Techniques in Breeding and Genetics.* Scholarly Pubns, New Delhi, India, pp. 350.

Singh M and Lallu 2004. Heterosis in relation to combining ability for seed yield and its contributing traits in Indian mustard. *Journal of Oilseeds Research*, **21**(1): 140-142.

Singh M, Satendra, Singh H L and Dixit R K 2006. Combining ability analysis of agronomic characters in Indian mustard (*B. juncea* L.). *Journal of Progressive Agriculture*, **6**(1): 69-72.

Heterosis and combining ability studies in sesame (*Sesamum indicum* L.)

SUSHILA SIROHI, S R KUMHAR AND BABITA KUMARI

Agricultural Research Station, Mandor, Agriculture University, Jodhpur-342 304, Rajasthan

(Received: November 18, 2019; Revised: February 27, 2020; Accepted: March 12, 2020)

ABSTRACT

Heterosis and combining ability analysis were carried out with three lines and nine testers during *kharif* 2018. The mean sum of squares due to parents showed significant differences for most of the characters, except oil content indicating the presence of sufficient variability among the parents. The mean squares due to hybrids were significant for almost all the characters studied. The estimation of gca variances were lower than sca variances which indicated the predominance of non-additive gene action for plant height, days to 50% flowering, days to maturity, number of effective branches/plant, number of capsules/ plant, number of seeds/capsule, harvest index, seed yield/plant, capsule bearing length and additive gene action for oil content. Non-additive genetic variances may be utilized to increase the yield levels by heterosis breeding. The parents, TKG-22, GT-10 and RT-372 were good general combiners for seed yield and contributing characters. The best specific crosses, RT-351 × TKG-22, RT-54 × TKG-22 and RT-54 × RT-372 were most heterotic hybrids for seed yield and found promising for yield contributing characters. These crosses involved average × average, average × poor, average × good parents.

Keywords: General combining ability, Heterosis, Specific combining ability, Sesame

Sesame (*Sesamum indicum* L.), is an ancient oilseed crop and is an important self-pollinated annual crop in the tropics and subtropics. Sesame is called 'queen of oilseeds' in view of its oil (38-54%) and protein (18-25%) contents of high quality and nearly 73% of the oil is used for edible purposes and preferred for cooking due to zero cholesterol, 8.3% for hydrogenation and 4.2% for industrial purposes in the manufacture of paints, pharmaceuticals and insecticides because of its stability, anti-bacterial, anti-viral, anti-fungal and anti-oxidant properties. For breaking the present yield barrier and evolving varieties with high yield potential, it is desirable to combine the genes from genetically diverse parents. The success in identifying such parents mainly depends on the gene action that controls the trait under improvement, combining ability and genetic architecture. There are several techniques for evaluating the varieties or cultivars or lines in terms of their combining ability and genetic architecture. Diallel, partial diallel and line × tester techniques are in common use. Among these, Line × Tester analysis technique is more suitable to test large number of genotypes for understanding the genetic basis at population level (Kempthorne, 1957). An added advantage of this method is that it gives an overall genetic picture of the material under investigation in a single generation. Considering the above, the present study was under taken with the objective of studying the magnitude of general and specific combining ability, heterosis and gene action for seed yield and its component characters in selected sesame material.

MATERIALS AND METHODS

The research work was carried out during the *kharif* season under irrigated condition at experimental field of Agricultural Research Station (ARS), Agriculture University, Mandor, Jodhpur, Rajasthan. Three released varieties of sesame, TKG-22, GT-10 and RT-372, were used as female and crossed with nine released varieties/genotypes. 27 crosses were made in line x tester fashion during *kharif* 2017 and were evaluated in randomized block design with three replications along with parents and standard check RT-127 during *kharif* 2018 at research farm of ARS, Mandor, Jodhpur. The recommended package of practices were adopted to raise a healthy crop. Observations were recorded on five randomly selected competitive plants for characters, plant height (cm), number of effective branches/plant, capsule bearing length (cm), number of seeds/capsule, number of capsules/plant, seed yield/plant and harvest index (%), while for days to 50% flowering, days to maturity, 1000-seed weight (g) and oil content (%) data from whole plot was considered. The data recorded for each character were analysed by the usual standard statistical procedure (Panse and Sukhatme, 1978). The mean of the character for the difference entries was subjected to L×T analysis for general combining ability (*gca*) of parents and specific combining ability (*sca*) of different cross combinations, worked out based on the procedure given by Kempthorne (1957).

RESULTS AND DISCUSSION

The analysis of variance showed significant differences among parents and hybrids for most of the characters. The analysis of variance for combining ability showed that general combining ability (*gca*) variances for males (M) were significant for all the characters except days to maturity and plant height, whereas for females (F) these parameters were significant for all characters except days to maturity, seed

Corresponding author's E-mail: srkumhar@gmail.com

yield/plant and oil content. Specific combining ability variances for F × M interaction were highly significant for all the characters except oil content. The extent of *gca* variance was lower than *sca* variance for most of the characters demonstrating the predominance of non-additive gene action except for oil content. In case of oil content *gca* variances were higher than *sca* variances, therefore, showed presence of additive gene action. Similar results were reported earlier by Kumar *et al.* (2004), Motilal and Manoharan (2005), Sharmila and Ganesh (2008), Kumar and Vivekanandan (2009), Kumar *et al.* (2012), Ramesh *et al.* (2014), Rani *et al.* (2015), Hassan and Sedeck (2015) and Beniwal *et al.* (2018). This point of view revealed that breeding for high yielding varieties in sesame developed by both additive and non-additive types of gene action.

With respect to heterosis, for days to 50% flowering and days to maturity, cross RT-54 × GT-10 recorded negatively significant mid parent heterosis and non-significant negative heterobeltiosis and standard heterosis for days to flowering. Similar findings were also reported earlier by Patel *et al.* (2005), Reddy *et al.* (2015) and Beniwal *et al.* (2018). The cross RT-351 × TKG-22 recorded the highest average heterosis, heterobeltiosis and standard heterosis for seed yield/plant and also desirable significant average heterosis and heterobeltiosis for capsule bearing length. The cross RT-54 × TKG-22 recorded second best average heterosis along with significant positive heterobeltiosis and standard heterosis for seed yield/plant. The cross also found significant heterosis for plant height, 1000-seed weight and harvest index. The cross also had significant positive average heterosis for number of seeds/capsule. Such results were also supported by Nijagun *et al.* (2003), Mothilal and Ganeshan (2005), Patel *et al.* (2005), Gaikwad and Lal (2011), Kumar *et al.* (2012), Beniwal *et al.* (2018) and Karande *et al.* (2018). Data for number of effective branches/plant revealed that one cross RT-351× RT-371 (64.71%) exhibited positive significant heterosis over better parent, whereas two crosses RT-346 × Pragati (45%), RT-351 × RT-371 (40%) depicted positive significant heterosis over standard check RT-127. For capsule bearing length, five crosses, RT-351 × RT-372 (21.21%), RT-351 × GT-10 (19.08%), RT-346 × TKG-22 (14.29%), RT-346 × TKG-22 (13.28%) and RT-351 × TKG-22 (10.69%) exhibited positive significant heterosis over better parent. Cross, RT-351 × RT-372 (21.67%) showed the highest mid parent heterosis. Similar research findings have been reported earlier by Singh *et al.* (2005) and Kumar *et al.* (2012). With respect to number of seeds/capsule, four crosses depicted positive significant heterosis over better parent. Cross, RT-54 × RT-372 exhibited the highest average heterosis and heterobeltiosis. Similar results have been recorded earlier by Singh *et al.* (2005), Kumar *et al.* (2012) and Reddy *et al.* (2015).

With respect to number of capsules/plant, six crosses designated for positive significant heterosis over better parent and sixteen crosses exhibited positive significant heterosis over standard check. Among these crosses, RT-54 × RT-371 recorded the highest average heterosis and heterobeltiosis, whereas RT-346 × GT-10 recorded the highest standard heterosis. These results were reported earlier by Yamanura (2009) and Kumar *et al.* (2012), Rani *et al.* (2015) and Virani *et al.* (2015). For the 1000-seed weight character, three crosses exhibited positive significant heterosis over better patent, while six crosses showed significant heterosis over standard check. Among positive crosses, RT-54 × RT-372 had maximum heterobeltiosis and RT-351×RT-372 depicted the highest average heterosis and standard heterosis. These results corroborated with the results reported earlier by Singh *et al.* (2005), Kumar *et al.* (2012) and Rani *et al.* (2015).

Table 1 Analysis of variance for combining ability of various characters in sesame

Source of variation	D.f.	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of effective branches/ plant	Capsule bearing length (cm)	No. of seeds/ capsule	No. of capsules/ plant	1000-seed weight (g)	Seed yield/plant (g)	Harvest index (%)	Oil content (%)
Replication	2	7.86**	3.72	150.31	0.01	2.33	4.68	0.64	0.01	3.38	8.53	32.37*
Male	8	9.99**	2.32	115.72	2.82**	103.97**	75.59*	505.02**	0.29**	8.88**	20.75*	4.34
Female	2	10.46**	3.35	436.58**	0.59*	320.26**	816.35**	311.57**	0.2*	2.44	86.23**	451.61**
Female × Male	16	4.49**	6.60**	194.01**	1.34**	110.20**	185.9**	444.17**	0.61**	10.56**	58.7**	8.95
Error	52	1.48	1.73	74.34	0.13	5.72	33.85	16.51	0.06	2.37	7.77	10.12
σ^2 m		0.20**	-0.16	-2.90	0.05**	-0.23**	-4.09*	2.25**	-0.01**	-0.06**	-1.41*	-0.17*
σ^2 f		0.66**	-0.36	26.95**	-0.44	23.34**	70.05**	-14.72**	-0.05*	-0.9	3.06**	49.18
σ^2 *gca*		0.32**	-0.21	4.56	0.02	5.66**	14.45*	-1.99**	-0.02*	-0.27	-0.29*	12.17
σ^2 *sca*		1.00**	1.62**	39.89**	0.404**	34.83**	50.68**	142.55**	0.18**	2.73**	16.98**	-0.39**
σ^2 *gca*/σ^2*sca*		0.32	-0.13	0.11	0.02	0.16	0.29	-0.01	-0.11	-0.10	-0.02	-31.20

*, ** Significant at 5% and 1% level of significance; 2 fm, 2 m, 2 *gca*,, 2 *sca* = Variance due to females, males, *gca* and *sca*, respectively d.f. = degree of freedom

Table 2 Estimates of general combining ability effect of parents for different character in sesame

Source of variation	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of effective branches/ plant	Capsule bearing length (cm)	No. of seeds/ capsule	No. of capsules/ plant	1000-seed weight (g)	Seed yield/ plant (g)	Harvest index (%)	Oil content (%)
Female											
RT-346	-0.14	-0.36	-0.4	0	0.41	-6.35	-3.88**	-0.08	-0.06	-1.95	1.97
RT-351	0.68	0.35	4.21	0	3.22	3.3	2.46	0.09	-0.27	0.4	2.73
RT-54	-0.54	0.01	-3.81	0.15	-3.63	2.99	1.42	-0.02	0.33	1.56	-4.7**
S.E(gi)	0.191	0.207	1.355	0.057	0.376	0.91	0.639	0.03	0.24	0.43	0.5
Male											
RT-103	1.42	0.01	-4.25*	-0.69**	-5.48*	-4.38	2.2	-0.26	0.28	0.45	0.54
RT-371	-0.25	0.57	0.41	-0.24	-0.82	0.17	0.75	-0.2	-0.86	-1.8	-0.57
RT-372	1.98*	0.68	-4.82	-0.3	2.63	4.84	3.53*	0.29**	0.87	-2.31*	-0.35
RT-380	0.09	-0.88	0.61	0.15	1.52	1.51	-6.14*	0.15	-0.03	0.47	0.03
RT-381	-0.58	0.01	0.06	-0.07	-4.37	-4.38	-10.58**	0.11*	-1.34	0.45	-1.13
Pragati	-0.47	0.24	1.45	0.48*	-0.48	-0.38	4.31	-0.17**	-1.39	2.74	-0.2
TKG-22	-0.03	-0.32	-3.28**	-0.41	3.3	0.51	-10.91**	0.05	1.41*	1.06	-0.19
RT-377	-1.14*	-0.54	5.05	-0.13	-0.93	1.51	7.42	0.04	0.66	-0.69	1.05
GT-10	-1.03	0.24	4.76	1.2**	4.63**	0.62	9.42**	-0.01	0.4*	-0.37	0.82
S.E.(gj)	0.382	0.413	2.71	0.114	0.751	1.83	1.277	0.070	0.480	0.870	1

*, ** Significant at 5% and 1%; S.E. (gi) = Standard error of males & S.E. (gj) = Standard error of females

Table 3 Estimates of specific combining ability for seed yield and its components characters in sesame

Crosses	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of effective branches/ plant	Capsule bearing length (cm)	No. of seeds/ capsule	No. of capsule/ plant	1000-seed weight (g)	Seed yield/plant (g)	Harvest index (%)	Oil content (%)
RT-346×RT-103	-0.98	-0.53	-0.72	-0.07	-0.19	-8.99**	-4.68	-0.47	-0.99	-1.99	-0.46
RT-346×RT-371	0.03	-0.09	-2.98	-0.02	4.82	-5.54	1.1	0.64**	0.39	-0.76	1.49
RT-346×RT-372	-1.86	1.47**	-9.49**	-0.96**	-2.63*	-3.88	-21.01**	-0.70**	-0.38	7.12**	-0.51
RT-346×RT-380	0.36	-0.64	-0.91	0.43	-7.19**	7.12	1.99	-0.12	2.46	0	-0.26
RT-346×RT-381	1.03	-0.86	-4.64	-0.19	-4.30**	-9.32**	-4.90**	0.15	-0.1	-4.15	-2.09
RT-346×Pragati	1.58**	-1.09	-2.02	0.26	1.48	4.68	9.21**	-0.01	0.52	-0.15	0.05
RT-346×TKG-22	-0.86	0.14	2.71	-0.02	4.37**	-0.21	-0.57	-0.08	-3.98**	-2.36**	1.29**
RT-346×RT-377	-0.42	1.03*	5.38	0	0.26	3.12	13.10**	0.32**	0.24	5.62**	1.38*
RT-346×GT-10	1.14*	0.58	12.67**	0.54*	3.37	13.01**	5.77	0.26	1.84	-3.34	-0.87
RT-351×RT-103	-0.79	-1.24*	4.4	0.11	-2	-0.36	5.65	-0.31*	0.09	3.37**	-0.02
RT-351×RT-371	-0.79	1.21*	-4.09	-0.17	-4.67*	11.09	-4.57	0.01	0.64	3.56	-0.02
RT-351×RT-372	0.65	-1.90**	3.77	0.22	7.56**	-4.58	0.65	0.42**	-1.77	-3.02	-0.64
RT-351×RT-380	0.21	-0.01	1.17	0.28	2.33NS	-4.58	8.65**	0.12	-2.20**	-1.93	-1.4**
RT-351×RT-381	-0.12	-0.57	-8.14**	0	-7.44**	5.98	-9.24**	-0.15*	0.41	5.84**	-0.96
RT-351×Pragati	-0.9	2.21**	0.97	-0.06	-1	-1.36	1.54	0.18	-0.4	0.39	2.23*
RT-351×TKG-22	0.32	-0.9	5.44*	0	1.89	2.09	-1.57	-0.30**	2.34**	-3.81	0.09
RT-351×RT-377	1.1	-0.35	-5.23	0.22	-0.89	-0.25	-11.57*	0.08	1.25	-5.39*	0.63
RT-351×GT-10	0.32	1.54	1.7	0.39	4.22*	-8.03	10.43**	-0.04	-0.35	0.99	0.08
RT-54×RT-103	1.77**	1.77	-3.68	-0.04	2.19	9.35**	-0.98	0.78**	0.9	-1.39	0.48
RT-54×RT-371	0.77	-1.12	7.07	0.19	-0.15	-5.54	3.47*	-0.65**	-1.03*	-2.8	-1.47
RT-54×RT-372	1.21	0.43	5.72	0.74**	-4.93	8.46*	20.36**	0.27	2.14	-4.09	1.15
RT-54×RT-380	-0.57	0.65	-0.26	-0.7**	4.85*	-2.54	-10.64**	-0.01	-0.26	1.93	1.67
RT-54×RT-381	-0.9	1.43	12.78	1.35**	11.74**	3.35	14.14*	-0.01	-0.31	-1.69	3.05
RT-54×Pragati	-0.68	-1.12*	1.05	-0.2	-0.48	-3.32	-10.75**	-0.17	-0.13	-0.24	-2.28
RT-54×TKG-22	0.54	0.7	-8.15**	-0.15	-6.26**	-1.88	2.14	0.38	1.64	6.17**	-1.38**
RT-54×RT-377	-0.68	-0.68	-0.15	0	0.63	-2.88	-1.53	-0.4	-1.48	-0.23	-2.01
RT-54×GT-10	-1.46	-2.12	-14.36**	-0.93**	-7.59**	-4.99	-16.2**	-0.22	-1.48	2.35	0.79
S.E.(ij)	0.54	0.58	3.83	0.16	1.06	2.58	1.8	0.1	0.68	1.23	1.41

*, ** Significant at 5% and 1%, S.E.(ij) = Standard error of crosses

Table 4 Summary of the best crosses along with the general combining ability effects of the parents in sesame

Characters	Cross	*Per se* performance	*sca* effects	Heterobeltiosis	*gca* of the parents
Days to 50% flowering	RT-54×RT-103	51	1.77**	9.22**	A×A
	RT-346×Pragati	50	1.58**	1.36	A×A
	RT-346×GT-10	49	1.14*	-0.68	A×A
Days to maturity	RT-54×Pragati	87	-1.12*	2.77**	A×A
	RT-351×RT-103	87	-1.24*	2.77**	A×A
	RT-351×RT-372	87	-1.90**	3.18**	A×A
Plant height (cm)	RT-351×RT-381	88.5	-8.14**	-1.01	A×A
	RT-54×TKG-22	77.1	-8.15**	39.40**	A×G
	RT-346×RT-372	77.7	-9.49**	-14.91	A×A
No. of effective branches/plant	RT-54×RT-381	1.3	1.35**	-55.46**	A×A
	RT-54×RT-372	2.2	0.74**	-43.38**	A×A
	RT-346×GT-10	3.8	0.54**	21.05*	A×G
Capsule bearing length (cm)	RT-54×RT-381	43.7	11.74**	11.97**	A×A
	RT-351×RT-372	53.3	7.56**	21.67**	A×A
	RT-54×RT-380	42.7	4.85*	8.02	A×A
No. of seeds/ capsule	RT-346×GT-10	63.7	13.01**	-1.55	A×A
	RT-54×RT-103	64.3	9.35**	35.92**	A×A
	RT-54×RT-372	72.7	8.46*	54.61**	A×A
No. of capsule/ plant	RT-54×RT-372	40.7	20.36**	-22.58*	A×G
	RT-54×RT-381	28.7	14.14*	-51.14**	A×P
	RT-346×RT-377	47.7	13.10**	17.21	P×A
1000-seed weight (g)	RT-54×RT-103	3.7	0.78**	21.41**	A×A
	RT-346×RT-371	3.6	0.64**	7.6	A×A
	RT-351×RT-372	4	0.42**	20.75**	A×G
Seed yield/plant (g)	RT-351×TKG-22	13	2.34**	62.09**	A×G
	RT-54×RT-371	7.9	-1.03*	-28.53**	A×A
	RT-351×RT-380	7	-2.20**	-36.75**	A×A
Harvest index (%)	RT-346×RT-372	32	7.12**	-4.7	A×P
	RT-54×TKG-22	38	6.17**	8.07	A×A
	RT-351×RT-381	35.9	5.84**	8.47	A×A
Oil content (%)	RT-351×Pragati	43	2.23*	5.36	A×A
	RT-54×TKG-22	32	1.38*	-21.24**	P×A
	RT-346×TKG-22	41.3	1.29**	-4.95	A×A

For seed yield/plant, six crosses showed significant positive average heterosis, five with heterobeltiosis and seven had standard heterosis but two crosses, RT-351 × TKG-22 and RT-54 × TKG-22 showed highly and positive significant values for all three kinds of heterosis. The crosses with low amount of desirable heterosis for seed yield/plant indicated presence of less effect of dominant genes. Similar results have also been reported by Nijagun *et al.* (2003), Mothilal and Ganeshan (2005), Patel *et al.* (2005), Gaikwad and Lal (2011), Kumar *et al.* (2012), Reddy *et al.* (2015), Saxena *et al.* (2017) and Beniwal *et al.* (2018).

The general combining ability effects of the parents showed that none of the females was a good general combiner for all characters, while males, GT-10, RT-372, TKG-22 and Pragati were good general combiners for yield and yield attributing traits. GT-10 was a good general combiner for traits like number of effective branches/plant, capsule bearing length, number of capsules/plant and seed yield/plant. Male, TKG-22 was a good general combiner for plant height, seed yield/plant, whereas RT-372 was a good general combiner for 1000-seed weight, number of capsules/plant. With regard to specific combining ability effects, none of the hybrids showed desirable *sca* effects for all the characters. In the present investigation, positive specific combining ability was favourable for all characters except days to 50% flowering, days to maturity and plant height. Desirable significant *sca* effects were seen in many crosses for different traits: days to maturity (3), plant height (4), capsule bearing length (5), number of seeds/capsule (3), number of capsule/plant (7), seed yield/plant (1), Harvest index (5), and Oil content (3). Sharmila and Ganesh (2008), Kumar and Vivekanandan (2009), Kumar *et al.* (2012), Ramesh *et al.* (2014) and Beniwal *et al.* (2018) have also documented similar results.

Seed yield is a main character which depends on the involvement of different characters affecting directly or indirectly. From the preceding discussion of the results of the investigation, it is evident that the extent of gca variance was lower than *sca* variance for most of the characters demonstrating the predominance of non-additive gene action except oil content. These were found to be supported by low extent of *gca* and *sca* variance ratios. Therefore, improvement of sesame for most of the characters under breeding methodology should be heterosis breeding. Cross, RT-351 × TKG-22 was found most promising hybrids for seed yield and contributing characters.

REFERENCES

Beniwal B R, Sastri E V D and Solanki Z S 2018. Combining ability and heterosis studies in sesame (*Sesamum indicum* L.). *International Journal of Plant Breeding and Genetics*, **10**(5): 414-419.

Gaikwad K B and Lal J P 2011. Heterosis and inbreeding depression in sesame (*Sesamum indicum* L.). *Current Advances in Agriculture Sciences*, **3**(1): 54-56.

Hassan S, Muhammad and Sedeck F S 2015. Combining ability and heterosis estimates in sesame. *World Applied Sciences Journal*, **33**(5): 690-698.

Karade G R, Yamgar S V, Waghmode A A and Wadikar P B 2018. Exploitation of heterosis for yield and yield contributing character in sesame (*Sesamum indicum* L.). *International Journal of Current Microbiology and Applied Sciences*, **7**(2): 299-308.

Kempthorne O 1957. *An Introduction to Genetic Statistics,* John Wiley and Sons, New York, pp. 458-471.

Kumar K B and Vivekanandan P 2009. Studies on combining ability studies in sesame (*Sesamum indicum* L.). *Electronic Journal of Plant Breeding*, **1**: 33-36.

Kumar P, Madhusudan H L, Nadaf H L, Patil R K and Deshpande S K 2012. Combining ability and gene action studies in inter mutant hybrids of sesame (*Sesamum indicum* L.). *Karnataka Journal of Agricultural Sciences*, **25**(1): 1-4.

Kumar P S, Puspha R, Karuppiah P and Ganesan J 2014. Studies on combining ability in sesame (*Sesamum indicum* L.). *Research on Crop*, **27**(1): 99-103.

Nijagun H G, Parameshwarappa K G, Muralikrshna S and Salimath P M 2003. Implication of non-additive genetic effects and heterosis for breeding hybrid in sesame (*Sesamum indicum* L.). *National Journal on Plant Improvement*, **5**(1): 26-30.

Mothilal A and Manoharan V 2005. Diallel analysis for the estimation of genetic parameters in sesame (*Sesamum indicum* L.). *Agricultural Science Digest*, **25**(2): 133-135.

Patel M A, Fatteh U G, Patel J S, Patel D H and Sriram S 2005. Heterosis in sesame (*Sesamum indicum* L.). *Crop Research*, **29**(2): 259-264.

Ramesh, Shekhawat N, Macwana S, Choudhary R, Patel B R 2014. Line × Tester analysis in Sesame (*Sesamum indicum* L.). *The Bioscan*, **9**(4): 1657-1660.

Rani T S, Babu T K and Thippeswamy S 2015. Combining ability studies in sesame (*Sesamum indicum* L.). *Electronic Journal of Plant Breeding*, **6**(4): 1011-1018.

Reddy V A, Parimala K and Rao P V R 2015. Exploitation of hybrid vigour in sesame (*Sesamum indicum* L.) *Electronic Journal of Plant Breeding*, **6**(1): 125-129.

Saxena K, Bisen R 2017. Line × tester analysis in sesame (*Sesamum indicum* L.) *International Journal on Current Microbiology and Applied Sciences*, **6**(7): 1735-1744.

Sharmila V and Ganesh S K 2008. Line x tester analysis for yield and powdery mildew resistance in sesame (*Sesamum indicum* L.). *Journal of Oilseeds Research*, **25**(2): 139-144.

Singh A K, Lal, J P and Kumar H 2005. Identification of certain heterotic crosses for their exploitation in the improvement of sesame (*Sesamum indicum* L.). *Sesame and Safflower Newsletters*, **20**: 24-26.

Yamanura K, Madhusudan and Nadaf H L 2009. Combining ability and gene action for yield and yield components in sesame (*Sesamum indicum* L.). *Karnataka Journal of Agricultural Sciences*, **22**(2): 255-260.

Jawahar Linseed Sagar-66 (JLS-66): Development and dissemination of newly developed linseed variety for nutritional security of India

DEVENDRA K PAYASI* AND M P DUBEY[1]

AICRP on Linseed, Regional Agricultural Research Station, JNKVV, Sagar-470 002, Madhya Pradesh

(Received: January 17, 2020; Revised: March 6, 2020; Accepted: March 10, 2020)

ABSTRACT

A linseed cultivar 'Jawahar Linseed Sagar 66 (JLS-66)' has been released in Madhya Pradesh for cultivation under rainfed cropping situations by the State Sub- Committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops, Government of Madhya Pradesh, Bhopal. It matures in 114 days, yields 1200 kg seed/hectare and contains 42.85 per cent drying oil. In All India coordinated trials, JLS-66 gave 11.11, 12.99, 10.80 and 20.97% higher seed and 21.51, 22.67, 16.03 and 37.80% higher oil yields over the prevailing varieties viz., JLS-67, NL-97, JLS-9 and T-397, respectively of the zone III comprising Bundelkhand part of UP, Rajasthan and Madhya Pradesh. It has resistance to major diseases and the most obnoxious pest, bud fly and is tolerant to moisture and high temperature stresses. The variety has recorded high alpha linolenic acid (55.96 %) which is known as Omega-3 and directly influences the quality of oil. Hence, on one hand the cultivators will be benefited with this variety containing high level of oil and quality, and on the other hand industrialists will also be benefitted by getting good nutritive raw material for their industries especially Omega-3 which has medicinal value.

Keywords: JLS-66, Linolenic acid, Linseed, Multiple resistance, Omega-3 fatty acid

Oilseed crops are the second most important determinant of agricultural economy, next only to cereals within the segments of field crops. The self-sufficiency in oilseeds attained through "Yellow Revolution" during early 1990's could not be sustained beyond a short period. Despite being the fifth largest oilseeds crop producing country in the world, India is also one of the largest importers of vegetable oils. Linseed containing about 36-40% oil is the richest (among crop plants) source of polyunsaturated fatty acids (PUFA) essential in the human diet (Patial *et al.*, 2019). Linseed (*Linum usitatissium* L.) (2n=30) is one of the world's oldest cultivated crops grown almost in every part of the country. It is an important oilseed crop belonging to Linaceae family, with 14 genera over 200 species, and is the only cultivated species amongst the nine species having economic and agronomic value (Tadesse *et al.*, 2009; Kumari *et al.*, 2018) belonging to the genus Linum. It is self-pollinated but cross pollination occurs up to 2% (Tadesse *et al.*, 2009). The crop is being cultivated since more than 3,000 years primarily for its seed oil and fibre. Almost every part of the plant is commercially utilized either directly or after processing. In the past, linseed was one of the major sources of industrial oil for use in paints, linoleum, polish, inks and cosmetics (Green and Marshall, 1984; Zhang *et al.*, 2007).

Now a days, this crop is emerging as a very good source of nutrition with special reference to having ample amount of Omega-3, which is a cheap and best source of essential nutrition for pregnant women, children and all categories of human beings. It is a source of complete protein (contains all eight essential amino acids), high order linolenic acid (an essential polyunsaturated Omega-3 fatty acid), complex carbohydrates, vitamins and minerals. Recent advances in medical research have found linseed as best herbal source of Omega-3 and Omega-6 fatty acids which have immense nutritional/medicinal effects on human body. The oil obtained from the crops high in linolenic acid content which has wide industrial applications. However, linseed oil is not desirable for cooking in spite of its health benefits due to occurrence of rancidity in the oil during storage. It contains. more than 50% of á linolenic acid (ALA), 28-30% protein and 35% fibre (Carter, 1993; Rubilar et al., 2010; Rabetafika *et al.*, 2011).

On a small scale, the seed and its oil are directly used for human consumption as flax seed breads, bagels and other baked and fried food stuffs. Linseed is highly nutritious. The high degree of unsaturation gives quick drying properties to the oil. Thus, it was once popular as a drying agent in paints and varnishes. Dybing and Lay (1981) have listed diverse uses of linseed oil in the manufacturing of hardboards, brake linings, printer's ink, anti-spalling treatments for concrete and caulking compounds. Besides these, linseed oil is also used in manufacturing of linoleum, oil cloth, soaps, patent leather and cigarette paper. High ALA content ensures rapid film formation, but it also leads to yellowing, that limit its usefulness as interior film compositions. Although, the petroleum based products have replaced linseed oil in such applications but they pose threat to the environment. Hence, the interest in linseed oil may rejuvenate in near future. Its cake is a very good source of cattle feed for production and health point of view.

---

[1]Regional Agricultural Research Station, Sagar-470 002, Madhya Pradesh;
*Corresponding author's E-mail: dpayasi@gmail.com

India is the third largest linseed growing country in the world and production wise it ranks fourth (6.57%) in the world after Canada (40.51%), China (18.68%) and Kazakhstan (10.89%) (FAO, 2017). In India, linseed is an input-starved crop predominantly grown under rain-fed (63%), utera (25%) and irrigated (17%) conditions and occupies an area of 3.84 lakh ha with a production of 1.54 lakh tonnes. The national average productivity (525 kg/ha) is very low as compared to that of world average (1058 kg/ha) (Singh and Chopra, 2018).

This important rainfed oilseed crop has made significant stride in area, production and productivity enhancement by registering 11.85%, 22.96% and 10.06% increase, respectively in 2016-17 over the preceding year at national level. The major linseed growing states of the country are Madhya Pradesh, Chhattisgarh, Uttar Pradesh, Maharashtra, Bihar, Odisha, Jharkhand, West Bengal, Nagaland and Assam accounting for about 97% of total area of the nation. Madhya Pradesh is the leading state both in area and production followed by Jharkhand and Uttar Pradesh and contributes more than 50% in area and production of the country. The state has enormous potential to further upscale the production and productivity. Its continued cultivation on marginal and sub marginal soils under starved conditions, low seed replacement ratio and lack policy intervention in terms of market price and procurement supports are the major factors leading to low productivity of the crop. The area, production and productivity of the crop can be enhanced by using high yielding and multi-resistant varieties having ability to pay high remunerative to the farmers. To fulfill these criteria, a number of improved varieties namely JLS-9, JLS-27, JLS-67, JLS-73, JLS-66, JLS-79 JLS-95 and JLS 93 are available in seed chain. Here we report the development, characteristic features and performance of JLS-66 variety.

MATERIALS AND METHODS

The newly released variety JLS-66 has been developed as a pure line selection form 'Accession No. 2512'. After selection, the genotype was advanced and nominated for testing in All India Coordinated Research trails during four consecutive years from 2004-05 to 2007-08. It was raised in a Randomized Complete Block Design (RCBD) replicated thrice to evaluate the performance of the same with two Zonal check varieties, NL-87 and JLS-9 and a National check, T-397 (Table 1). Similarly, the same variety was tested to generate data on agronomic requirements. Large scale front line demonstrations at farmers' fields were also carried out and compared *vis-à-vis* farmers' practices during 2007-08 to 2015-16 (Table 2). JLS-66 is medium (45-50 cm) in plant height with dark green broad leaves, moderately branched (3-5), semi-spreading canopy which distinguishes it from a medium height, thin narrow, light green leaves and profusely branched spreading canopy of 'T-397' and medium height profusely branched, small round shaped, green leaves and spreading canopy of the variety 'Padmini'. Capsules of JLS-66 are large, bold, round with blunt apex non-dehiscing and can be distinguished from a small, round, pointed apex and non-dehiscing capsule of 'T-397' and from the bold, round, blunt apex and whitish non-dehiscing capsule of 'Padmini' (Table 6). The fatty acid profiling was done at All India Coordinated Research Project, Linseed Value Addition Centre, Pune by Gas chromatography method.

RESULTS AND DISCUSSION

The variety is recommended for rainfed situation and gave average yield of 1200 kg/ha (Table 1). However, it has recorded highest yield potential of 2049 kg/ha in varietal trials. Over four years, JLS-66 recorded yield superiority of 11.11, 12.99, 10.80 and 20.97% over the checks *viz.,* JLS-67, NL-97 (ZC), JLS-9 (ZC) and T-397 (NC), respectively at 11 locations of zone III (comprising the states of Madhya Pradesh, Rajasthan, Bundelkhand part of Uttar Pradesh, Maharashtra, Odisha, Chhattisgarh and Karnataka) of the country. The frequency of this variety in top significant group tested over four years at 11 locations was 6/11 (Table 1). JLS-66 showed consistent superiority of seed yield over the checks NL-97, JLS-9 & T-397 with yield gains of 22.28, 8.20 and 52.44 and 25.91, 37.66 and 45.14% during I and III year while in II year of testing, JLS-66 showed a marginal yield advantage of 0.08, 3.43% over NL-97 and JLS-9 respectively. National check variety T-397 produced 7.68% higher grain yield over JLS-66 under breeding trials (Table 1) exceptionally. In IV year JLS-66 gave 4.49 and 7.71% higher seed yield over NL-97 and T-397 respectively while the qualifying variety JLS-67 and JLS-9 (ZC) produced 15.93 and 2.68% higher seed yields over JLS-66. JLS-66 performed well when sown with 100% NPK of 40:20:20 kg/ha. JLS-66 also gave 8.8 and 43.28 % higher grain yield over JLS-9 and T-397 respectively during 2006-07. As for as seed rate (kg/ha) is concerned, 25 kg seed/ha was found optimum. Further it was well tested at farmers' field through a large scale front line demonstration during eight years from 2007-08 to 2015-16.

Pooled analysis of the data from 49 demonstrations revealed that JLS-66 recorded highest grain yield of 1448 kg/ha which gave 47.30% higher seed yield over local mixed linseed varieties available with farmers. Hence newly developed variety JLS-66 proved its superiority over local linseed mixers in terms of productivity. As far as acceptability of the newly developed variety by farmers/consumers/industry is concerned, it covered almost all the districts of the state and was highly accepted by the farmers/consumers due to its higher seed yield under rainfed/irrigated condition as well as oil yield. With regard to seed production, the newly notified variety provides bold seed non-dehiscing capsules suitable for mechanical harvesting through combined harvester or manual harvesting by labour. Under best agronomic management, it could produce as high as 2049 kg/ha seed yield. The variety JLS-66 is registered with NBPGR, New Delhi also as an Indian Collection (IC 587755). As far as nutrition is concerned, the fatty acid profiling for two mega varieties have been done at AICRP, LVAC, Pune and results revealed that the JLS-66 recorded 55.96% Omega 3 fatty acid (Alpha linolenic acid) as compared to mega linseed variety JLS 27 (53.06%). Whereas, Omega 6 remained almost same (15.94%) for both the varieties tested (Table 3). The ratio of Omega 3 to Omega 6 was found to be 3.51:1 and 3.32:1 for JLS-66 and JLS 27 respectively indicating the better use of JLS-66 as a functional food as well as industrial and nutraceuticals market of the country to serve for nutritional security by linseed and their value added products. JLS-66 was rated as a multiple disease resistant culture possessing resistance to rust and moderate resistance against wilt, powdery mildew and Alternaria blight disease (Table 4). It also recorded moderate resistance against most obnoxious pest i.e. budfly (*Dasyneura lini*) (Table 5).

Table 1 Summary of seed yield data of coordinated varietal trial

Year of testing Varieties		No. of Trials	Proposed variety JLS-66	Qualifying variety JLS-67	Checks		
					NL-97 (ZC)	JLS-9 (ZC)	T-397 (NC)
I Year (2004-05)		3	1372	-	1122	1268	900
II Year (2005-06)		3	1238	-	1237	1197	1341
III Year (2006-07)		3	1283	-	1019	932	884
IV Year (2007-08)		2/3	908	1080	869	933	843
Mean		11/12	1200	1080	1062	1083	992
Percentage increase/ decrease of JLS-66 over the checks							
I Year (2004-05)		-	-		(+)22.28	(+)8.20	(+)52.44
II Year (2005-06)		-	-		(+)0.08	(+)3.43	(-)7.68
III Year (2006-07)		-	-		(+)25.91	(+)37.66	(+)45.14
IV Year (2007-08)				(-)15.93	(+) 4.49	(-)2.68	(+) 7.71
Overall Percentage increase/ decrease of JLS-66				(+) 11.11	(+)12.99	(+)10.80	(+)20.97
Frequency in top group with non-significant difference	2004-05	3	2/3	-	0/3	1/3	0/3
	2005-06	3	0/3	-	0/3	0/3	1/3
	2006-07	3	3/3	-	1/3	1/3	1/3
	2007-08	2/3	½	2/3	0/3	0/3	0/3
Total		11/12	6/11	2/3	3/12	2/12	2/12
Mean oil content (%)			42.85	39.14	39.49	40.98	37.76
Mean oil yield (kg/ha)			514	423	419	443	373
% increase over checks				(+)21.51	(+)22.67	(+)16.03	(+) 37.80

* Two for proposed entry and three for Checks.

JLS-66 is novel, distinctive, uniform and stable having combination of morphological traits *viz*., medium plant height, blue disc shaped flower, round petals, large capsule and light brown seed colour. JLS-66 can easily fit into the double cropping system after soybean and rice, bold seed size and non dehiscing capsules containing 42.85% of oil content. It has high linolenic acid (55.96). Large scale demonstrations at farmers' fields have demonstrated the suitability of this variety for mechanical harvesting by combine harvester.

DNA finger printing : DNA fingerprinting studies were carried out at ICAR-IIOR, Hyderabad. DNA Profiling was done for the linseed variety JLS-66 along with the new varieties JLS-79, SLS-96, SLS-98, SLS-99, SLS-101 and reference varieties T 397, Padmini, Shekhar and JLS-95.

DNA from all the ten genotypes was extracted with the CTAB method (Doyle and Doyle, 1990). Molecular analysis was done with 24 linseed specific SSR primers that were found polymorphic with the Indian cultivars (Deng *et al.,* 2010).

Table 2 Performance of proposed variety JLS-66 at farmers' fields under large scale frontline demonstrations (0.40 ha) during *rabi* 2007-08 to 2015-16

Year	No of Demonstrations conducted	Grain Yield (kg/ha)		% Yield increased
		JLS-66	Local	
2007-08	2	800	600	33.33
2008-09	2	850	575	43.48
2009-10	3	1350	900	66.67
2010-11	5	1840	1380	33.33
2011-12	4	1925	1300	48.08
2013-14	15	1817	1183	53.59
2014-15	7	1993	1157	72.20
2015-16	11	1011	594	70.20
Mean	49	1448.25	983	57.61

Table 3.Nutritional and pharmacological properties of mega linseed varieties

Parameters	JLS-27	JLS-66	Specifications
Total oil content	37.76 %	40.84 %	
Fat	100 %	100 %	100 %
Saturated Fat	10.54	10.35 %	11.05-13.75
Mono saturated Fat	20.42 %	17.73	18.66-21.66
Poly saturated Fat	69.01 %	71.90 %	64.58-69.32
Omega 3 Fat (ALA)	53.06 %	55.96 %	52-57.14
Omega 6 Fat	15.95 %	15.94 %	12.18-13.01
Omega 9 Fat	20.42 %	17.73 %	18.66-21.66
Ratio of 3:6	3:32:1	3:51:1	-

Table 4 Reaction of major diseases prevailing in the region

Disease	Trial	Year	Proposed Variety JLS-66	Checks		
				NL-97 (ZC)	JLS-9 (ZC)	T-397 (NC)
Alternaria Blight	Varietal	04-05	R	MS	MS	MS
		05-06	-	MS	MS	MR
		06-07	-	MR	S	S
		07-08	-	MS	MR	S
	Mean		R	MS	MS	MS
Under Natural Condition	UDN	04-05	MS	MS	MS	MS
		05-06	MS	MS	MS	MS
		06-07	MR	MR	MR	MS
		07-08	MS	MR	MR	MS
	Mean		MS	MS	MS	MS
Under Artificial Condition	UDNA	04-05	MS	MS	MS	S
		05-06	MS	-	-	MS
		06-07	MR	MS	MS	MS
		07-08	-	-	-	-
	Mean		MS	MS	MS	MS
	Overall Mean		MR	MS	MS	MS
Rust Under Natural Condition	UDN	04-05	MR	HS	MS	HS
		05-06	MR	MR	R	S
		06-07	MR	S	MS	HS
		07-08	MR	HS	MS	HS
	Mean		MR	S	MS	HS
Rust Under Artificial Condition	UDNA	04-05	R	HS	S	HS
		05-06	R	-	-	S
		06-07	R	HS	R	HS
		07-08	-	-	-	MS
	Mean		R	HS	MS	MS
	Overall Mean		MR	HS	MS	S

Table 5 Year-wise reaction to budfly (*Dasyneura lini*)

Variety	Years					Mean
	I Year 2004-05	II Year 2005-06	III Year 2006-07	IV Year 2007-08 (Breeding)	IV Year 2007-08 Entomology	
JLS-66	R	-	MR	R	MR	MR
NL-97(ZC)	MR	MS	MS	MR	MR	MS
JLS-9 (ZC)	MR	MS	MS	MR	MR	MS
T-397 (NC)	MS	MS	MS	R	MR	MS

DUS characterization of the variety JLS-66: Seeds of different species and varieties within plant species have specific characters, which are suitable for distinguishing of varieties differences. This fact has important place for DUS testing and variety identification and verification (Keefe, 1999). The requirement of distinctness, uniformity and stability are assessed on the basis of characteristics. Describing the characteristics of a crop species based on standard descriptors is effective for better utilization and conservation of germplasm (Diederichsen and Richards, 2003). As per the National Guidelines to Conduct the Tests for Distinctness, Uniformity and Stability (Shrivastava *et al.*, 2006), DUS characterization was carried out at optimum plant growth stages. JLS-66 has a large disc shaped flower, blue corolla with round petals and bluish white, medium pollen sacs with grey anther which clearly distinguishes it from small red violet, cup shaped corolla, pointed petals and whitish blue pollen sacs of T-397 and red violet, big flower having free petals pointed with medium dull white pollen sacs of Padmini. The variety has medium plant height (45-50 cm) plant with dark green and broad leaves moderately branched (3-5), semi spreading canopy of JLS-66 distinguishes it from medium height, thin narrow, light green leaves and profusely branched spreading canopy of T-397 and medium height profusely branched, small round shaped, green leaves and spreading canopy of Padmini. The capsule large, bold round with blunt apex non dehiscing capsule of JLS-66 distinguishes it from small, round, pointed apex and non dehiscing capsule of T-397 and bold, round, blunt apex and whitish non dehiscing capsule of Padmini (Table 6).

Table 6 Distinguishing morphological characteristics (DUS test) of linseed variety, JLS-66

1.	Name of the variety	:	JLS-66	
2.	Name under which tested	:	SLS-66	
3.	Parentage	:	Selection from Accession No. 2512	
4.	Days to flower	:	46-54	
5.	Days to maturity	:	109-120	
6.	Flower color	:	Blue	
7.	Flower shape	:	Disc	
8.	Anther's color	:	Bluish Grey	
9.	Flower size	:	Medium	
10.	Plant height	:	Short (45-50 cm)	
11.	No. of primary branches /plant	:	3-5	
12.	No. of lateral branches /plant	:	35-40	
13.	No. of capsules/plant	:	60-70	
14.	No. of seed/capsule	:	8	
15.	Seed colour	:	Light Brown	
16.	Test weight (1000 seed weight (g)	:	7.6	
17.	Reaction to diseases:			
	(a) Wilt	:	Moderately Resistant	
	(b) Powdery mildew	:	Moderately Resistant	
	(c) Alterneria blight	:	Moderately Susceptible	
	(d) Rust	:	Resistant	
18.	Reaction to pest	:	Moderately Resistant (MR)	
	(Budfly infestation %)	:	(16.04%)	
19.	Yield (kg/ha)	:	Seed Yield	Oil Yield
	(a) Mean yield in Varietal trials	:	1200	514
	(b) Highest yield in Varietal trials	:	2049	
	(c) Highest yield in agronomical trials	:	1617	
20.	Oil content (%)	:	42.85	

To conclude, the linseed variety Jawahar Linseed Sagar 66 has high yield potential in varied eco-edaphic climatic condition particularly rainfed condition. It is rated as a multiple disease resistant culture possessing resistance to rust and moderate resistance against wilt, powdery mildew and Alternaria blight disease and with moderate resistance to budfly. It is novel, distinctive, uniform and stable having combination of morphological traits *viz.,* medium plant height, blue disc shaped flower, round petals, large capsule and light brown seed colour. JLS-66 can easily fit into the double cropping system after soybean and rice, bold seed size and non dehiscing capsules containing 42.85% of oil content. It has high linolenic acid (55.96). Large scale demonstrations at farmers' fields have demonstrated the suitability of this variety for mechanical harvesting by combine harvester.

ACKNOWLEDGEMENTS

The authors feel grateful to Indian Council of Agriculture Research, Project Coordinator Linseed, Kanpur and Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur for providing financial grant, land and other facility to carry out the research work in the current study. AICRP on Linseed, Regional Agricultural Research Station, Sagar, Madhya Pradesh coordinated unit is duly acknowledged. Also the help extended by ICAR-IIOR for DNA fingerprinting is acknowledged.

REFERENCES

Carter J F 1993. Potential of flaxseeds and flaxseed oil in baked goods and other products in human nutrition. *Cereal Foods World*, **38**: 754-759.

Deng X, Long S H, He D F, Li X, Wang Y F, Liu J and Chen X B 2010. Development and characterization of polymorphic microsatellite markers in *Linum usitatissimum. Journal of Plant Research*, **123**: 119-123.

Diederichsen A and Richards K 2003. Cultivated flax and the genus Linum L.: taxonomy and germplasm conservation. *In: Flax: the genus Linum,* Muir A D and Westcott N D (Eds) CRC Press, London, pp. 22-54.

Doyle J J and Doyle J L 1990. Isolation of plant DNA from fresh tissue. *Focus*, **12**: 13-15.

Green A G and Marshall D R 1984. Rheological and chemical properties of mucilage in different varieties from linseed (*Linum usitatissimum*). *Euphytica*, **33**: 321-328.

Hooker J D 1875. *The flora of British India.* Reeve and Co Ltd., London, pp. 410-411.

Keefe P D 1999. Measurement of linseed (*Linum usitatissimum* L.) seed characters for distinctness, uniformity and stability testing using image analysis. *Plant Varieties and Seeds*, **12**(2): 79-90.

Lukaszewicz M, Szopa J and Krasowska A 2004. Susceptibility of lipid from different flax cultivar to peroxidation and its lowering by added antioxidants. *Food Chemistry*, **88**: 225.

Patial R, Paul S, Sharma D, Sood V K and Kumar N 2019. Morphological characterization and genetic diversity of linseed (*Linum usitatissimum*). *Journal of Oilseeds Research*, **36**: 8-16.

Rubilar M, Gutiérrez C, Verdugo M, Shene C and Sineiro J 2010. Flaxseed as a source of functional ingredients. *Journal of Soil Science and Plant Nutrition*, **10**: 373-377.

Rabetafika H N, Remoortel V V, Danthine S, Paquot M and Blecker C 2011. Flaxseed proteins: food uses and health benefits. *International Journal of Food Science & Technology*, **46**: 221-228.

Naik B S, Mishra D, Lenka D and Sahoo K C 2017. Arpita: a new linseed cultivar for Orissa. *Electronic Journal of Plant Breeding*, **8**(1): 84-88.

Nzikou J M , Matos L, Moussounga J E, Ndangui C B, Pambou-Tobi N P and Bandzouzi E M, 2009. Study on oxidative and thermal stability of vegetable oils during frying. *Research Journal of Applied Sciences*, **4**: 94.

Shrivastava R L, Dubey S D and Kerkhi S A 2006. *Draft National Guidelines to Conduct the Tests for Distinctness, uniformity and Stability,* Project Coordinating Unit (Linseed), CSAUA&T, Kanpur, Uttar Pradesh.

Singh P K and Chopra Pankaj 2018. Double purpose linseed: a viable option for doubling farmer's income in the north-western Himalayan region. *Indian Farming*, **68**(01): 49-54.

Zhang Z S, Li D, Wang L J, Ozkan N, Chen X D, Mao Z H and Yang H Z 2007. Optimization of ethanol-water extraction of lignans from flaxseed. *Separation and Purification Technology*, **57**: 17-24.

Effect of iron sulphate application on yield, nutrients uptake, phosphorus and iron fractions in soil at harvest of soybean [*Glycine max* (L.) Merr.] in Vertisols of Karnataka

SHIVANAND* AND B M RADDER

University of Agricultural Sciences, Dharwad-580 005, Karnataka

(Received: December 13, 2019; Revised: February 21, 2020; Accepted: February 24, 2020)

ABSTRACT

A field experiment was conducted during *kharif* 2014 in Main Agriculture Research Station (MARS), University of Agricultural Sciences (UAS), Dharwad in Vertisols to study the effect of iron sulphate application on yield, nutrients uptake, residual nutrient status in soil, phosphorus and iron fractions in soil at harvest of soybean (*Glycine max* L.). The field experiment laid-out in RCBD design with three replications, comprised of 12 treatments of combinations such as soil application of 0, 10, 20 and 30 kg $FeSO_4$/ha with no foliar spray, one foliar spray at 30 DAS and two foliar sprays at 30 and 45 DAS of 0.5 % $FeSO_4$. Application of iron sulphate at the rate of 20 kg/ha with two iron sulphate (0.5%) foliar sprays at 30 and 45 DAS (T9) resulted in highest seed (15.3 q/ha) and stover yield (25.6 q/ha) and was at par with T8, T10, T11 and T12 with respect to seed yield and T6, T8 and T10 for stover yield. The lowest seed yield (12.5 q/ha) and stover yield (18.4 q/ha) were recorded in control plot (40:80:25 kg NPK/ha + soil application of FYM @ 6 t/ha + $ZnSO_4$. $7H_2O$ @ 12 kg/ha). Nitrogen, potassium, sulphur and iron uptake by the crop and available iron status in soil at harvest were highest in treatment T9.

Keywords: Iron and phosphorus fractions, Iron sulphate, Nutrient uptake, Seed yield, Soybean

Soybean [*Glycine max* (L.) Merill], a legume oilseed crop is considered a wonder crop due to its dual qualities of protein (40-43%) and oil (18-22%). It is a rich source of amino acids (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, thionine, tryptophan and valine) (Singer *et al.*, 2019), unsaturated fatty acids (mainly linoleic acid and oleic acid) (Prabakaran *et al.*, 2018), vitamins and minerals (vitamin K1, folate, copper, manganese and phosphorous). The protein, vitamin and mineral rich crop is widely used in different forms and acquires special importance in diet of Indians and other Asian countries to relieve from malnutrition. Soybean finds diverse utilities as oil and protein, in medicines and industrial applications. Its protein contains five per cent lysine which is deficient in most of the cereals and therefore, enriching the cereal flour with soybean improves the nutritive quality of flour. Soybean ranks first in area and second in production of oil among oilseed crops grown in the country. The simulation studies and on farm demonstrations of soybean in India have indicated that yield potential of about 2.1 t/ha with current varieties under rainfed conditions against the national average productivity of 1.2 t/ha (Agarwal *et al.*, 2013). Hence, large yield gap exists between the potential and actual yield harvested by the farmers. Being oilseed and pulse crop, proper nutrient management is one of the crucial factors for getting optimum yield.

Iron (Fe) is the fourth most abundant element in the earth's crust after oxygen, silicon and aluminium, with its concentration of 1-5 per cent (by weight). However, its deficiency in plants is commonly observed. Iron plays important role in the synthesis of chlorophyll, carbohydrates, cell respiration, chemical reduction of nitrates and sulphate and in N assimilation. In plants, iron deficiency leads to chlorosis in younger leaves and in case of severe deficiency, leaves become almost pale-white due to loss of chlorophyll. In India, iron deficiency in soil is reported to be one-fourth (11.2%) as extensive as that of Zn (48.1%) amongst the micronutrients (Gupta, 2005). In Karnataka state, 39 per cent of soil samples are reported to be deficient in iron (Sakal and Singh, 2001). In general, information on overcoming soil Fe deficiency by fertilizer addition is either meagre or nil particularly for rainfed crops. Crop yield and nutrient content in seeds in such a depleted situation is reported to be often low.

The amount of Fe and its application to soil assumes greater significance as it has antagonistic effect particularly on soil available phosphorus and other micronutrient such as Cu, Zn and Mn (Chakerolhosseini *et al.*, 2013). Moosavi and Ronaghi (2011) reported that foliar Fe/Mn application are obligatory in preventing yield reduction and nutrient imbalance in soybean grown on calcareous soils. There is no reported study in India on the effect of Fe application on yield and availability of other micronutrients in soybean. In addition, fractionation of iron and phosphorus by sequential extraction is useful for the determination of which form of phosphorus and iron is more likely be affected by the application of Fe and vice versa. Such information is valuable in predicting the bio-availability, leaching rates,

*Corresponding author's E-mail: shivanandkhandal@gmail.com

transformation between the chemical forms of iron and phosphorus and their availability to the crop. Hence, present study was undertaken to study the influence of iron sulphate ($FeSO_4$) application on seed and stover yields and nutrients uptake by the soybean crop and on iron and phosphorus transformations and residual soil fertility.

MATERIALS AND METHODS

Soil characteristics and weather: A field experiment was conducted on Vertisols during *kharif* season of 2014 in MARS, UAS, Dharwad, (15° 26' N latitude, 75° 07' E longitude, at an altitude of 678 m above mean sea level) to study the effect of iron sulphate application on yield, nutrients uptake by soybean, available nutrients status, phosphorus and iron fractions in soil at harvest of soybean (cultivar JS-335).The experimental soil was clay in texture with 1.38 Mg/m^3 bulk density, neutral in reaction (pH 7.8), free from salts (EC 0.18 dS/m), calcareous (5.5%) in nature, medium in organic carbon (0.54%), available nitrogen (340 kg/ha) and P_2O_5 (30 kg/ha) and high in available K_2O (365 kg/ha) and sulphur (21 kg/ha). Soil was inherently deficient in DTPA-extractable iron (3.41 mg/kg).

The rainfall received during the cropping season was above the long term average for the region. The rainfall of 604 mm was received during cropping period (July-October) in 69 days. The mean maximum temperature during the period of experimentation ranged from 27° to 30°C.

Treatment details and materials used: The field experiment was laid-out in RCBD design with three replications. Treatments comprised combinations of soil and foliar applications of $FeSO_4$ *viz.,* T1- RPP (40:80:25 kg NPK/ha + soil application of FYM @ 6 t/ha + $ZnSO_4$. 7 H_2O @ 12 kg/ha), T2- T1 + Foliar application of Fe at 30 DAS, T3- T1 + Foliar application of Fe at 30 and 45 DAS, T4- T1+ Soil application of Fe @ 10 kg/ha (soil), T5- T1+ Soil application of Fe @ 10 kg/ha + Foliar application of Fe at 30 DAS, T6- T1+Soil application of Fe @ 10 kg/ha + Foliar application of Fe at 30 and 45 DAS, T7- T1+ Soil application of Fe @ 20 kg/ha, T8- T1+ Soil application of Fe @ 20 kg/ha + Foliar application of Fe at 30 DAS, T9- T1+ Soil application of Fe @ 20 kg/ha + Foliar application of Fe at 30 and 45 DAS, T10- T1+ Soil application of Fe @ 30 kg/ha, T11- T1+ Soil application of Fe @ 30 kg/ha + Foliar application of Fe at 30 DAS, T12- T1+ Soil application of Fe @ 30 kg/ha + Foliar application of Fe at 30 and 45 DAS (Table 1). In all the treatments, Fe was applied as $FeSO4.7H_2O$ @ 0.5% in case of foliar applications and as per treatments (10, 20, 30 kg/ha for soil application). Soil application of iron sulphate heptahydrate ($FeSO_4.7H_2O$) was made after treatment with FYM in 1:1 ratio for 15 days before application. Seeds were inoculated with Rhizobium and PSB @ 1250 g/ha seeds. Seed rate used was 65 kg/ha. Crop was sown at spacing 30 x 10 cm on 15 July 2014 and harvested on 28 October 2014. Pest management, irrigation and other practices were followed as per package of practices to raise a healthy crop. Field data were collected on seed and stover yield.

Soil and plant analysis: Chemical properties of soil like pH, EC, organic carbon, available phosphorus, potassium and sulphur at harvest were estimated by using the methods given by Sparks (1996). $CaCO_3$ (Piper, 2002), available nitrogen (Sharawat and Burford, 1982) and DTPA extractable micronutrient (Cu, Fe, Mn, Zn) (Lindsay and Norvel, 1978) were also analysed before sowing and at harvest of the crop. Plant uptake of nutrients was obtained by using the methods given by Tandon (1998). Sequential extraction method was used for analysis of phosphorus (Peterson and Corey, 1966) and iron (Miller *et al.,* 1986) fractions.

RESULTS AND DISCUSSION

Crop yield: Application of 20 kg $FeSO_4$/ha to soil with two iron sulphate foliar sprays at 30 and 45 DAS (T9) resulted in significantly higher seed yield (15.3 q/ha) over treatments T1, T2, T3, T4, T5, T6 and T7 and stover yield (25.6 q/ha) over T1, T2, T3, T4, T5, T7 and T11. The lowest seed yield (12.5 q/ha) and stover yield (18.4 q/ha) were recorded in control plot (T1) which received only recommended package of practices (RPP). However, treatment, T9 was at par with T8, T10, T11 and T12 with respect to seed yield (14.2 to 15.0 q/ha) and T6, T8 and T10 for stover yield (23.4 to 24.2 q/ha). This might be due to increased iron availability in soil which tested inherently deficient in available iron and higher concentration of iron in soybean leaves due to foliar iron application. Earlier studies also revealed favourable effect of iron sulphate application in increasing the seed (Chatterjee *et al.,* 2017; Moosavi and Ronaghi, 2011) and stover yield (Rajamani and Shanmugasundaram, 2014).

Nutrient uptake: Uptake of total nutrients (N, K and S) by soybean differed significantly with the application of iron sulphate (Table 1). But P uptake was not affected. The treatment which received 20 kg $FeSO_4$/ha to soil with two iron sulphate foliar sprays at 30 and 45 DAS registered highest nitrogen (176.45 kg/ha), potassium (61.96 kg/ha) and sulphur (19.41 kg/ha) uptake by soybean crop at harvest which was at par with treatment T8 (soil application of 20 kg $FeSO_4$/ha with one iron sulphate foliar spray at 30 DAS) for N, K and S uptake and was also at par with T10 for S uptake. Lowest of N (118.64 kg/ha), K (36.86 kg/ha) and S (11.67 kg/ha) uptake was recorded in control. The higher uptake of nitrogen, potassium and sulphur by soybean crop could be due to increased iron availability in soil and the direct uptake of ferrous (Fe^{2+}) form of iron by the leaves resulting in higher production of chlorophyll, drymatter, yield and yield components *viz.,* pod number and seed yield/plant. These findings are in accordance with Bansal and Singh (1975) who recorded increase in S, N uptake and chlorophyll content in cowpea leaves with 0.1 per cent spray of $FeSO_4$.

Micronutrient (Mn, Cu and Zn) uptake by soybean did not differ significantly with the application of iron sulphate, but Fe uptake increased significantly (Table 1). Highest total iron uptake at harvest was recorded in treatment T9 (264.5 g/ha) which was at par with T8 (243 g/ha) and significantly higher than all other treatments (202.9-221.9 g/ha), that were at par with each other. Increase in total iron content in plant at harvest could be due to increased iron availability in an inherently iron deficient soil and the direct uptake of ferrous iron by leaves in treatment receiving foliar spray. Earlier Basappa (1990) reported that both soil and foliar application of iron increased the total iron content in groundnut genotype which was more at harvest stage of the crop than at flower initiation stage.

Soil available nutrient status: The nutrients status in soil (N, P_2O_5, K_2O, Zn, Mn and Cu) at soybean harvest did not differ significantly due to iron sulphate application (Table 2). Results of DTPA-extractable iron indicate that levels of applied iron significantly increased the DTPA-extractable iron at harvest of soybean. Application of 30 kg $FeSO_4$/ha to soil and two iron sulphate (0.5%) foliar spray at 30 and 45 DAS (T12) resulted in the highest DTPA-extractable iron (3.84 mg/kg) in soil which was at par with T7 (3.64 mg/kg), T8 (3.65 mg/kg), T9 (3.67 mg/kg), T10 (3.80 mg/kg) and T11 (3.82 mg/kg) and significantly superior over the remaining treatments. Lowest iron in soil was recorded in T1 (3.33 mg/kg). Increased dose of iron resulted in more vegetative growth, seed yield, root growth and thus resulted in more uptake of this nutrient. Similar observations were recorded by Papastylianou (1989) and Marschner and Romheld (1995). Increased biomass production due to application of iron sulphate might also have facilitated increased availability of iron in soil upon decomposition by release of phenolic compounds and organic acids as well as due to availability of unutilised iron by the crop.

Table 1 Effect of soil and foliar application of ferrous sulphate on seed yield, stover yield and major and micronutrient uptake by soybean at harvest

Treatments	Yield (q/ha)		Major nutrient uptake (kg/ha)												Micronutrient uptake (g/ha)			
			Nitrogen			Phosphorus			Potassium			Sulphur			Iron	Manganese	Zinc	Cupper
	Seed	Stover	Seed	Stover	Total	Seed	Stover	Total	Seed	Stover	Total	Seed	Stover	Total	Total uptake			
T_1	12.5	18.4	72.15 (5.79)	46.49 (2.52)	118.64	5.29 (0.42)	6.44 (0.35)	11.72	7.65 (0.62)	29.20 (1.59)	36.86	5.24 (0.42)	6.44 (0.35)	11.67	162.61	77.60	56.09	38.23
T_2	12.9	20.0	75.61 (5.83)	52.23 (2.61)	127.84	5.54 (0.43)	7.10 (0.36)	12.64	8.29 (0.64)	33.45 (1.66)	41.74	5.82 (0.45)	7.10 (0.36)	12.92	178.24	82.73	62.86	40.99
T_3	13.2	21.1	80.16 (6.05)	56.92 (2.70)	137.09	5.84 (0.44)	7.64 (0.36)	13.48	8.78 (0.66)	35.81 (1.71)	44.59	6.40 (0.49)	7.70 (0.36)	14.10	195.85	86.91	67.20	42.83
T_4	12.9	19.7	78.03 (6.03)	52.51 (2.66)	130.55	5.57 (0.43)	6.92 (0.35)	12.53	8.49 (0.66)	32.95 (1.67)	41.44	5.94 (0.46)	7.11 (0.36)	13.05	180.38	81.83	61.00	41.17
T_5	13.4	21.6	83.33 (6.21)	58.89 (2.73)	142.23	5.99 (0.45)	7.92 (0.37)	13.91	8.98 (0.67)	37.88 (1.75)	46.86	7.11 (0.54)	8.05 (0.37)	15.16	202.91	89.32	68.23	43.88
T_6	13.6	23.4	85.87 (6.32)	67.44 (2.88)	153.32	6.30 (0.46)	8.64 (0.37)	14.95	9.98 (0.74)	42.76 (1.83)	52.73	7.36 (0.54)	8.89 (0.38)	16.25	220.25	94.16	71.34	46.40
T_7	13.8	22.6	86.08 (6.24)	63.24 (2.79)	149.33	6.20 (0.45)	8.24 (0.36)	14.44	9.64 (0.70)	40.06 (1.76)	49.70	6.94 (0.50)	8.36 (0.37)	15.30	212.58	92.44	68.03	45.91
T_8	15.0	24.2	96.27 (6.14)	70.49 (2.91)	166.77	7.05 (0.47)	9.30 (0.38)	16.36	11.54 (0.77)	45.55 (1.88)	57.09	8.35 (0.56)	9.62 (0.40)	17.97	243.01	102.63	74.54	49.90
T_9	15.3	25.6	100.52 (6.58)	75.92 (2.97)	176.45	7.53 (0.40)	10.06 (0.39)	17.59	12.82 (0.84)	49.14 (1.92)	61.96	8.93 (0.58)	10.48 (0.41)	19.41	264.47	107.61	78.67	52.08
T_{10}	14.8	23.4	92.91 (6.26)	66.63 (2.85)	159.54	6.87 (0.46)	9.04 (0.39)	15.91	11.16 (0.75)	42.13 (1.80)	53.29	8.27 (0.56)	9.24 (0.40)	17.51	221.92	100.38	70.51	48.75
T_{11}	14.5	22.7	89.97 (6.19)	63.45 (2.80)	153.42	6.57 (0.45)	8.30 (0.37)	14.87	10.73 (0.74)	39.64 (1.75)	50.37	7.66 (0.53)	8.78 (0.39)	16.44	212.46	97.28	65.90	47.45
T_{12}	14.2	22.1	87.46 (6.13)	61.51 (2.78)	148.98	6.33 (0.44)	7.67 (0.35)	14.00	10.33 (0.73)	38.13 (1.73)	48.46	7.37 (0.52)	8.47 (0.38)	15.83	203.69	94.86	64.61	46.22
SE m (±)	0.5	1.0	4.07	3.20	5.49	0.65	0.69	9.42	0.54	2.21	2.00	0.27	0.43	0.60	8.36	6.22	4.21	2.83
CD (0.05)	1.5	2.9	11.95	9.38	16.11	NS	NS	NS	1.60	6.48	5.87	0.78	1.27	1.76	24.53	NS	NS	NS

Recommended Dose of Nutrients (40:80:25 kg NPK/ha + soil application of FYM @ 6 t/ha + $ZnSO_4$. $7H_2O$ @ 12 kg/ha) was applied to all treatments
Values in parenthesis indicate per cent nutrient content

Table 2 Effect of soil and foliar application of ferrous sulphate on available nutrients in soil at harvest of soybean

Treatments	Available nutrients (kg/ha)				Available micronutrients (mg/kg)			
	N	P_2O_5	K_2O	S	Iron	Manganese	Zinc	Cupper
T1	323.3	29.1	371.1	24.4	3.33	5.35	0.46	0.41
T2	320.0	29.0	369.7	24.3	3.34	5.36	0.46	0.43
T3	316.6	28.6	381.2	24.1	3.35	5.4	0.47	0.44
T4	322.3	28.9	365.5	24.1	3.46	5.38	0.46	0.43
T5	315.6	28.2	364.6	23.9	3.49	5.43	0.47	0.44
T6	308.6	28.1	361.3	23.8	3.53	5.46	0.48	0.45
T7	312.6	28.2	359.6	23.7	3.64	5.41	0.47	0.44
T8	308.6	27.9	357.2	23.6	3.65	5.48	0.49	0.45
T9	306.6	27.7	354.9	23.5	3.67	5.51	0.50	0.47
T10	313.3	27.4	361.7	23.7	3.80	5.47	0.46	0.45
T11	315.4	27.3	365.7	23.9	3.82	5.45	0.45	0.45
T12	318.5	27.0	369.0	24.0	3.84	5.44	0.43	0.44
SEm (±)	11.62	1.00	15.58	1.27	0.09	0.23	0.01	0.02
CD (0.05)	NS	NS	NS	NS	0.28	NS	NS	NS
Initial	340.00	30.0	365.00	21.0	3.41	5.51	0.49	0.46

Table 3 Effect of soil and foliar application of ferrous sulphate on iron and phosphorus fractions in soil at harvest of soybean

Treatments	Iron fractions (mg/kg)							phosphorus fractions (mg/kg)				
	Water soluble iron	Exchangeable iron	Acid soluble iron	Pb-displaceable iron	Mn oxide occluded Iron	Organically bound iron	Amorphous iron oxide occluded iron	Saloid-P	Al-P	Fe-P	Occl-P	Ca-P
T1	0.64	2.11	1.15	35.02	206.28	478.59	1702.13	2.14	12.67	9.93	15.97	58.57
T2	0.64	2.12	1.15	35.02	206.28	478.58	1702.14	2.14	12.67	9.94	15.96	58.58
T3	0.65	2.12	1.16	35.03	206.29	478.58	1702.14	2.14	12.66	9.94	15.97	58.58
T4	0.98	2.48	1.40	38.45	210.23	481.23	1706.57	1.93	12.37	11.63	14.99	58.07
T5	0.99	2.49	1.39	38.45	210.22	481.24	1706.59	1.93	12.35	11.64	15.01	58.08
T6	0.99	2.48	1.40	38.47	210.23	481.24	1706.59	1.92	12.35	11.65	15.01	58.08
T7	1.18	2.68	1.65	41.82	213.16	485.16	1713.49	1.78	11.78	12.24	14.24	57.66
T8	1.18	2.67	1.66	41.83	213.17	485.16	1713.50	1.78	11.78	12.23	14.23	57.67
T9	1.19	2.68	1.67	41.83	213.17	485.17	1713.51	1.76	11.76	12.25	14.25	57.67
T10	1.29	3.04	2.08	44.11	217.01	490.71	1724.04	1.54	11.20	14.49	13.74	57.49
T11	1.28	3.05	2.08	44.12	217.02	490.73	1724.06	1.54	11.21	14.51	13.73	57.50
T12	1.29	3.06	2.07	44.14	217.02	490.73	1724.06	1.53	11.20	14.51	13.75	57.50
SEm (±)	0.04	0.10	0.08	1.57	6.28	11.28	65.90	0.09	0.37	0.67	0.59	2.77
CD (0.05)	0.14	0.30	0.25	4.61	NS	NS	NS	0.27	1.10	1.96	NS	NS
Initial	0.96	2.78	1.23	38.45	208.00	480.00	1704.00	2.31	12.53	10.42	14.99	59.77

DAS-Days after sowing; NS- Non significant

Iron and phosphorus fractions: The properties of iron fractions (water soluble, acid soluble, exchangeable and Pb-displaceable) status in soil at soybean harvest differed significantly due to applied iron levels (Table 3). However, the iron fractions like, Mn oxide occluded, organically bound and amorphous iron oxide occluded were not significantly influenced by iron application. Significantly, higher water soluble, exchangeable and Pb-displaceable iron of 1.29, 3.16 and 44.14 mg/kg, respectively were registered in the treatment that received 30 kg $FeSO_4$/ha with two iron sulphate foliar sprays at 30 and 45 DAS. However higher acid soluble iron (2.07 mg/kg) was registered in T10 and T11, whereas lowest values of 0.64, 2.11, 1.15 and 35.02 mg/kg of water soluble, exchangeable, acid soluble and Pb-displaceable, respectively were recorded in the control treatment that received only RPP and T2 (except for exchangeable iron). This might be due to increased total dry matter production and yield of soybean as a result of increased iron availability and its absorption and translocation by plant. Thus, addition of soluble iron salt increased the water soluble, exchangeable, acid soluble and Pb-displaceable iron in soil. Similar observations were made by Mahendra Singh and Dahiya (1975) and Sposito (1984).

Generally, it is considered that the saloid bound-P is the most important fraction of inorganic P on which the crop depends and after that Al-P, Fe-P, occl-P and Ca-P are important because these fractions of inorganic - P may come into the soil solution as the various reaction products of mineralization. Treatment T1, T2 and T3 registered significantly higher saloid-P (2.14 mg.kg) and Al-P (12.67 mg/kg) fractions both were at par with T4 (1.93 and 12.37 mg/kg), T5 (1.93 and 12.35 mg/kg) and T6 (1.92 and 12.35 mg/kg) treatments. Treatment T12 and T11 recorded higher Fe-P (14.51 mg/kg) which was at par with T10 (14.49 mg/kg) (Table 3). Lowest saloid-P and Al-P of 1.53, 11.20 mg/kg, respectively was recorded in treatment T12 and lowest Fe-P (9.93 mg/kg) was recorded in T1. This increased Fe-P might be due to conversion of phosphorus to Fe-P with applied iron.

Table 4 Economics of soybean as influenced by different treatments of iron sulphate application

Treatments	Cost of cultivation (₹/ha)	Grass returns (₹/ha)	Net returns (₹/ha)	B:C
T1	24585	39260	14675	1.59
T2	24940	40800	15860	1.63
T3	25400	41610	16210	1.63
T4	25410	40730	15590	1.62
T5	25600	42095	16495	1.64
T6	26050	42725	16675	1.64
T7	25460	43490	18030	1.70
T8	25920	47270	21350	1.82
T9	26380	48175	21795	1.82
T10	25780	46700	20920	1.81
T11	26240	45770	19530	1.74
T12	26700	44900	18200	1.68

Economic analysis: The data on economics of soybean cultivation as influenced by various treatments are presented in Table 4. The treatment T9 (soil application of 20 kg FeSO4/ha followed by two iron sulphate sprays at 30 and 45 DAS) realized the highest gross return (₹ 48175/ha) followed by T8 i.e. soil application of 20 kg $FeSO_4$/ha along with one iron sulphate spray at 30 DAS (₹ 47270/ha) and T10 i.e. soil application of 30 kg $FeSO_4$/ha alone (₹ 46700/ha). While, the highest net return was obtained from T9 (₹ 21795/ha) followed by T8 (₹ 21350/ha) and T10 (₹ 20920/ha). Similarly, the highest benefit cost ratio (1.82) was observed in T9 and T8 followed by T10. The lowest benefit cost ratio (1.59) was observed in the treatment control i.e. recommended package of practices.

From the analysis of the experimental data it could be concluded that soil application of 20 kg $FeSO_4$/ha along with foliar sprays of iron sulphate (0.5%) at 30 and 45 DAS (T9) was at par with T8, T10, T11 and T12 with respect to seed yield and T6, T8 and T10 for stover yield and superior to other treatments. The lowest seed yield (12.46 q/ha) and stover yield (18.42 q/ha) were recorded in control plot which received only recommended package of practices (RPP). Nutrient uptake (N, K, S and Fe) by soybean crop and available iron content in the soil after harvest of the crop were higher in treatment T12 (30 kg $FeSO_4$/ha with two iron sulphate foliar sprays at 30 and 45 DAS). Significantly, higher water soluble, exchangeable and Pb-displaceable iron of 1.29, 3.16 and 44.14 mg/kg respectively were registered in the treatments T10, T11 and T12 which comprised soil application of 30 kg $FeSO_4$/ha alone or with one (30 DAS) or two foliar sprays (30 and 45 DAS) of $FeSO_4$ compared to treatments T1 to T6. Treatment T1, T2 and T3 registered significantly higher saloid-P (2.14 mg/kg) than treatments T7 to T12 and Al-P (12.67 mg/kg) fractions than treatments T10, T11 and T12. The study concluded that application of RDF along with soil application of iron sulphate at 20 kg/ha with two iron sulphate foliar sprays at 30 and 45 DAS is recommended for better yield and economic returns.

REFERENCES

Agarwal D K, Billore S D, Sharma A N, Dupare B U and Srivastava S K 2013. Soybean: introduction, improvement and utilization in India-problems and prospects. *Agricultural Research*, **2**: 293-300.

Bansal K N and Singh H G 1975. Interaction between sulphur and iron in the prevention of iron chlorosis in cowpea. *Soil Science*, **120**: 20-24.

Basappa B S 1990. Studies in distribution forms and availability of iron in Vertisols of Upper Krishna project area, Karnataka. M. Sc. (Agri.) Thesis, University of Agricultural Sciences, Dharwad, Karnataka.

Chakerolhosseini M R, Ronaghi A, Maftoun M and Karimian N 2013. Response of soybean to phosphorus and iron in a calcareous soil. *Journal of Water and Soil Sciences*, **6**(4): 91-102.

Chatterjee A, Lovas S, Ramussen H and Goos R J 2017. Foliar application of iron fertilizers to control iron deficiency chlorosis of soybean. *Crop Forage and Turfgrass Management*, **3**: 1-7.

Gupta A P 2005. Micronutrient status and fertilizer use scenario in India. *Journal of Trace Elements in Medicine and Biology*, **18**(4): 325-331.

Lindsay W L and Norvell W A 1978. Development of a DTPA- soil test for Zn, Fe, Mn and Cu. *Soil Science Society of America Journal*, **42**: 421-428.

Mahendra Singh and Dahiya S S 1975. Effect of $CaCO_3$ and iron on the availability of iron in light textured soil. *Journal of Indian Society of Soil Science*, **23**(2): 247-252.

Marschner H and Romheld V 1995. Strategies of plants for acquisition of iron. *Plant and Soil*, **165**: 261-274.

Miller W P, Martens D C and Zelazny L W 1986. Effect of sequence in extraction of trace metals from soils. *Soil Science Society of America Journal*, **50**: 598-601.

Moosavi A A and Ronaghi A 2011. Inluence of foliar and soil application of iron and manganese on soybean dry matter yield and iron manganese relationship in a calcareous soil. *Australian Journal of Crop Science*, **5**(12): 1550-1556.

Papastylianou 1989. Effect of selected soil factors on chlorosis of peanut plants grown in calcareous soils in cyperus. *Plant and Soil*, **17**(2): 291-294.

Peterson G W and Corey R B 1966. A modified Chang and Jackson procedure for routine fractionation of inorganic soil phosphates. *Soil Science Society of America Proceedings*, **30**: 563-565.

Piper C S 2002. *Soil and Plant Analysis,* Hans Publishers, Bombay, India.

Prabakaran M, Kyoung-Jin Lee, Yeonju An, Chang Kwon, Soyeon Kim, Yujin Yang, Ateeque Ahmad, Seung-Hyun Kim and III-Min Chung 2018. Changes in soybean(*Glycine max* L.) Flour fatty-acid content based on storage temperature and duration. *Molecule*, **23**(10): 2713.

Rajamani P and Shanmugasundaram R 2014. Effect of application of ferrous sulphate on performance of black gram genotypes in calcareous soil. *Asian Journal of Soil Science*, **9**(1): 32-35.

Sakal R and Singh A P 2001. Micronutrients in relation to yield response and quality of crops. *Indian Jouranl of Agricultural Chemistry*, **34**(1-2): 1-13.

Sharawat K L and Burford J R 1982. Modification of alkaline permanganate method for assessing the availability of soil nitrogen in upland soils. *Soil Science*, **133**: 53-57.

Singer W M, Bo Zhang, Rauf Mian M A and Huang H 2019.Soybean amino acids in health, Genetics and evaluation. Provisional chapter intechopen. http://doi.org/10.5772/intechopen.89497.

Sparks 1996. *Methods of Soil Analysis Part-II: Chemical Methods*. Soil Science Society of America, USA.

Sposito G 1984. *The Surface Chemistry of Soils.* Oxford University Press, New York, pp. 79-112.

Tandon H L S 1998. Methods of analysis of soils, plant, water and fertilizers. Fertiliser *Development and Consultation Organisation*, **31**: 9-16.

Effect of phosphorus management on yield, nutrient uptake by sesame (*Sesamum indicum* L.) and soil fertility under irrigated conditions of southern Haryana

M K JAT, R SINGH, P K YADAV, ABHA TIKKOO, R S DADARWAL AND J S YADAV

Regional Research Station, CCS HAU, Bawal-123 501, Haryana

(Received: November 28, 2019; Revised: March 4, 2020; Accepted: March 6, 2020)

ABSTRACT

Field experiments were carried out during *kharif* season from 2015 to 2017 in randomized block design with three replications. There were five graded levels of phosphorus application viz., 0, 10, 20, 30, and 40 P_2O_5 kg/ha. Seed yield increased significantly with application of 20 P_2O_5 kg/ha. The increase in mean seed and stalk yield was 6.1, 13.2, 15.4 and 18.0% and 6.2, 14.3, 17.6 and 19.9% due to application of 0, 10, 20, 30 and 40 P_2O_5 kg/ha, respectively over control. Application of 20 kg P_2O_5/ha recorded significantly higher protein content (21.10%) and oil content (48.69%) in seed, which was statistically at par with 30 and 40 kg P_2O_5/ha. P use efficiency varied from 14.1 to 20.3% and was maximum (20.3%) with application of 20 P_2O_5 kg/ha. The mean post-harvest available P status was 9.9, 11.3, 12.7, 13.5 and 14.1 kg/ha at 0, 10, 20, 30 and 40 P_2O_5 kg/ha, respectively. Based on the results of research experiment, on farm trials (OFT) were conducted on the farmers' fields with two treatments, control and 20 kg P_2O_5/ha. The result of OFT revealed that the application of 20 kg P_2O_5/ha increased the seed yield of sesame by 11.71 per cent over control. Application of 20 P_2O_5 kg/ha was optimum for the cultivation of sesame crop in coarse textured medium phosphorus status soils under irrigated condition of south-west Haryana.

Keywords: Available soil P, Economics, Sesame, Yield, Uptake

In India, sesame is cultivated on 1.56 million ha with a total production of 0.7 million tonnes. The average productivity of the crop is 478 kg/ha (Anonymous, 2018). But the average productivity is very low in comparison to global as well as national level. Increasing global demand has opened up prospective market options for sesame. The use of mineral fertilizers and organic manures in balanced amount can ensure sustainable production at higher productivity and higher quality level of this oil seed crop. The average productivity of sesame in Haryana is very low in comparison to national level. Low and scanty rainfall, cultivation of crop on marginal and sub-marginal lands under very poor agronomic practices and inadequate use of fertilizers are the major factors responsible for low productivity of the crop. For optimum utilization of other essential inputs, fertilizer requirements need to be fine-tuned. Phosphorus is very important macro plant nutrient which helps the growth and development of plant and increases crop yield. It is involved in many bio-chemical functions in the plant physiology systems and is essential part of skeleton of plasma membrane, nucleic acid, many coenzymes, organic molecules and phosphorylated compounds in plant system (Pandey and Sinha, 1986). Refinement of on-site nutrient management for sesame is very important. The present study was taken up to determine the optimum dose of phosphorus for growth and yield performance of sesame in coarse textured soils of southern Haryana and to create awareness among the farming community about the judicious use of phosphorus fertilizer to get maximum production.

Corresponding author's E-mail: mukesh.rca@gmail.com

MATERIALS AND METHODS

The experiments were conducted at Regional Research Station, CCS HAU, Bawal, Haryana during *kharif* seasons of 2015 to 2017. The site is situated at latitude 28.1°N, longitude 76.5°E having an altitude of 266 m above mean sea-level. The soil properties of the experimental site (mean of three years) are presented in Table 1. The climate of the site was characterized by hot summers and cold winters with an average annual rainfall received was 378, 575.5 6 and 565.10 mm during 2015, 2016 and 2017 respectively.

Table 1 Physico-chemical properties of the experimental field at 0-15 cm depth

Soil properties	Mean value
Soil texture	loamy sand
pH (1:2)	8.36
EC (dS/m)	0.19
OC (g/kg)	1.95
Available N (kg/ha)	110.9
Available P (kg/ha)	11.0
Available K (kg/ha)	169.5

The experiments were laid out in randomized block design with three replications. There were five graded levels of phosphorus application *viz*., 0, 10, 20, 30, and 40 kg/ha P_2O_5. Recommended dose of nitrogen (37.5 kg N/ha) was applied through urea. Irrigation and plant protection measures were taken as per recommended package of practices. Crop was harvested at physiological maturity. Plot wise yield was recorded. Seed, stalk and soil samples were taken and analyzed for P concentration (Jackson, 1967) and available P in soil (Olsen *et al.,* 1954). The data was statistically analyzed and economics of P application was also worked out.

Based on the results of field experiments conducted at research station, on farm trials (OFTs) were conducted during 2018 and 2019 on farmer's field with control (without P) and 20 kg P_2O_5/ha. The soils of these villages were sand to loamy sand in texture, alkaline in reaction, low in organic carbon and low to medium in available P and K. The total area of each OFT was 0.4 hectare. Full basal dose of N and K were applied at the sowing time as per the recommended dose of fertilizer. The crop was raised with all the standard package of practices and harvested between September and October. Seed and stalk yields were recorded by visiting the field of each farmer. Soil, seed and stalk samples were analyzed for P content as per standard procedures.

RESULTS AND DISCUSSION

Effect of P fertilization on seed and stalk yield: The results revealed that there was a consistent increase in seed and stalk yield of sesame by increasing graded levels of phosphorus from 10 to 40 kg/ha in three *kharif* seasons (Table 2). A significant increase in seed yield was found with the application of 20 kg P_2O_5/ha whereas the seed yield of sesame crop was statistically at par with the application of 20, 30 and 40 kg P_2O_5/ha. The mean seed and stalk yields increased to the tune of 6.06, 13.17, 15.38 and 18.04 and 6.20, 14.28, 17.62 and 19.85 % respectively due to the application of 0, 10, 20, 30 and 40 kg P_2O_5/ha over control. The positive effect of phosphorus fertilization on seed and stalk yield of sesame might be attributed to the medium level of available phosphorus content of the experimental soil. This necessitated the high demand of phosphorus by the crop as P is known to enhance the development of good root system (Russel, 1973) which in turn increases efficiency of the roots in absorbing various nutrients. Marschner (1986) reported that the application of phosphorus stimulates photosynthesis, carbohydrate metabolism and synthesis of protein in turn increases the amount of metabolites synthesized by sesame plants. Also, it plays an important role in enhancing translocation of metabolites which might be the reason for the increasing seed and stalk yield. The improved growth and profuse branching due to P fertilization as discussed earlier coupled with increased photosynthates on one hand and greater mobilization of photosynthates toward reproductive parts of the plants on the other hand might have been responsible for significant improvement in yield attributes of sesame. These findings are in accordance with those reported by Singh *et al.* (1994), Ravinder *et al.* (1996) and Patra (2001) in sesame crop.

Table 2 Effect of application of phosphorus on seed and stalk yield in sesame

P_2O_5 levels (kg/ha)	Seed yield (q/ha)				Stalk yield (q/ha)			
	2015	2016	2017	Mean	2015	2016	2017	Mean
P0	6.91	6.60	6.76	6.76	20.98	19.31	20.15	20.15
P10	7.39	7.10	7.03	7.17	22.10	20.60	21.49	21.40
P20	8.18	7.38	7.40	7.65	23.46	23.68	22.30	23.15
P30	8.36	7.55	7.50	7.80	23.60	23.95	23.57	23.70
P40	8.50	7.68	7.76	7.98	23.80	24.50	24.14	24.15
CD (P = 0.05)	0.62	0.60	0.56	0.59	1.64	1.79	1.81	1.75

Effect of P fertilization on protein content in seed and oil content: Experimental data indicated that different levels of phosphorous application exerted their significant influence on quality of sesame in terms of protein and oil content (Table 3). Application of 20 kg P_2O_5/ha recorded significantly higher protein content in seed (21.10 %) and oil content (48.69 %) which was statistically at par with that of 30 and 40 kg P_2O_5/ha. This might be due to the synergistic effect of phosphorous on nitrogen uptake which facilitates protein synthesis and activates different enzymes and it is also known that P facilitates uptake and assimilation of N into simple amino acids and amides, which in turn increases the peptide synthesis leading to protein synthesis. Hence, increased concentration of N in seed might have increased the protein content. These results are in close conformity with the findings of Thakur *et al.* (1998) in sesame. The increased content of oil coupled with significantly higher seed yield of sesame could be the most possible reason for higher oil yield obtained due to phosphorus fertilization. Thakur *et al.* (1998) and Thanki *et al.* (2004) have also reported improvement in these quality characters of sesame due to phosphorus application.

P uptake, P use efficiency and available P content: The total P-uptake in sesame plant was also significantly influenced by level of P application. The phosphorous uptake increased significantly with the increased levels up to 40 kg P_2O_5/ha. The uptake was increased from 5.24 to 10.89 kg/ha with increasing P_2O_5 levels of phosphorous from 0 to 40 kg P_2O_5/ha (Table 4). The progressive increase in the supply of phosphorous to the crop resulted in higher availability of this nutrient, resulting in higher biomass yield. The impact of higher uptake of phosphorous under these treatments was reflected in the growth and yield performance of the crop. Similarly, good supply of phosphorus is usually associated with increased root density and proliferation which aid in extensive exploration and supply of nutrients and water to the growing plant (Shehu *et al.,* 2010).

Table 3 Effect of phosphorus application on protein and oil content in sesame seed

P_2O_5 levels (kg/ha)	Protein content in seed (%)	Oil content (%)
P0	18.25	42.28
P10	19.51	45.30
P20	21.10	48.69
P30	21.87	48.88
P40	22.05	48.98
CD(P=0.05)	1.31	3.10

The phosphorus use efficiency (PUE) ranged from 14.12 to 20.30%. PUE increased with application of 10 and 20 kg P_2O_5/ha from 16.30 to 20.30% and decreased from 16.80 to 14.12% at 30 and 40 P_2O_5/ha, respectively. The highest PUE of 20.3% was recorded with the application of 20 kg P_2O_5/ha. The increased supply of nutrients and good response by the plants resulted in enhanced translocation of nutrients and ultimately build-up of the available P content in the soil and improve PUE as reported also by Ulukan (2008) and El-Ghamry *et al.* (2009).

Increasing levels of phosphorous from 0 to 40 kg/ha significantly improved the available phosphorous in soil after harvesting of crop. The initial mean available P status was 11.00 kg P/ha whereas it was 9.90, 11.30, 12.68, 13.52 and 14.08 kg/ha with the application of 0, 10, 20, 30 and 40 kg P_2O_5/ha, respectively (Table 4). The soil available P significantly increased upto the application of 20 kg P_2O_5/ha. Increasing levels of phosphorous from 30 and 40 kg/ha significantly improved available phosphorous in soil over control but at par with 20 kg P_2O_5/ha. The highest available P content of 14.08 kg/ha was observed with the application of 40 kg P_2O_5/ha which was significantly superior over control. Javia *et al.* (2010) also observed improved post-harvest build-up of soil available P as compared without P application in sesame crop.

Effect of P fertilization on crop economics: It is evident from the data presented in Table 5 that gross returns and net returns of sesame increased with increasing levels of phosphorous at 10, 20, 30 and 40 kg P_2O_5/ha, respectively which might be due to the increasing seed and stalk yield with increasing phosphorous levels. The minimum and maximum gross return of ₹37840 and ₹ 44699 were recorded with control and application of 40 kg P_2O_5/ha, respectively. The results also indicated that the total cost of cultivation followed the same trend. The highest net return (₹ 7241) was recorded from the phosphorous application of 40 kg P_2O_5/ha, while minimum net return obtained with 0 kg P_2O_5/ha (₹ 2181).The mean economic data analysis revealed that benefit cost ratio also increased with the application of increasing levels of phosphorous. Whereas, the additional returns per rupee invested on P at 10, 20, 30 and 40 kg P_2O_5/ha levels of phosphorous were ₹ 5.05, 5.51, 4.35 and 4.02, respectively. The highest additional returns per rupee (5.51) invested on P was obtained with application of 20 kg P_2O_5/ha, owing to higher seed and stalk yield (Table 2). These findings are in agreement with what has been reported by Sharma (2005), Hanumanthappa *et al.* (2008) and Javia *et al.* (2010).

Effect of P fertilization in sesame at farmer's field: The results from OFT's indicated that application of phosphorous @ 20 kg /ha increased the mean seed yield of sesame by 11.71 per cent over control (Table 6). The mean initial soil available P status of farmer's fields was 11.36 kg/ha whereas after the harvest of sesame it was depleted/buildup 9.86 and 13.43 kg/ha at 0 and 20 kg/ha level of phosphorous application, respectively. A critical look into the data of available P status in the soil before sowing and after harvest of sesame, revealed that there was a slight depletion/buildup in available phosphorous which could be due to the absorption by plant and translocation of applied P into different parts of the plant (Table 7).

Table 4 Effect of phosphorus application on total P uptake and available phosphorus in sesame

P_2O_5 levels (kg/ha)	Total P uptake (kg/ha)				PUE (%)	Available P (kg/ha)			
	2015	2016	2017	Mean		2015	2016	2017	Mean
P0	5.40	5.10	5.21	5.24	-	10.05	9.85	9.80	9.90
P10	6.79	6.94	6.87	6.87	16.30	13.55	11.85	11.60	11.30
P20	9.50	9.30	9.10	9.30	20.30	14.90	13.10	13.05	12.68
P30	10.31	10.24	10.28	10.28	16.80	15.25	14.05	14.25	13.52
P40	10.90	10.92	10.86	10.89	14.12	15.50	14.95	14.80	14.08
CD(P=0.05)	0.53	0.50	0.51	0.51	-	1.51	1.48	1.50	1.50

*PUE- Phosphorus use efficiency

Table 5 Effect of phosphorus application on economics in sesame

P_2O_5 levels (kg/ha)	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio	Additional returns/ ₹ invested on P
P0	35658	37840	2182	1.06	-
P10	36108	40111	4003	1.11	5.05
P20	36558	42800	6242	1.17	5.51
P30	37008	43722	6714	1.18	4.35
P40	37458	44699	7241	1.19	4.02

Table 6 Effect of phosphorous application on sesame seed yield in OFT's

Year	Name of farmer	Village/ District	Seed yield (q/ha)	
			P0	P20
2018	Sh. Baljeet S/o Sh. Kishan Chand	Atela (Bhiwani)	3.50	5.00
2018	Sh. Dinesh Kumar S/o Sh. Nar Singh	Sahidsahapur (Gurugram)	7.00	7.60
2018	Sh. Rohit Kumar S/o Sh. Lala Ram	Telpuri- (Patodi)	6.85	7.45
2018	Sh. Ramparsad S/o Sh. Amar Singh	Sahapur (Rewari)	5.50	6.20
2018	Sh. Vikash Kumar S/o Sh. Partap	Jaitpur (Rewari)	6.00	6.50
2018	Sh. Bijender S/o Sh. Jagmohan	Jaitpur (Rewari)	5.90	6.25
2018	Sh. Jagdul Kumar S/o Sh. Dault Ram	Bhatsana (Rewari)	6.20	6.65
2019	Sh. Sandeep Kumar S/o Sh. Sona Ram	Bawal (Rewari)	4.70	5.20
2019	Sh. Charan Singh S/o Sh. Roshan Lal	Bahin (Mewat)	3.60	4.10
2019	Sh. Krishan S/o Sh. Tarachand	Khatodhara (M. Garh)	5.1	5.8
2019	Sh. Sajjan S/o Sh. Dalip Singh	Khatodhara (M. Garh)	4.8	5.4
	Mean		5.38	6.01
	Per cent increase in yield		11.71	

Table 7 Effect of phosphorous application on available P status of soils at farmers' field

Name of farmer	Initial Av. P (kg/ha)	Av. P at harvest (kg/ha)	
		P0	P20
Sh. Dinesh Kumar S/o Sh. Nar Singh	11.17	10.08	14.40
Sh. Rohit Kumar S/o Sh. Lala Ram	11.25	9.65	13.20
Sh. Ramparsad S/o Sh. Amar Singh	11.35	9.70	13.15
Sh. Vikash Kumar S/o Sh. Partap	11.27	9.85	12.70
Sh. Bijender S/o Sh. Jagmohan	11.20	10.05	13.12
Sh. Jagdul Kumar S/o Sh. Dault Ram	11.15	9.85	13.10
Sh. Sandeep Kumar S/o Sh. Sona Ram	11.60	9.80	13.05
Sh. Charan Singh S/o Sh. Roshan Lal	11.90	9.90	14.68
Mean	11.36	9.86	13.43

Based on the results of research trial carried out for three years, it could be concluded that application of phosphorous at 20 kg P_2O_5/ha resulted in significantly higher yield, protein content, oil content, uptake and use efficiency of phosphorous, and additional returns of sesame. The results of OFT's, also revealed that the application of 20 kg P_2O_5/ha in coarse textured low to medium phosphorus status soils is optimum for higher yield, returns and maintenance of available phosphorus status in soil.

ACKNOWLEDGEMENTS

The authors are thankful to all soil scientists working in this experiment on response of phosphorus in sesame at

Regional Research Station, Bawal. The authors are also especially thankful to Regional Director, RRS, Bawal and Professor and Head, Department of Soil Science, Chaudhary Charan Singh Haryana Agricultural University, Hisar for providing facilities, technical help and necessary guidance for this study.

REFERENCES

Anonymous 2018. *Agriculture Statistics.* Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Government of India.

El- Ghamry A M, El-Hadi K M and Ghoneem K M 2009. Amino and humic acids promote growth, yield and disease resistance of faba bean cultivated in clayey soil. *Australian Journal of Basic Applied Sciences*, **3**: 731-739.

Gupta S K, Yadava T P, Parkash K and Thakral N K, Kumar P 1998. Influence of date of sowing on oil and fatty acid composition in sesame (*Sesamum indicum* L.). *Annals of Biology*, **14**: 67-68.

Hanumanthappa M and Dalavai B L 2008. Dry matter production nutrient uptake and economics of sesame (*Sesamum indicum* L.) as influenced by organic manure and fertilizer levels. *Mysore Journal of Agriculture Sciences*, **42**(4): 629-634.

Jackson M L 1967. *Soil Chemical Analysis.* Prentice Hall of India Pvt. Ltd., New Delhi, pp. 38-226.

Javia R M, Vora V D, Sutaria G S, Akbari, K N and Padmani D R 2010. Effect of nutrient management on productivity of sesame and soil fertility of sandy loam soils under rainfed condition. *An Asian Journal of Soil science*, **5**(1): 80-82.

Marschner H 1986. *Mineral Nutrition of Higher Plants.* Academic Press Inc., USA, pp. 674.

Olsen S R, Cole C W, Watanable F S and Dean L A 1954. *Estimation of available phosphorus in soils by extraction with* $NaHCO_3$. United States Department of Agriculture, pp.939.

Pandey S N and Sinha B K 1986. *Plant Physiology.* Vikas Publishing House Pvt. Ltd., New Delhi, pp. 112-130.

Patra A K 2001. Yield and quality of sesame (*Sesamum indicum* L.) as influenced by N and P during post rainy-season. *Annals of Agricultural Research*, **22**(2): 249-252.

Ravinder N, Satyanarayana V Rao, V P, Latchanna A and Varaprasad P V 1996. Influence of irrigation and fertilization on seed yield, nutrient uptake and fertilizer use efficiencies in summer sesame (*Sesamum indicum* L.). *Journal of Oilseeds Research*, **13**(2): 173-177.

Russel E W 1973. *Soil conditions and plant growth.* Language Book Society and Longman, London, pp. 30-37.

Sharma P B 2005. Fertilizer management in sesame (*Sesamum indicum* L.) based intercropping system in tawa command area. *Journal of Oilseeds Research*, **22**(1): 63-65.

Shehu H E, Kwar J D and Sandab M K 2010. Effects of N, P and K fertilizers on yield, content and uptake of N, P and K by sesame (*Sesamum indicum*). *International Journal of Agriculture and Biology*, **12**(6): 845-850.

Singh I, Nagda B L and Choudhary L S 1994. Response of sesame (*Sesamum indicum* L.) varieties to nitrogen and phosphorus. *Annals of Agricultural Research*, **15**(2): 250-251.

Thakur D S, Patel S R and Lal N 1998. Yield and quality of sesame (*Sesamum indicum* L.) as influenced by nitrogen and phosphorus in light textured inceptisols. *Indian Journal of Agronomy*, **43**(2): 325-328.

Thanki J D, Patel A M and Patel M P 2004. Effect of date of sowing, phosphorus and biofertilizer on growth, yield and quality of summer sesame. *Journal of Oilseeds Research*, **21**(2): 301-302.

Ulukan H 2008. Effect of soil applied humic acid at different sowing times on some yield components in wheat (*Triticum* spp.) hybrids. *International Journal of Botany*, **4**: 164-175.

Evaluation of conservation tillage practices for enhancing productivity of sunflower (*Helianthus annuus* L.) under rice fallow environment of Odisha

D PATEL, A MAHAPATRA, K RAMESH* AND S N JENA

Odisha University of Agriculture and Technology, Bhubaneswar-751 003, Odisha

(Received: December 21, 2019; Revised: March 25, 2020; Accepted: March 27, 2020)

ABSTRACT

Field experiment was conducted to assess the effect of conservation tillage (reduced, minimum and zero tillage) and conventional tillage with three hybrids (DRSH-1, KBSH-44, MSFH-17) and three fertility levels (50% RDF, 100% RDF and 150% RDF) on productivity of sunflower. Zero tillage recorded highest growth parameters, yield attributing characters and seed yield (1.91 t/ha), stover yield (4.36 t/ha) and oil yield (0.73 t/ha). Crop grown under zero tillage conditions was taller (165.7 cm), had more number of leaves/plant (30.3) and accumulated more dry matter (565 g/m^2). Among the hybrids, KBSH-44 recorded the highest seed yield (1.81 t/ha), stover yield (4.22 t/ha) and oil yield (0.70 t/ha). Sunflower fertilized with 150% RDF recorded significantly highest seed yield (2.09 t/ha), stover yield (5.0 t/ha) and oil yield (0.81 t/ha) as well as the highest values of yield attributing characters which were promoted by the better growth attributing characters. Sunflower hybrids under zero tillage fertilized with 150% RDF (90:120:90 kg N: P_2O_5: K_2O/ha) found most remunerative under rice fallow environment.

Keywords: Conservation tillage, Rice fallow, Seed yield, Sunflower

Appropriate land management practices that conserve soil and water coupled with integrated nutrient management would restore and ensure higher crop yields (Somasundaram *et al*., 2014). However, tillage systems are location specific and their success depends on the soil, climate and local practices. Sunflower yield greatly varies between varieties and hybrids due to differences in nutrient uptake, growth and vigour (Sheoran *et al*., 2016). Balanced fertilization (Ramesh *et al*., 2017) is one of the soil and crop management practices, which exert a great influence on seed yield. Application of NPK fertilizer above or below the optimum level adversely affects the growth and yield. Hence, balanced fertilizer application is very important for high crop yield. Therefore, this experiment was conducted with an objective to study the influence of different tillage methods and fertilization level on agronomic traits and oil yield of sunflower hybrids in rice fallow.

MATERIALS AND METHODS

A field experiment was carried out at All India Coordinated Research Project on Sunflower, OUAT, Bhubaneswar during summer 2019. The station is geographically located at 20° 12' N latitude and 85° 52' E longitude respectively with an altitude of 25.9 m above mean sea level. The experiment was laid out in a split-split plot design, replicated thrice with four tillage management in mainplot (M1-conventional, M2-reduced, M3-minimum and M4-zero); three genotypes in sub-plot (G1-DRSH-1, G2-KBSH-44 and G3-MSFH-17) along with three fertility levels in sub-sub plot [F1-50% RDF, F2-100% RDF (60:80:60 kg N: P_2O_5: K_2O/ha), F3- 150% RDF]. The hybrid DRSH-1 is of 100-105 days duration with plant height of 160-170 cm, head diameter of 15-20 cm, test weight (50-55 g), oil content of 40-44 % and seed yield potential of 20-25 q/ha. The hybrid KBSH-44 is of 95-100 days duration with plant height of >170 cm, head diameter of 14-18 cm,test weight of 45 g, oil content of 36-38 % and seed yield potential of 17.5-28 q/ha. The hybrid MSFH-17 is of 85-88 days duration with plant height of 120-150 cm, head diameter of 15-20 cm, oil content of 35-37 % and seed yield potential of 13-16 q/ha. The gross plot size was 5.5 m×3.2 m (17.6 m^2). The soil of experimental field was sandy loam having 200 kg/ha available N, 11.7 kg/ha available P, 210.0 kg/ha exchangeable K, 0.34% organic carbon and a soil pH of 5.5.

The land was prepared as per the tillage treatments, conventional tillage (two ploughings followed by twice with cultivator and once with rotavator), reduced tillage (one ploughing followed by once with cultivator and rotavator), minimum tillage (once with cultivator followed by once with rotavator) and zero tillage (herbicide spray + seed dibbling) were done after harvest of the previous rice crop. Well decomposed FYM @ 5t/ha was applied to the soil at the time of final land preparation. The fertilizer was applied as per the treatments 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 top dressing was done at 30 days after sowing (DAS) with 25% N + 50% K while the balance25% N was top dressed at

*ICAR-Indian Institute of Oilseeds Research, Hyderabad-500 030, Telangana

45 DAS. Three sunflower hybrids *viz.,* DRSH-1, KBSH-44 and MSFH-17 suitable for summer season were dibbled manually @5 kg/ha in line by maintaining 60 cm inter-row and 30 cm intra-row distance, at a depth of 3-4 cm. Gap filling and thinning was also done at appropriate stage. For weed management, glyphosate @1.0 kg a.i/ha was sprayed in zero tillage plots after harvesting of rice and pre-emergence spray of pendimethalin @ 1.0 kg/ha was done in all the plots. Two hand weedings were done at 20 DAS and 40 DAS. During experimental period, a total of five irrigations were given uniformly to all plots and irrigation was ceased at 25 days before harvesting. 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. Five plants were selected from net plot and all the observations were recorded on these plants. The data obtained were statistically analysed using the F-test (Gomez and Gomez, 1984). Critical difference (CD) values at P=0.05 were used for determining the significance of differences between means.

RESULTS AND DISCUSSION

Growth parameters: Zero tillage registered taller plants of 165.7 cm and highest total dry matter (565 g/m^2) at harvest which remained at par with minimum tillage (160 cm). Taller plants might be due to higher availability of nutrients and moisture and the better crop growth (Table 1). Better crop growth might be attributed to better residue retention, higher moisture content, lower soil temperature and less evaporation loss in zero tillage which resulted in maximum dry matter accumulation. Similar findings in maize were also reported by Ita *et al*. (2014). Zero tillage recorded highest leaf area index (LAI) (3.58) at 60 DAS. Increase in plant height of maize under zero tillage was found by Ashish (2015). Tillage practices did not influence the number of functional leaves/plant, crop growth rate (CGR) and relative growth rate (RGR) of sunflower significantly. Tillage practices did not influence the days to 50% flowering significantly in sunflower as it is a genetically determined character (Sridhar *et al*., 2012).

Hybrids showed significant variation in the growth parameters (Table1). KBSH-44 produced significantly greater plant height (175.8 cm), number of functional leaves/plant (29.7), LAI (3.70), dry matter accumulation (571 g/m^2) and CGR (12.85 g/m^2/day). The higher plant height and maximum number of leaves/plant favoured higher canopy development. It might have increased the light interception, absorption and utilization of solar radiation thus enhancing the photosynthesis which was reflected in LAI, dry matter production and CGR. These results are in agreement with those reported by Pattanayak (2015). Among the hybrids, MSFH-17 attained the days to 50 % flowering by 56 days while DRSH-1 and KBSH-44 attained it after 65.7 and 66.6 DAS respectively. A difference in days to 50% flowering among sunflower hybrids was also reported by Bakht *et al.* (2010).

Fertilization at 150% RDF produced significantly higher growth parameters like plant height of 164.6 cm, number of leaves (29.4), LAI (3.74), dry matter accumulation (606 g/m^2), CGR (14.87 g/m^2/day) over 100% RDF and 50% RDF. The LAI also increased with the increasing doses of fertilizer. Similar results have been observed by Nasim *et al.* (2017). Availability of inorganic fertilizer during the early stages of crop growth contributed positively resulting in taller plants with a greater number of leaves, higher LAI which in turn contributed to higher net photosynthesizing area that facilitated higher rate of photosynthesis resulting in higher amount of dry matter production. The findings corroborated with the findings of Khakwani *et al.* (2014). The number of days required to 50% flowering significantly decreased with increasing levels of fertility. Fertilizer applied at 150% RDF required fewer number of days (61.8) to 50% flowering as compared to rest of the fertility levels while 50% RDF required more number of days (64.1). Increase in number of days to different growth stages could be due to increased vegetative growth. This result was in conformity with earlier work done by Khakwani *et al.* (2014).

Yield attributes: Zero tillage produced significantly highest head diameter (15.5cm), head dry weight (84.54g), total number of seeds/head (829), number of filled seeds/head (731) with highest filling (87.9%) than other tillage practices (Table 2) whereas conventional tillage produced the least values. The test weight of sunflower remained unaffected due to tillage practices. This finding corroborated with the results of Sridhar *et al.* (2012). In zero tillage, retention of straw as mulch on soil surface helped to conserve soil moisture, controlled the weeds and increased the population of micro flora which helped the crop to compete with the crop sown on conventional tillage, which augments the crop yield by increasing the yield attributing characters (Gupta *et al.*, 2011).The highest head diameter of 15.7 cm, head dry weight of 83 g, total number of seeds/head (787) and filling (87.2%)was registered with KBSH-44 followed by DRSH-1 and lowest in MSFH-17. This variation in total seeds/head was due to the varietal character of the cultivars, which is governed by its genetic makeup. Similar results have been observed by Kailash (2015). Among the hybrids, the highest number of filled seeds (689) and test weight (47.5 g) was recorded with KBSH-44 followed by DRSH-1 and the least under MSFH-17. This variation might be due to differences in translocation of photosynthates to the developing seeds. It corroborated with the findings of Pattanayak (2015). The fertility level significantly influenced the yield attributes (Table2).

Table 1 Growth parameters of sunflower influenced by tillage practices, hybrids and fertility levels

Treatments		Plant height (cm) at harvest	Dry matter at harvest (g/m^2)	No of functional leaves/plant at 60 DAS	LAI at 60 DAS	CGR ($g/m^2/d$) at 45-60 DAS	RGR (g/g/d) during 45-60 DAS	Days to 50% flowering
	Tillage practices							
M1	Conventional	145.0	488	27.6	3.12	11.79	0.0570	62.9
M2	Reduced	150.2	510	26.6	3.26	12.05	0.0580	63.5
M3	Minimum	161.0	537	27.9	3.43	12.37	0.0566	62.8
M4	Zero	165.7	565	30.3	3.58	13.07	0.0548	62.5
	SEm ±	1.83	9.7	0.55	0.051	0.596	0.00083	0.56
	CD (P=0.05)	8.2	43	NS	0.23	NS	NS	NS
	Hybrids							
G1	DRSH-1	167.7	526	28.4	3.42	12.12	0.0573	65.7
G2	KBSH-44	175.8	571	29.7	3.70	12.85	0.0560	66.6
G3	MSFH-17	122.9	477	26.2	2.95	11.98	0.0565	56.5
	SEm ±	2.46	5.5	0.35	0.068	0.183	0.00061	0.48
	CD (P=0.05)	8.0	18	1.15	0.22	0.60	NS	1.6
	Fertility levels							
F1	50% RDF	146.4	437	26.5	2.98	9.32	0.0543	64.1
F2	100% RDF	155.5	532	28.3	3.42	12.77	0.0569	62.9
F3	150%RDF	164.6	606	29.4	3.74	14.87	0.0586	61.8
	SEm ±	1.81	5.7	0.39	0.065	0.257	0.00047	0.28
	CD (P=0.05)	5.3	17	1.2	0.19	0.75	0.0014	0.8

Table 2 Yield attributes of sunflower influenced by different tillage practices, hybrids and fertility levels

Treatments		Head diameter (cm)	Head dry weight (g)	Test weight (g)	No of seeds/head	Filled seeds	Unfilled seeds	Filling %
	Tillage practices							
M1	Conventional	14.4	68.78	46.0	744	638	106	85.0
M2	Reduced	14.7	76.94	46.4	746	644	101	85.7
M3	Minimum	15.2	75.84	46.2	768	669	100	86.5
M4	Zero	15.5	84.54	46.7	829	731	98	87.9
	SEm ±	0.12	1.577	0.35	9.5	13.5	1.9	0.58
	CD (P=0.05)	0.4	5.25	NS	32	45	NS	NS
	Hybrids							
G1	DRSH-1	15.1	80.73	46.86	771	673	98	86.7
G2	KBSH-44	15.7	83.01	47.5	787	689	97	87.2
G3	MSFH-17	14.1	65.85	44.6	758	649	109	84.8
	SEm ±	0.25	1.383	0.16	10.2	8.8	2.1	0.59
	CD (P=0.05)	0.8	4.51	0.52	33	29	7	1.9
	Fertility levels							
F1	50% RDF	13.6	70.81	45.8	643	437.5	118	81.5
F2	100% RDF	15.1	77.50	46.3	782	585.5	102	86.8
F3	150%RDF	16.1	81.28	46.8	891	716.3	84	90.6
	SEm ±	0.21	1.888	0.26	7.9	8.3	1.7	0.64
	CD (P=0.05)	0.6	5.51	0.5	23	24	5	1.9

Application of 150% RDF produced significantly highest head diameter (16.1cm), head dry weight (81.28 g), total number of seeds/head (891), number of filled seeds/head (716) and filling (90.6%) than the other fertility levels, whereas 50% RDF gave least values. Increased nutrient availability enhanced the uptake of nutrients, which plays a major role in seed filling. NPK fertilization leads to better assimilation of carbohydrates and increased head size (Osman and Awed, 2010). Better seed filling might be because of increased metabolic activity due to the proper utilization of phosphorus in the presence of nitrogen, which in turn increased fill percent. Khakwani *et al.* (2014) also reported enhanced number of seeds/head with increase in levels of fertilization. Test weight did not vary significantly under various fertility levels.

Yield: Zero tillage recorded significantly highest seed yield (1.91 t/ha) and stover yield (4.36 t/ha). Conventional tillage gave the least seed and stover yield of 1.63 t/ha and 3.95 t/ha respectively. 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 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 (2011). Jha *et al.* (2012) reported that 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. Aggregate stability is considered as a good indicator of soil health (Patra *et al.,* 2017). This led to higher labile C formation in soil, which improved acquisition of nutrients to the plant and finally reflected in yield. The oil content was found non-significant among the tillage practices. The highest HI of 30.45% was obtained under zero tillage. Nitrogen can increase oil content in seed via increasing vegetative growth and higher production of carbohydrate in plant and transferring to seeds. Similar results were reported by Mollashahi (2013). Zero tillage recorded significantly highest oil yield of 0.73 t/ha followed by minimum tillage which might be due to higher economic yield of sunflower as compared to other tillage practices. These findings are in conformity with those of Sridhar *et al.* (2012).

Among the hybrids, KBSH-44 recorded significantly highest seed (1.81 t/ha) and stover yield (4.22 t/ha) which was at par with DRSH-1 (1.73 and 4.16 t/ha respectively). MSFH-17 gave least seed and stover yield of 1.65 t/ha and 3.95 t/ha respectively. The highest seed yield in KBSH-44 was the result of a greater number of leaves, highest head diameter, and the maximum test weight. 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. DRSH-1 resulted in the highest oil content whereas KBSH-44 (0.7 t/ha) resulted in highest oil yield which was due to its higher seed yield. The ability of better photosynthate partitioning than other hybrids resulted in creating a favourable condition for higher oil yield. The variation in yield and oil content due to genotypes are in conformity with those reported by Bakht *et al.* (2010).

150% RDF produced significantly higher seed and stover yield of 2.09 and 5.00 t/ha respectively followed by 100% RDF (1.75 and 4.16 t/ha). The treatment 50% RDF gave least seed (1.35 t/ha) and stover yield (3.17 t/ha). The variation in yield and oil content due to fertility levels are in conformity with those reported by Bakht *et al.* (2010). The seed yield increased progressively with increasing level of fertilizer in all the hybrids as reported by Nasim *et al.* (2017). Increased seed yield of sunflower was due to increase in yield attributes like number of seeds/head, filled seeds/head, seed weight/head and test weight. Higher nitrogen availability during seedling and grand vegetative stage might have increased dry matter production and better partitioning of photosynthates resulting in improvement in yield attributes (Sridhar *et al.,* 2012). The oil content (38.43%) and oil yield (0.8 t/ha) in sunflower seeds were influenced significantly due to fertility levels. It was found highest under 150% RDF followed by 100% RDF. Increase in seed oil content (%) by adding nitrogen, phosphorous and potassium fertilization might be attributed to important role of nitrogen, phosphorous and potassium in the metabolism of lipids. Positive effect of P application on oil yield/ha could be due to the increase in seed yield/ha and seed oil content (Ali *et al.,* 2014).

Interaction effect: Interaction effect between hybrids and fertility levels as well as between hybrids and tillage methods was non-significant. The interaction between tillage methods, hybrids and fertility levels was also non-significant. Interaction effect of tillage practices and fertilizer levels was significant with respect to seed yield and oil yield where zero tillage with 150% RDF was the best combination producing highest seed yield of 2.11 t/ha and oil yield of 0.82 t/ha. While conventional tillage produced the lowest seed yield (1.17 t/ha) and oil yield (0.44 t/ha) when 50% RDF was applied.

On the basis of above findings, zero tillage during rice fallow/summer 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. Among the hybrids KBSH-44 gave the best performance and performed significantly better than existing hybrid MSFH-17. Application of 150% RDF gave higher seed and oil yield in sunflower. Growing of sunflower hybrid under zero tillage fertilized with 150% RDF (90:120:90 kg N: P_2O_5: K_2O/ha) found most remunerative combination for achieving higher yield during rice fallow/summer season in Odisha.

Table 3 Seed yield, stover yield, oil content, oil yield and harvest index of sunflower influenced by different tillage practices, hybrids and fertility levels

	Treatments	Seed yield (t/ha)	Stover yield (t/ha)	HI (%)	Oil content (%)	Oil yield (t/ha)
	Tillage practices					
M1	Conventional	1.63	3.95	29.15	37.43	0.61
M2	Reduced	1.66	4.04	29.12	37.66	0.63
M3	Minimum	1.73	4.09	29.69	38.58	0.67
M4	Zero	1.91	4.36	30.45	38.29	0.73
	SEm ±	0.035	0.051	0.575	0.332	0.012
	CD (P=0.05)	0.12	0.17	NS	NS	0.04
	Hybrids					
G1	DRSH-1	1.73	4.16	29.40	40.06	0.69
G2	KBSH-44	1.81	4.22	29.99	38.79	0.70
G3	MSFH-17	1.65	3.95	29.41	35.11	0.58
	SEm ±	0.035	0.044	0.3642	0.176	0.015
	CD (P=0.05)	0.11	0.14	NS	0.57	0.05
	Fertility levels					
F1	50% RDF	1.35	3.17	29.73	37.57	0.51
F2	100% RDF	1.75	4.16	29.57	37.97	0.67
F3	150% RDF	2.09	5.00	29.50	38.43	0.80
	SEm ±	0.024	0.051	0.360	0.123	0.008
	CD (P=0.05)	0.07	0.15	NS	0.36	0.02
	Interaction					
	M within F					
	SEm ±	0.053	0.097	0.822	0.387	0.018
	CD (P=0.05)	0.19	0.33	NS	NS	0.06
	F within M					
	SEm ±	0.049	0.101	0.720	0.245	0.017
	CD (P=0.05)	0.14	0.30	NS	NS	0.05

Table 4 Interaction of different tillage practices and fertility levels on seed and oil yield (t/ha)

Tillage practices	Fertility levels			Mean
	50% RDF	100% RDF	150%RDF	
Seed yield (t/ha)				
Conventional	1.17	1.63	2.07	1.63
Reduced	1.22	1.67	2.10	1.66
Minimum	1.38	1.71	2.09	1.73
Zero	1.62	1.99	2.11	1.91
Mean	1.35	1.75	2.09	1.73
Interaction (M×F)	SEm ±		CD (P=0.05)	
M within F	0.053		0.19	
F within M	0.049		0.14	
Oil yield (t/ha)				
Conventional	0.44	0.61	0.78	0.61
Reduced	0.46	0.63	0.80	0.63
Minimum	0.52	0.66	0.81	0.67
Zero	0.61	0.76	0.82	0.73
Mean	0.51	0.67	0.80	0.66
Interaction (M×F)	SEm ±		CD (P=0.05)	
M within F	0.018		0.06	
F within M	0.017		0.05	

REFERENCES

Bakht J, Shafi M, Yousaf M and Shah H U 2010. Physiology, phenology and yield of sunflower (autumn) as affected by NPK fertilizer and hybrids. *Pakistan Journal of Botany*, **42**(3): 1909-1922.

Gomez K A and Gomaz A A 1984. *Statistical Procedures for Agricultural Research*. John Wiley & Sons, Singapore.

Govaerts B, Verhulst N and Sayre K D 2011.The effect of tillage practices and residue management on wheat yield and yield stability in agro-ecological environments in Maxico. *In: Proceedings of 5th World Congress on Conservation Agriculture, Resilient Food System for Changing World*, 25-29 September 2011, Brisbane, Australia, pp. 71-79.

Gupta M, Bali A S, Sarabdeep Kour, Rajeev Bharat and Bazaya B R 2011. Effect of tillage and nutrient management on resource conservation and productivity of wheat (*Triticum aestivum*). *Indian Journal of Agronomy*, **56**(2): 116-120.

Hillel D 1972. *Optimizing the Soil Physical Environment Toward Greater Crop Yields.* Academic Press, New York.

Ita B N, Ariga E S, Michieka R W and Muiru W M 2014. Comparative efficiency of tillage practices in maize (*Zea mays* L.). *Current Agriculture Research Journal*, **2**(2): 89-93.

Jha P, Garg N, Lakaria B L, Biswas A K and Rao A S 2012. Soil and residue carbon mineralization as affected by soil aggregate size. *Soil and Tillage Research*, **121**: 57-62.

Kailash B A 2015. Response of sunflower (*Helianthus annuus* L.) varieties to nitrogen levels during *rabi* season. M. Sc. Thesis, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra.

Khakwani A A, Noor Sharif, Sadiq Muhammad, Awan I U, Munir Muhammad, Ghazanfarullah M B and Bakhsh I 2014. Impact of plant densities and NPK fertilization on growth and optimum economic return of sunflower. *Sarhad Journal of Agriculture*, **30**(2): 157-164.

Mollashahi M, Ganjali H and Fanaei H 2013. Effect of different levels of nitrogen and potassium on yield, yield components and oil content of sunflower. *International Journal of Farming and Allied Science*, **2**: 1237-1240.

Nasim W, Ahmad A, Ahmad S, Nadeem M, Masood N, Shahid M and Fahad S 2017. Response of sunflower hybrids to nitrogen application grown under different agro-environments. *Journal of Plant Nutrition*, **40**(1): 82-92.

Osman E B A and Awed M M M 2010. Response of sunflower (*Helianthus annuus* L.) to phosphorus and nitrogen fertilization under different plant spacing at new valley. *Assiut University Bulletin for Environmental Researches*, **13**: 11-18.

Pattanayak S 2015. Performance of summer sunflower (*Helianthus annuus* L.) hybrids under different nutrient management practices in Coastal Odisha. Ph. D. thesis, Odisha University of Agriculture and Technology, Bhubaneswar.

Ramesh K, Patra A K and Biswas A K 2017. Best management practices for soybean under soybean-wheat system to minimize the impact of climate change. *Indian Journal of Fertilisers,* **13**: 42-55.

Sapkota T B, Majumdar K, Jat M L, Kumar A, Bishnoi D K, McDonald A J and Pampolino M 2014. Precision nutrient management in conservation agriculture-based wheat production of Northwest India: Profitability, nutrient use efficiency and environmental footprint. *Field Crops Research,* **155**: 233-244.

Sheoran P, Sardana V, Singh S, Kumar A, Mann A and Sharma P 2016. Agronomic and physiological assessment of nitrogen use, uptake and acquisition in sunflower. *International Journal of Plant Production*, **10**(2): 109-122.

Somasundaram J, Lakaria B L, Saha R, Sinha N K, Jha P, Chaudhary R S, Singh R K, Manadal D, Hati K M, Ramesh K, Vassanda C, Biswas A K, Dey P, Reddy K S and Subba Rao A 2014. Management of stressed soils of dryland agriculture in semi-arid tropics-A review. *Indian Journal of Soil Conservation*, **42**: 178-187.

Sridhar K, Yakadri M, Prasad J V N S, Ramesh T, Sarawad I M, Angadi V V and Mishra 2012. Nitrogen management in rabi sunflower (*Helianthus annuus* L.) in relation to different tillage practices imposed during *kharif. Indian Journal of Dryland Agricultural Research and Development*, **27**(2): 69-72.

Effect of organic manures and site specific nutrient management practices (SSNM) in safflower (*Carthamus tinctorius* L.)

C SUDHAKAR, C SUDHA RANI, K K K REDDY[2], T RAJESHWAR REDDY, S N C V L PUSHPAVALLI[3], K SANDYA RANI AND P PADMAVATHI[4]

Agricultural Research Station, PJTSAU, Tandur-501 141, Telangana

(Received: December 24, 2019; Revised: March 21, 2020; Accepted: March 24, 2020)

ABSTRACT

A field experiment was conducted at the Agricultural Research Station, Tandur during 2014-15, 2015-16, 2016-17 and 2017-18 to evaluate the effect of FYM and site specific nutrient management (SSNM) practices in safflower. FYM was applied two weeks before sowing and fertilizers were applied to the crop based on uptake pattern, target yield and soil fertility status. The field trial was laid out in split plot design with four replications. In main plots two treatments were assigned *viz.,* M1 - No manure, M2 - FYM @ 5 t/ha and five sub plots consisted of S1 - Control (No fertilizer), S2 - Recommended NPK, S3- SSNM (STCR equation) for target yield of 1.5 t/ha, S4 - S3 + micronutrients (Zn @ 5 kg/ha + S @ 10 kg/ha), S5 - S3 + if soil is deficient add 25% more than S2, if soil is medium apply as S2 and if soil is high apply 25% less than S2. Application of FYM @ 5 t/ha (M2) resulted in significantly higher plant height (105.89 cm), primary branches (10.14), number of capitula (30.14), seed weight/plant (9.40 g), 100 seed weight (6.42 g), dry weight/plant (58.92 g), Seed yield (1377 kg/ha), biological yield (5862 kg/ha), harvest index (20.16%) and gross returns (₹39626/ha). However, net returns (₹16669/ha) and B:C ratio (2.00) was higher in no manure application. Application of fertilizers based on S4- SSNM (STCR equation) for targeted yield of 1.5 t/ha + micronutrients (Zn @ 5 kg/ha + S @ 10 kg/ha) recorded significantly higher plant height (115.07 cm), primary branches (12.23), number of capitula/plant (36.33), seed weight/plant (11.28 g), 100 seed weight (6.54 g), dry weight/plant (64.47 g), seed yield (1650 kg/ha), biological yield (6227 kg/ha), harvest index (21.81 %), gross returns (₹ 47511 /ha) and net returns (₹ 20881 /ha).

Keywords: Growth, Organic manures, Safflower, SSNM, STCR, Yield

Safflower (*Carthamus tinctorius* L.) is one of the world's oldest crop (Vargas *et al.,* 2008) grown in India with an area of 1.275 lakh ha, 53,000 tonnes production and 415.7 kg/ha productivity (CMIE, 2016). Safflower occupies an area of 4000 ha with production and productivity of 3000 tonnes and 750 kg/ha respectively in Telangana (CMIE, 2016). In India safflower is grown in *rabi*/winter dry season in mixture with other *rabi* crops, such as wheat and sorghum. Safflower has been grown in India since ancient times not only for orange red dye extracted from florets and additionally for oil. The dye is largely used for colouring purposes in food and textile industry. Safflower produces oil rich in polyunsaturated fatty acids which play essential role in reducing blood cholesterol level and is considered as a healthy cooking medium.

Several factors were found responsible for low production of safflower *viz.,* inadequate fertilizer use and emergence of multiple-nutrient deficiencies due to poor recycling. Intensification of agriculture through the use of fertilizer remains one of the dependable options for enhancing agricultural productivity in general and oilseed crops in particular. In the recent past, indiscriminate use of only major nutrients (NPK) containing chemical fertilizers has led to secondary and micronutrients deficiencies including sulphur and zinc as there is a continuing mining of secondary and micronutrients greater than the applied. Besides, lesser use of organics and greater use of high analysis chemical fertilizers resulted in unhealthy soil status. Site specific nutrient management (SSNM) is gaining popularity of late due to its superiority over blanket nutrient recommendations as it takes into account site, season and crop growth variability to take crop decision. This approach enables farmers to apply the right amount of nutrients at the right time. Nutrient application thus matches the crop demands, thereby minimizing the risk of excess application of fertilizer. It ensures balanced application of all nutrients to maintain productivity and soil quality over time. Higher dose of chemical fertilizer and agricultural chemicals but insufficient use of organics leads to negative results on fertility and productivity of soil. By and large, Indian soils show either deficiency or inadequacy in cluster of major and micronutrients. Regular and prolonged exploitation of soil resources for crop cultivation without addition of fertilizers and in adequate supply of fertilizers create nutrient imbalance in soil. Hence, the present investigation was undertaken to evaluate the effect of organic manures and site specific nutrient management practices (SSNM) in safflower.

[2]Department of Agronomy, PJTSAU, Rajendranagar-500 030, Telangana; [3]Institute of Biotechnology, PJTSAU, Rajendranagar-500 030, Telangana; [4IIOR-]Indian Institute of Oilseeds Research, Rajendranagar-500 030, Telangana; Corresponding author's E-mail: chouratsudhakar@yahoo.com

MATERIALS AND METHODS

The field experiment was carried out for consecutive four seasons during *rabi* 2014-15, 2015-16, 2016-17 and 2017-18 at Agricultural Research Station, Tandur, PJTSAU, Telangana. The experiment was laid out in split plot with four replications. The gross plot size was 43.2 m^2 (5.4m×8.0m) whereas the net plot size was 25.92 m^2 (3.6m×2m). Two main plot treatments consisted of : M1 - No Manure, M2 - FYM @ 5 t/ha and five sub plots *viz.,* S1 - Control (No fertilizer), S2 - Recommended NPK (40 kg N/ha, 25 kg P_2O_5/ha), S3- SSNM (STCR equation) for targeted yield of 1.5 t/ha, S4- S3 + micronutrients (Zn @ 5 kg/ha + S @ 10 kg/ha), S5- S3 + if soil is deficient add 25% more than S2, if soil is medium apply as recommended and if soil is high apply 25% less than recommended. Amount of fertilizers added to different treatments are presented in Table 1. Composite soil samples were collected from the experimental field before sowing and subjected to soil chemical analysis. The soil was low in organic carbon (0.37%), low in available nitrogen (218 kg/ha), medium in available phosphorous (12.8 kg/ha), high in available potassium (405 kg/ha) and low in available sulphur (10.6 ppm). Inorganic fertilizer used were urea and DAP which were applied at the time of sowing. Source of zinc and sulphur were applied in the form of zinc sulphate monohydrate and elemental sulphur. Based on these soil test values by following the principles of site specific nutrient management, the chemical fertilizers were applied. The safflower crop was sown at 45×20 cm spacing. The crop was grown completely under residual soil moisture conditions. The FYM (5 t/ha) was applied as per the treatment before two weeks of sowing. The amount of rainfall received during *kharif* was 541mm, 343 mm, 966.7 mm and 755 mm in 2014-15, 2015-16, 2016-17 and 2017-18 respectively. Rainfall received during crop period was 91 mm, 28.25 mm, 0 mm and 0 mm in 2014-15, 2015-16, 2016-17 and 2017-18 respectively. The results were analyzed by using standard procedures.

STCR equation for targeted yield for safflower crop in Vertisol at Tandur (Sudhakar *et al*., 2012)

Target yield : 1.5 t/ha

Target yield equations

F.N = 9.04 T - 0.75 S.N (O.C %)

F.P_2O_5 = 3.74 T - 0.85 S.P_2O_5 (Olsen's P_2O_5)

F.K_2O = 5.76 T - 0.50 S.K_2O (NH_4OAC - K_2O)

Where in,

F.N = Fertilizer N (kg/ha)

F.P_2O_5 = Fertilizer P_2O_5 (kg/ha)

F.K_2O = Fertilizer K_2O (kg/ha)

T = Target yield (t/ha)

S.N = Soil test value nitrogen (O.C %)

S.P = Soil test value P_2O_5 (kg/ha)

S.K = Soil test value K_2O (kg/ha)

RESULTS AND DISCUSSION

The pooled analysis (2014-15, 2015-16, 2016-17, 2017-18) of results revealed that, application of FYM @ 5 t/ha (M2) had significant influence on growth parameters of safflower and resulted in higher plant height (105.89 cm), primary branches (10.14) and dry weight/plant (58.92 g) as compared to no FYM application (Table 2). Addition of FYM is known to have favourable effect in modifying the soil environment to hold more moisture and nutrients and also increase aeration as well as the microbial activity of the soil. Better aeration and microbial activity are known to influence the uptake of nutrients and improve in growth of the crop. In our experiment the favourable effect of optimum nutrition on higher dry matter distribution in leaf, stem and capitulum resulted in higher total dry matter production. The increase in growth and growth attributes might be due to greater availability of nutrients that helped in the metabolic processes of the plant leading to greater cell division, elongation and dry matter production. Similar findings were also reported by Ram *et al.* (1992) in sunflower and Anand (2010) in sunflower and maize.

Table 1 Amount of fertilizers added to different treatments

Treatments (Sub plots)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	$ZnSO_4$ H_2O (kg/ha)	S (kg/ha)
S1: Control (No fertilizer)	-	-	-	-	-
S2: Recommended NPK	40.0	25	-	-	-
S3: SSNM (STCR equation) for targeted yield of 15 q/ha	13.3	45.22	-	-	-
S4: S3 + micronutrients (Zn @ 5 kg/ha + S @ 10 kg/ha)	13.3	45.22	-	22.70	6.60
S5: S3 + if soil is deficient add 25% more than S2, if soil is medium apply as S2 and if soil is high apply 25% less than S2	50.0	25	-	-	-

Table 2 Growth parameters of safflower as influenced by organic manures and SSNM practices

Treatment	Plant height (cm)					Primary branches					Dry weight/plant (g)				
	14-15	15-16	16-17	17-18	Pooled	14-15	15-16	16-17	17-18	Pooled	14-15	15-16	16-17	17-18	Pooled
Main plots															
M1: No manure	97.39	100.17	105.30	102.83	101.24	8.34	8.80	10.36	10.06	9.39	14.71	17.04	22.95	21.25	18.99
M2: FYM @ 5 t/ha	100.96	103.18	110.93	108.50	105.89	9.25	9.53	11.06	10.73	10.14	15.69	17.46	24.44	23.05	20.16
S.Em±	0.68	0.80	0.53	1.20	0.50	0.02	0.06	0.12	0.07	0.02	0.16	0.55	0.26	0.53	0.10
C.D (P≤0.05)	3.06	3.62	2.37	5.41	2.24	0.10	0.29	0.53	0.31	0.09	0.72	2.45	1.19	2.37	0.46
Sub plots															
S1: Control (No fertilizer)	86.33	94.09	98.31	95.93	93.38	7.75	7.91	9.16	8.86	8.42	13.47	17.25	21.78	19.97	18.12
S2: Recommended NPK	101.86	102.65	110.63	108.04	105.79	8.65	9.38	10.26	10.03	9.58	15.52	16.42	23.83	22.70	19.62
S3: SSNM (STCR equation)	109.34	108.28	115.41	113.04	111.52	9.99	10.20	12.70	12.30	11.30	16.62	18.08	25.46	23.78	20.99
S4: S3 + micronutrients (Zn @ 5 kg/ha + Sulphur @ 10 kg/ha)	111.88	111.21	119.89	117.31	115.07	10.81	10.93	13.66	13.51	12.23	17.10	18.61	26.79	24.73	21.81
S5: S3 + if soil is deficient add 25% more than S2, if soil is medium apply as S2 and if soil is high apply 25% less than S2	108.38	106.53	113.58	111.08	109.89	9.08	9.90	11.48	11.30	10.44	16.20	17.38	24.51	23.16	20.31
S.Em±	1.17	2.04	1.14	1.17	0.65	0.07	0.18	0.32	0.30	0.10	0.37	0.66	0.53	0.55	0.20
C.D (P≤0.05)	3.43	5.97	3.31	3.41	1.89	0.21	0.52	0.94	0.87	0.30	1.07	1.93	1.53	1.62	0.60
Interaction	NS	NS	S	S	S	S	NS	NS	NS	S	NS	NS	NS	NS	NS

Application of fertilizers based on SSNM (STCR equation) for targeted yield of 1.5 t/ha + micronutrients [Zn @ 5 kg/ha + S @ 10 kg/ha (S4)] recorded significantly higher yield parameters *viz*., taller plant height (115.07 cm), higher primary branches (12.23) and more dry weight/plant (64.47 g) (Table 2). The improvement in growth attributes might be due to proper nourishment of crop which helped in acceleration of various metabolic processes and optimum growth. The present findings are in conformity with that of Subramaniyan et al. (2001), Anand (2010), Veeramani *et al.* (2012) and Rahevar *et al.* (2017). The higher total dry matter might be due to the improvement in plant growth parameters as a result of increased nutrient concentration in plant parts which are the constituent of proteins, chlorophyll etc. which in turn resulted in increased synthesis of carbohydrates that are being utilized for build-up of new cells and their accumulation leading to higher dry matter production. Similar results were also reported by Subramaniyan *et al.* (2001), Anand (2010), Veeramani *et al.* (2012) and Bholanath Saha *et al.* (2015).

Table 3 Yield attributes of safflower as influenced by organic manures and SSNM practices

Treatment	No of capitula/plant					Seed weight/plant (g)					100-seed weight				
	14-15	15-16	16-17	17-18	Pooled	14-15	15-16	16-17	17-18	Pooled	14-15	15-16	16-17	17-18	Pooled
Main plots															
M1: No manure	25.69	25.75	29.15	27.75	26.99	12.03	10.59	10.36	10.06	9.39	6.62	6.32	6.31	6.05	6.33
M2: FYM @ 5 t/ha	29.84	29.92	30.79	29.58	29.92	14.15	11.66	11.06	10.73	10.14	6.63	6.43	6.43	6.18	6.42
S.Em ±	0.17	0.24	0.83	0.79	0.37	0.17	0.40	0.12	0.07	0.02	0.01	0.02	0.05	0.05	0.02
C.D (P≤0.05)	0.77	1.08	3.72	3.57	1.67	0.78	1.81	0.53	0.31	0.09	0.05	0.09	0.21	0.21	0.07
Sub plots															
S1: Control (No fertilizer)	21.72	26.71	26.71	25.14	23.81	10.39	10.60	9.16	8.86	8.42	6.58	6.23	6.24	5.98	6.26
S2: Recommended NPK	28.16	28.78	28.78	27.34	28.00	13.29	13.20	10.26	10.03	9.58	6.61	6.41	6.39	6.13	6.38
S3: SSNM (STCR equation)	33.43	34.43	34.43	33.51	33.54	15.60	14.13	12.70	12.30	11.30	6.67	6.48	6.49	6.24	6.47
S4: S3 + micronutrients (Zn @ 5 kg/ha + Sulphur @ 10 kg/ha)	36.23	36.98	36.98	36.44	36.17	17.26	11.46	13.66	13.51	12.23	6.76	6.54	6.54	6.30	6.54
S5: S3 + if soil is deficient add 25% more than S2, if soil is medium apply as S2 and if soil is high apply 25% less than S2	30.42	32.65	32.65	30.66	31.14	14.54	9.58	11.48	11.30	10.44	6.63	6.44	6.43	6.19	6.42
S.Em ±	0.76	0.76	1.22	1.05	0.64	0.37	0.60	0.32	0.30	0.10	0.02	0.03	0.03	0.03	0.01
C.D (P≤0.05)	2.21	2.21	3.56	3.05	1.86	1.07	1.75	0.94	0.87	0.30	0.05	0.09	0.09	0.09	0.03
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	S	NS	NS	NS	NS	NS

Table 4 Seed yield (kg/ha), biological yield (kg/ha) and harvest index (%) as influenced by organic manuring and SSNM in safflower

Treatment	Seed yield (kg/ha)					Biological yield (kg/ha)					Harvest index (%)				
	14-15	15-16	16-17	17-18	Pooled	14-15	15-16	16-17	17-18	Pooled	14-15	15-16	16-17	17-18	Pooled
Main plots															
M1: No manure	1307	1089	1163	1052	1153	7510	5253	3863	3870	5124	14.71	17.04	22.95	21.25	18.99
M2: FYM @ 5 t/ha	1518	1229	1510	1251	1377	8086	5829	4653	4159	5682	15.69	17.46	24.44	23.05	20.16
S.Em ±	8.67	43.0	40.6	25.6	5.48	70.9	70.0	158	86	27.2	0.16	0.55	0.26	0.53	0.10
C.D (P≤0.05)	39	195	183	115	24.7	319	315	711	388	122	0.72	2.45	1.19	2.37	0.46
Sub plots															
S1: Control (No fertilizer)	1105	1011	1071	967	1038	7095	4838	3803	3840	4894	13.47	17.25	21.78	19.97	18.12
S2: Recommended NPK	1432	1088	1293	1158	1243	7787	5530	4132	3954	5351	15.52	16.42	23.83	22.70	19.62
S3: SSNM (STCR equation)	1700	1378	1645	1330	1513	8511	6254	4837	4249	5963	16.62	18.08	25.46	23.78	20.99
S4: S3 + micronutrients (Zn @ 5 kg/ha + Sulphur @ 10 kg/ha)	1843	1529	1793	1437	1650	8940	6683	4918	4366	6227	17.10	18.61	26.79	24.73	21.81
S5: S3 + if soil is deficient add 25% more than S2, if soil is medium apply as S2 and if soil is high apply 25% less than S2	1547	1214	1561	1262	1396	7998	5741	4826	4175	5685	16.20	17.38	24.51	23.16	20.31
S.Em ±	38.6	59.0	44.2	47.6	23.5	112	120	177	82	64.7	0.37	0.66	0.53	0.55	0.20
C.D (P≤0.05)	112	172	129	139	68.7	352	304	518	239	189	1.07	1.93	1.53	1.62	0.60
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 5 Gross returns (₹/ha), Net returns (₹/ha) and B:C ratio as influenced by organic manures and SSNM practices in safflower

Treatment	Gross returns (₹/ha)					Net Returns (₹/ha)					B:C Ratio				
	14-15	15-16	16-17	17-18	Pooled	14-15	15-16	16-17	17-18	Pooled	14-15	15-16	16-17	17-18	Pooled
Main plots															
M1: No manure	38548	31593	33151	29455	33187	22030	15075	16633	12937	16669	2.32	1.91	1.98	1.77	2.00
M2: FYM @ 5 t/ha	44779	35643	43038	35045	39626	18861	9725	17120	9127	13708	1.71	1.37	1.65	1.35	1.52
Sub plots															
S1: Control (No fertilizer)	32588	29326	30526	27087	29882	13438	10176	11376	7937	10732	1.78	1.59	1.61	1.45	1.61
S2: Recommended NPK	42248	31566	36862	32421	35774	21230	10548	15844	11403	14756	2.09	1.57	1.81	1.60	1.77
S3: SSNM (STCR equation)	50156	39962	46895	37241	43563	26670	16476	23409	13755	20077	2.18	1.75	2.03	1.63	1.90
S4: S3 + micronutrients (Zn @ 5 kg/ha + Sulphur @ 10 kg/ha)	54363	44341	51101	40239	47511	27733	17711	24471	13609	20881	2.09	1.70	1.95	1.54	1.82
S5: S3 + if soil is deficient add 25% more than S2, if soil is medium apply as S2 and if soil is high apply 25% less than S2	45649	35206	44490	35351	40174	24164	13721	23005	13866	18689	2.21	1.70	2.12	1.70	1.93

FYM application had significant influence on yield parameters of safflower as compared to no FYM application. Application of FYM @ 5 t/ha (M2) produced higher yield parameters *viz.,* number of capitula (30.14), seed weight/plant (9.40 g), 100 seed weight (6.42 g), seed yield (1377 kg/ha), biological yield (5862 kg/ha) and harvest index (20.16) (Table 3 and 4). The superiority in yield attributes was mainly due to improvement in growth parameters. Application of organic manure increased the total dry matter production and its accumulation into various plant parts. The results are in conformity with findings of Patel *et al.* (2007), who have reported that increase in groundnut yield due to the effect of FYM attributed to release of macro and micronutrients during mineralization and carbon which supplies energy to microbes for their activities and favour decomposition of organic matter which also acts as source of energy for soil micro flora. Microbial activity is known to bring about chelation of micronutrient cations. Application of fertilizers (S4) based on SSNM (STCR equation) for targeted yield of 1.5 t/ha + micronutrients (Zn @ 5 kg/ha + S @ 10 kg/ha) recorded higher number of capitula (36.33), seed weight/plant (11.28 g), 100 seed weight (6.54 g), seed yield (1650 kg/ha), biological yield (6227 kg/ha) and harvest index (21.81) (Table 3 and 4). Enhancement in yield usually depends upon the total dry matter produced and its distribution among different parts of the plant. This was mainly due to the application of a balanced and optimum quantity of nutrients at the root zone that enable the crop to utilize and put higher total dry matter accumulation which translocates into sink (Mahesh *et al.,* 2017 and Qureshi *et al.,* 2016). This might have contributed to the increase in the yield attributes. Similar reports of an increase in yield were noticed by Mishra *et al.* (1995), Reddy and Sudhakara Babu (1997) and Biradar *et al.* (2016). The higher yield may be attributed to higher total dry matter accumulation which in turn might be due to the availability of balanced and higher nutrition (available nitrogen, phosphorus, potassium as well as zinc and sulphur) their uptake and translocation to the reproductive parts and their cumulative effect on improvement in yield attributing characters. Similar results were obtained by Mishra and Vyas (1992), Subramaniyan *et al.* (2001), Anand *et al.* (2017) and Rahevar *et al.* (2017).

Application of FYM @ 5 t/ha (M2) registered higher gross returns (₹39,626/ha). However, net returns (₹ 16,669/ha) and B:C ratio (2.00) was higher in no manurial treatment (M1) (Table 5). The cost incurred on FYM application reduced B:C ratio. Application of fertilizers based on S4 - SSNM (STCR equation) for target yield of 1.5 t/ha + micronutrients (Zn @ 5 kg/ha + S @ 10 kg/ha) recorded higher gross returns (₹47,511 /ha) and net returns (₹ 20,881 /ha) (Table 5). This was due to higher economic yield in these treatments. Similar results of economic benefits have been reported by Prasad and Singh (2002), Reddy *et al.* (2002) and Thavaprakash and Malligawad (2002) in sunflower and Anand (2010) in chickpea and maize. Higher B:C ratio was recorded in S5 (S3 + if soil is deficient add 25% more than S2, if soil is medium apply as S2 and if soil is high apply 25% less than S2). The interaction between manure and fertilizer combinations did not show any significant difference. The above results established that application of FYM @ 5 t/ha along with fertilizers based on SSNM (STCR equation) for targeted yield of 1.5 t/ha + micronutrients (Zn @ 5 kg/ha + S @ 10 kg/ha) resulted in higher yield and profitability in safflower.

REFERENCES

Anand S R 2010. Site specific nutrient management (SSNM) for maximization of crop productivity in southern Karnataka. Ph.D. Thesis, UAS, Bangalore.

Anand S R, Vishwanatha J and Rajkumar R H 2017. Site specific nutrient management using "nutrient expert" for hybrid maize (Zea mays L.) under zero tillage in Thungabhadra project (TBP) command area of Karnataka. *International Journal of Current Microbiology and Applied Sciences*, **6**(8): 3597-3605.

Biradar D P, Aladakatti Y R, Rao and Tiwari K W 2016. Site specific nutrient management for maximization of crop productivity in Northern Karnataka. *Better Crops International*, **90**(3): 33-35.

Bholanath Saha, Sushanta Saha, Hazra G C and Biswapati Mandal 2015. Effect of Zn, B and S on the yield and quality of groundnut, *Legume Research*, **38**(6): 832-836

CMIE 2016. http://commodities.cmie.com.

Mahesh C M, Dwivedi B S and Datta S P 2017. Site-specific nutrient management is a key for enhancing productivity of rapeseed-mustard in India. *Journal of Oilseed Brassica*, **8**(2): 95-105.

Mishra A P, Dash and Palkaray R K 1995. Yield and nutrient uptake by winter sunflower (*Helianthus annuus* L.) as influenced by nitrogen and phosphorous. *Indian Journal of Agronomy*, **40**(1): 137-138.

Mishra C M and Vyas M D 1992. Response of fertilizer application on groundnut in West Nimar Region of Madhya Pradesh. *Bharatiya Krishi Anusandhan Patrika*, **7**(4): 251-254.

Patel B T, Patel J J and Patel M M 2007. Responses of groundnut (*Arachis hypogaea* L.) to FYM, sulphur and micronutrients and their residual effect on wheat (*Triticum aestivum* L.). *Journal of Soils and Crops*, **17**(1): 18-23.

Prasad K and Singh L 2002. Effect of fertility levels and incorporation of potato haulms on yield and profit of sunflower. *Crop Research*, **20**: 541-543.

Qureshi A D K, Singh Pandey, P C, Singh, V P and Raverkar K P 2016. Site specific nutrient management approaches for enhancing productivity and profitability in rice and wheat under rice-wheat cropping system. *International Journal of Agricultural Sciences*, **8**(54): 2838-2842.

Rahevar H D, Patel P P, Joshi, S K and Vaghela S J 2015. Effect of FYM, iron and zinc on growth and yield of summer groundnut (*Arachis hypogaea* L.) under North Gujarat Agro-climatic conditions. *Indian Journal of Agricultural Research*, **49**(3): 294-296.

Ram G, Patel J K, Chaurra, N K and Choudhary K K 1992. Single and combined effect of bio, organic and inorganic fertilizers on yield of sunflower and soil properties under rainfed condition. *Advances in Plant Sciences*, **5**(1): 161-167.

Reddy B N and Sudhakara Babu 1997. Effect of levels of nutrients on sunflower and their residual effect on productivity, economics, land use and profit efficiency of *rabi* crops in sequence. *Journal of Oilseeds Research*, **14**(1): 47-50.

Reddy S S, Yadahalli Y H, Kumar, V K, Kumar O and Boraiah B 2002. Effect of fertilizer, gypsum and boron on drymatter accumulation, yield and nutrient content in sunflower hybrids. *Karnataka Journal of Agricultural Sciences*, **15**(3): 569-572.

Subrahmaniyan K, Kalaiselvan P and Arulmozhi N 2001. Response of confectionery groundnut to micronutrients. *Legume Research*, **24**(2): 139-140.

Sudhakar C, Sudha Rani C, Patibanda A K, Reddy D V R, Riyazuddin S A 2012. Soil test based prescriptions for safflower on Vertisols in southern Telangana region of Andhra Pradesh region of India. *Journal of Oilseeds Research*, **29** (special issue): 292-295.

Thavaprakash N and Malligawad L H 2002. Effect of nitrogen and phosphorus levels and ratios on yield and economics of sunflower. *Research on Crops*, **3**: 40-43.

Vargas R I, Stark J D, Hertlein M and Speirs R D 2008. Evaluation of SPLAT with spinosad and methyl Eugenol or Cue-Lure for attract and kill of oriental and melon fruit flies (Diptera: Tephritidae) in Hawaii. *Journal of Economic Entomology*, **5**(10): 936-940.

Veeramani P and Subrahmaniyan K 2012. Physical and economic optimum of response model for NPK application in irrigated groundnut (*Arachis hypogaea* L.). *Madras Agricultural Journal*, **99**: 526-529.

Impact of frontline demonstration (FLD) and trainings on knowledge and adoption level of mustard growers of Western Rajasthan

M L MEHRIYA[1*], R L BHARDWAJ[1], M KUMAR[1], I SINGH[1] AND J R VERMA[1]

[1]Agricultural Research Station, Mandor, Agriculture University, Jodhpur-342 304, Rajasthan

(Received: December 17, 2019; Revised: March 4, 2020; Accepted: March 6, 2020)

ABSTRACT

Agricultural Research Station, Mandor organized five, two days on-campus trainings, 100 frontline demonstrations (FLDs) and five field days for selected 480 mustard growers during 2016-17. One hundred farmers comprising of 20 from each block i.e. Nagaur, Maulasar, Jalore, Barmer and Jodhpur were selected purposively for the study. It was observed that the farmers adopted new high yielding variety, seed treatment, crop rotation, integrated nutrient management, plant protection measures and used recommended seed rate after undergoing the trainings. The results also revealed that due to enhanced knowledge and adoption of scientific practices, the yield of mustard increased from 11.1 to 29.2% over the yield obtained under farmer's practices during the year 2016-17. The extension gap (167-416 kg/ha), technological gap (84-967 kg/ha) and technology index (4.20-42.04%) exhibited the feasibility of demonstrated technology. The farmers under medium and higher level of knowledge groups increased from 20 to 52% and from 15 to 31%, respectively. Besides, the adoption level increased from 18 to 63% and 9 to 17% in medium level and high level, respectively. Further, farmers under low level of adoption declined from 73 to 20%. Thus, this study suggests the need of conducting intensive trainings and FLDs to educate the mustard growers for achieving higher production of mustard in the western districts of Rajasthan.

Keywords: Adoption, Impact, Knowledge, Mustard, Technology dissemination, Training

Mustard (*Brassica juncea* L., Czern and Coss) is the second most important oil seed crop in India after soybean. It accounts for nearly 20-22% of the total oilseeds produced in the country. Globally, with 21.6% production, India has become the leading rapeseed-mustard growing country (USDA, 2016). Indian mustard is mainly used for extraction of mustard oil. Rajasthan and Uttar Pradesh are the major mustard producing states in the country. The total area under mustard cultivation in Rajasthan is 26.0 lakh ha with a production of 38.0 lakh tonnes having 1521 kg/ha productivity. Mustard crop is mostly cultivated in North-eastern districts where Bharatpur, accounts for 48% of total production of the State. Mustard is also an important crop of Jodhpur, Nagaur, Jalore and Barmer districts, where farmers grow mustard due to its low water requirement. But in these areas, the yield levels are low compared to state level yield. Low yield of mustard was due to weather variations, monsoon failure, low adoption of improved varieties, plant protection measures, weed management practices, nutrient management and low level of knowledge of farmers. Central and state government endeavoured to enhance the mustard production through several incentives i.e. adoption of recommended technologies by the farmers and by overcoming the production constraints (Anonymous, 2013). In spite of best possible efforts of the Central and State Governments to increase the income of farmers there is a wide gap between technology available at research centre and its use by the farmers. Therefore, it is very crucial to know the knowledge, adoption, attitude and problems associated with mustard production by the farmers and efforts should be made to minimise the problems for adoption of new technologies of mustard cultivation. Keeping this as the goal, FLDs and trainings were organised by Agricultural Research Station, Mandor at different Krishi Vigyan Kendras of Western Rajasthan for technology transfer among mustard growers. The present study was conducted to assess the impact of trainings and FLDs, on the potential yield and demonstration yield, extension gaps, technological gap, technological index, knowledge and adoption level of farmers.

MATERIALS AND METHODS

The FLDs on mustard were conducted at farmer's fields in different villages of Nagaur, Maulasar, Jalore, Barmer and Jodhpur blocks of arid region of Rajasthan during *rabi* season of 2016-17 and 2017-18 under irrigated conditions. The soils of the area under study were sandy loam to loam, poor in fertility status and water holding capacity. Two days training programme entitled "Improved production technologies for mustard in Western Rajasthan" was conducted at ARS Mandor, Jodhpur in which 125 farmers participated. Training schedule was arranged with theory and practical classes for 5 to 6 hour/day by 3 to 4 experts of different fields. The respondents for the study were selected through equal allocation from each block using purposive sampling technique for representing the whole area (Cochran and Cox, 1950). The responses were collected from 20

*Corresponding author's E-mail: mlmehriya@gmail.com

mustard growers from each block with a total sample of 100 respondents.

FLDs were conducted to study the gaps between the potential yield and demonstration yield, extension gap and technology index. One hundred FLDs covering an area of 40 ha were laid out in different blocks with selected mustard growers. In the present study, the data on seed yield were collected from FLD plots. Besides, data on commonly adopted practices by the farmers were also collected.

In demonstration plots, a few critical inputs in the form of quality seed, balanced fertilizers, agro-chemicals etc. were provided and non-monetary inputs like timely sowing, line sowing and timely weeding were also performed. Whereas, traditional practices were adopted in case of local checks. The demonstration farmers were guided by the scientists of KVK and ARS in performing field operations like sowing, spraying, weeding, harvesting etc. during the course of training and visits. The technologies demonstrated and local practices are mentioned in Table 1. Proper monitoring and supervision of the FLD plots were conducted from sowing to harvesting by frequent visits and suitable suggestions were given whenever required. Five field days were organised at pre-harvest stage of the crop for popularization of improved agro-techniques among mustard growers (Table 1). The materials of the present study with respect to FLDs and farmers' practices are presented in Table 2.

Table 1 Details of the trainings, field days and FLDs on improved cultivation method of mustard

Area/ Block of FLD	Name of extension activity	Number of participant farmers		
		Men	Women	Total
	Training on improved production technologies for mustard	43	3	46
Nagaur	Front Line Demonstrations	13	7	20
	Field Day	120	17	137
	Training on improved production technologies for mustard	25	10	35
Maulasar	Front Line Demonstrations	17	3	20
	Field Day	107	16	123
	Training on improved production technologies for mustard	22	13	35
Jalore	Front Line Demonstrations	11	9	20
	Field Day	77	14	91
	Training on improved production technologies for mustard	20	0	20
Barmer	Front Line Demonstrations	14	6	20
	Field Day	53	6	59
	Training on improved production technologies for mustard	15	12	27
Jodhpur	Front Line Demonstrations	20	0	20
	Field Day	43	27	70
	Training on improved production technologies for mustard	125	38	163
Total	Front Line Demonstrations	75	25	100
	Field Day	400	80	480

Table 2 Particulars showing the details of mustard cultivation practices under FLD and existing practices

Operation	Existing practice	Improved practices demonstrated
Use of quality seed	Local seed/old varieties like Pusa bold, T 59, Bio 902	Improved varieties NRCDR-2,NRCHB-101 and RH-406
Seed treatment	None	Seed treatment with Apron 35 SD @ 2.5g/kg seed
Sowing method	Broadcasting	Line sowing at 45x15 cm by tractor operated seed drill followed by thinning at 30 DAS
Fertilizer application	20 N: 0 P : 0 K (kg/ha)	60 N:40 P: 0 K: 20 S (kg/ha) Urea in two split doses. Foliar spry of thiourea @1g/l of water at 40 DAS
Control of mustard aphid	No any control measure	One spray of malathion 50EC @ 1225 ml/ha
Control of white rust disease	No any control measure	Seed treatment, removal of crop debris, spray of Metalaxyl 8% + Mancozeb 64% WP @ 2.0 g/l with 600-700 litres of solution/ha at 60-80 DAS.

A survey questionnaire was designed to capture most of the variables that would show efficiency in various levels of production technology development and transfer. This approach resolved major analytical problem of differences between technology and knowledge (Sanyang *et al.,* 2008). One hundred mustard grower's respondents of the selected five blocks were interviewed in the year 2017-18. After collection of data, a tally sheet was prepared which facilitated the enumeration of answer of each question.

By using descriptive statistics, the data were analysed by calculating simple mean and percentages. To estimate the extension gap, technology gap and the technology index, the following formulae were used (Samui *et al.,* 2000).

Extension gap = Demonstration yield - Farmers yield

Technology gap = Potential yield - Demonstration yield

$$\text{Technology index} = \frac{\text{(Potential yield - Demonstration yield)}}{\text{Potential yield}} \times 100$$

RESULTS AND DISCUSSION

Effect on knowledge and adoption level of technologies: In order to assess the impact of training programmes on the knowledge level of farmers regarding mustard cultivation practices, the data were collected pre- and post- training programme (Table 3). It was observed that initially 65% farmers were possessing low, 20% medium and 15% high level of knowledge whereas after acquiring training, the values were 17% for low, 52% for medium and 31% for high level of knowledge. Thus, our results indicated that there was considerable increase in the knowledge level of farmers who attended the on-campus training as well as field days. These results corroborated with the findings of Bhardwaj *et al.* (2013) and Meena and Gupta (2016).

Table 3 Change in knowledge level of farmers before and after training

Knowledge level	Pre-training	Post-training	Increase (%)
Low	65	17	-73.84
medium	20	52	160
High	15	31	106

Demonstration of various production technologies resulted in increased level of adoption, thus confirming the notion that "Seeing is believing" (Table 4). The data showed that 73% of the farmers had low level of adoption before the trials and that got reduced to 20% after the trainings and FLDs. The overall knowledge level and adoption level of the farmers about package of practices of mustard had increased by 72.6% in low level adoption category, up to 250 % in medium level adoption and up to 88 % in high level adoption after acquiring training and conductance of FLDs. The farmers took keen interest in observing the performance of new and improved varieties and at the same time all the farmers were aware about seed rate, time of sowing, weeding, harvesting and storage practices (Table 5). The knowledge was quite low with regard to physiological aspects of crop management and bio-fertilizers. These findings were in agreement with Alagukannan *et al.* (2015) in banana, Tandel *et al.* (2015) in sapota, Khajuria *et al.* (2016) in chilli and Morwal *et al.* (2019) in ber.

Table 4 Change in adoption level of scientific cultivation technology of mustard

Category	Before training (%)	After training (%)	% increase
Low level	73	20	-72.6
Medium level	18	63	250
High level	09	17	88

Table 5 Knowledge level of farmers about package of practices of mustard after intervention

Particulars	Knowledge level		
	Low	Medium	High
High yielding varieties	13	19	68
Field preparation	8	10	82
Seed treatment	2	12	86
Crop rotation	10	20	70
Time of sowing	6	23	69
Seed rate and spacing	16	18	66
Manure, Bio-fertilizer and Chemical fertilizers	18	5	77
Irrigation scheduling	27	12	61
Weeding	5	12	83
Plant protection measures	15	12	73
Physiological aspects	22	38	40
Integrated nutrient management	27	20	53
Harvesting, thrashing and storage	8	13	81
Grading and drying	32	44	14
Packing and marketing	28	35	37

The knowledge level of farmers regarding mustard cultivation practices increased significantly from low to high category (Table 5). Large number of farmers have sufficient knowledge about all package of practices of mustard viz., use of high yielding varieties (68%), field preparation (82%), seed treatment (86%), crop rotation (70%), time of sowing (69%), seed rate and spacing (66%), manure, bio-fertilizer and chemical fertilizers (77%), irrigation scheduling (61%), weeding (83%), plant protection measures (73%), integrated nutrient management (40%), harvesting, threshing and storage (53%), grading and drying (81%). These findings were in agreement with that of Borate *et al.*

(2012), Changadeya *et al.* (2012), Meena and Gupta (2016). Joseph (2008) also reported that the knowledge levels increased for weeding, fertilizer application, plant protection measures and harvesting practices of maize after attending the training programmes.

Data reveal that the gain in knowledge level of farmers about package of practices of mustard after intervention increased appreciably *viz.,* high yielding varieties (45%), field preparation (35%), seed treatment (71%), crop rotation (60%), time of sowing (29%), seed rate and spacing (50%), manure, bio-fertilizer and chemical fertilizers (49%), irrigation scheduling (34%), weeding (56%), plant protection measures (58%), integrated nutrient management (26%), harvesting, threshing and storage (49%), grading and drying (10%) (Table 6). In contrary to it, the knowledge acquired by the beneficiary farmers was high but its adoption was less for the technologies. This implies that still more awareness on this technology has to be imparted to the farmers. This finding was in agreement with Dubey *et al.* (2010) in black gram, Singh *et al.* (2014) in Pusa basmati, Alagukannan *et al.* (2015) in banana and Morwal *et al.* (2019) in ber. Mundial (2008) reported that new agricultural technologies are often correlated with risks and uncertainties about proper application, scale appropriateness and suitability with the prevailing environment, and importantly with farmers' perceptions and expectations. These factors may be responsible for low adoption by farmers' inspite of high knowledge.

Table 6 Effect of intervention on gain in knowledge of mustard growers about package of practices of mustard

Particulars	Knowledge level (%)		
	Before intervention	After intervention	Gain in knowledge
High yielding varieties	23	68	45
Field preparation	47	82	35
Seed treatment	15	86	71
Crop rotation	10	70	60
Time of sowing	40	69	29
Seed rate and spacing	16	66	50
Manure, Bio-fertilizer and Chemical fertilizers	28	77	49
Irrigation scheduling	27	61	34
Weeding	27	83	56
Plant protection measures	15	73	58
Integrated nutrient management	27	53	26
Harvesting, thrashing and storage	32	81	49
Grading and drying	17	27	10
Packing and marketing	11	37	26

Yield gap analysis of mustard cultivation: Results of FLDs (Table 7) revealed that the yield performance of variety NRCDR 2 grown under the Nagaur condition was 1975 kg/ha which was 18.6 % higher over farmer's practices (1665 kg/ha). Similarly, mustard variety NRCHB 101 grown in Maulasar area showed 11.1% higher yield over the local variety used by farmers. Respective increases in seed yield in variety RH 406 in Jalore, Barmer and Jodhpur were 14.3, 14.9 and 29.2%. The results also showed that due to enhanced knowledge and adoption of scientific practices, the yield of mustard increased by 17.6% over the yield obtained under farmers' practices during the year 2016-17. The results further indicated that the B:C ratio of mustard cultivation enhanced up to 3.41, 2.50, 1.65, 1.68 and 3.28 in comparison to 3.09, 2.36, 1.57, 1.51, and 2.63 in local check at Nagaur, Maulasar, Jalore, Barmer and Jodhpur, respectively.

Economic analysis of the yield performance revealed that crop in FLDs grown with recommended practices recorded higher mean gross monetary return (₹58,923/ha) and additional net monetary return (₹7,166/ha) with higher benefit cost ratio (2.50) as compared to farmers practices (2.23). These results are in accordance with the findings of Nandal and Ojha (2012) and Bhardwaj *et al.* (2013). Increase in mustard yield due to FLDs had very good impact on the farming community of all Districts as they were motivated towards adoption of new agricultural technologies applied in the FLD plots (Table 7). Fluctuations in yields were due to variations in prevailing social, economic and prevailing micro agro-climatic conditions of that particular village. Yield enhancement in different crops in FLDs has been documented by Patel *et al.* (2009), Dubey *et al.* (2010) and Morwal *et al.* (2019).

Moreover, farmers co-operated enthusiastically in carrying out of FLDs which led to encouraging results. Results revealed an extension gap of 310 kg/ha in NRCDR 2 at Nagaur, 190 kg/ha in NRCHB 101 at Maulasar, 167 kg/ha in RH 406 at Jalore, 173 kg/ha at Barmer, 416 kg/ha at Jodhpur including average of 251 kg/ha. More and more use of latest production technologies with high yielding varieties will subsequently change the alarming trend of high extension gap. This study emphasized the need to educate the farmers through various means for the adoption of improved agricultural production technologies to reverse this trend of wide extension gap. The technology gap of 238 kg/ha at Nagaur, 84 kg/ha at Maulasar, 958 kg/ha at Jalore, 967 kg/ha at Barmer, 415 kg/ha at Jodhpur and average 533 kg/ha was observed with respective varieties. It may be attributed to differences in the soil fertility status, agricultural practices, local climate conditions, rainfed agriculture and timeliness of availability of inputs. Hence, variety-wise location specific recommendation is necessary to minimize the technology gap for yield level in different farming situations.These findings are in agreement with Patel *et al.* (2009) in mustard, Dubey *et al.* (2010) in black gram, Bhardwaj *et al.* (2013) in fennel and Morwal *et al.* (2019) in ber.

The results of technology index depicted in Table 8, revealed that the technology index value was 10.8% in NRCDR 2 at Nagaur, 4.2% in NRCHB 101 at Maulasar, 41.7% in RH 406 at Jalore, 42.1% at Barmer, 18.04% at Jodhpur. The average value of technology index was 24.0%. The results of the present study were in consonance with the findings of Patel et al. (2009) in mustard, Hiremath and Nagarajuna (2009) in case of onion crop, Khajuria *et al.* (2016) in chilli. Nandal and Ojha (2012) and Bhardwaj *et al.* (2013) who reported that the training of farm women for adoption of primary processing and value addition of farm produce at farmers' level increased market rate of produce and minimize technology gap and extension gap. The results emphasized the need to educate the farmers through various means like training, demonstration and exposure visit for adopting mustard growing technologies to reverse this trend of wide extension gap. When more and more farmers adopt the improved technology, it will subsequently change this alarming trend of extension, technological gap and will minimise technology index.

Therefore, it could be concluded that knowledge and adoption level of the farmers was enhanced after imparting training and conducting FLDs. FLD and farmers training leads to adoption of recommended practices. The productivity gain under FLDs over farmer's practice created awareness and motivated other farmers to adopt improved crop management practices and high yielding variety of mustard in the Districts. Thus, timely training and well framed FLD conducted under the close supervision of scientists are the most important tools of extension to demonstrate newly released crop production and protection technologies and its management practices in the farmers' field under different agro-climatic regions and farming situations. Trainings and FLDs are playing important role in motivating the farmers for adoption of improved agriculture technology resulting in increased seed yield and profits.

Table 7 Exploitable productivity, technology gaps, technology index, extension gaps and cost benefit ratio of mustard as grown under FLD and existing package of practices (N=100, 20 from each block)

Area/ Block of FLD	Varieties used in IP	Situation Irrigated/ Rainfed	Varieties used in FP	Mean yield (kg /ha)		YIOFP (%)	Dist. (in which FLD conducted) productivity (kg/ha)	State (in which FLD conducted) productivity (kg/ha)	COC (Rs/ha)		GMR (₹ha)		ANMR (₹ha)	B:C Ratio	
				IP	FP				IP	FP	IP	FP		IP	FP
Nagaur	NRCDR 2	Irrigated	Pusa bold	1975	1665	18.60	1208	1521	19650	18300	67150	56610	9190	3.41	3.09
Maulasar	NRCHB 101	Irrigated	T59/ Bio 902	1916	1726	11.05	1208	1521	26000	24800	65174	58709	5265	2.50	2.36
Jalore	RH 406	Irrigated	Non Descript	1342	1175	14.28	1013	1521	28500	26100	46987	41125	3462.5	1.65	1.57
Barmer	RH 406	Irrigated	Non Descript	1333	1160	14.92	690	1521	29000	26600	49330	42975	3954	1.68	1.51
Jodhpur	RH 406	Irrigated	PM 26	1885	1469	29.19	1096	1521	20100	19500	65975	51415	13960	3.28	2.63
Mean				1690	1439	17.61	1043	1521	24650	23060	58923	50167	7166	2.50	2.23

Abbreviations used IR: Irrigated; RF: Rainfed; YIOFP: Yield increase over farmer's practice; CoC: Cost of cultivation; GMR: Gross monetary return; ANMR: Additional Net Monetary Return; IP: Improved practices; FP: Farmers' Practices; B:C : Benefit : Cost

Table 8 Exploitable productivity, technology gaps, technology index, extension gaps and cost benefit ratio of mustard as grown under FLD and existing package of practices. (N=100, 20 from each block)

Area/ of FLD	Varieties used in IP	Number of demonstration	Demonstration yield (kg/ha)	Farmers yield (kg/ha)	Potential yield (kg/ha)	Extension gap (kg/ha)	Technological gap (kg/ha)	Technology index (%)
Nagaur	NRCDR 2	20	1975	1665	2213	310	238	10.75
Maulasar	NRCHB 101	20	1916	1726	2000	190	84	4.20
Jalore	RH 406	20	1342	1175	2300	167	958	41.65
Barmer	RH 406	20	1333	1160	2300	173	967	42.04
Jodhpur	RH 406	20	1885	1469	2300	416	415	18.04
	Mean of RH 406	60	1520	1268	2300	252	780	33.91
	Mean	100	1690	1439	2223	251	533	23.98

REFERENCES

Alagukannan G, Velmurugan P and Ashokkumar M 2015. Impact of interventions on knowledge and adoption of improved technologies in banana cultivation. *Journal of Krishi Vigyan*, **3**(2): 54-58.

Anonymous 2013. FAO-STAT Trade and Market Division, Food outlook 2012- 13. Food and Agriculture Organization (FAO) of the United Nations, Rome. Italy. "Agricultural Statistics Databases" available at http://faostat.fao.org.

Bhardwaj R L, Nandal U and Vyas L 2013. The impact of fennel primary processing technology transfer to tribal women on income and employment opportunities in district Sirohi of Rajasthan. *Journal of Spices and Aromatic Crops*, **23**(2): 205-210.

Borate H V, Mahadik R P, Hake A D and Sawant P A 2012. Knowledge and adoption of sapota growers in Thane district. *International Research Journal of Agricultural Economics and Statistics*, **3**(1): 159-161.

Changadeya W, Ambali J D A and Kambewa D 2012. Farmer's adoption potential of improved banana production techniques in Malawi. *International Journal of Physical and Social Sciences*, **2**(4): 32-48.

Cochran W G and Cox G M 1950. *Experimental Design,* Pub. John Willey Inc., New York, pp.106-110.

Dubey S, Tripathy S, Singh P and Sharma R K 2010. Yield gap analysis of black gram production through frontline demonstration. *Journal of Progressive Agriculture*, **1**(1): 42-44.

Hiremnath S M and Nagaraju M V 2009. Evaluation of front line demonstration trials on onion in Haveri district of Karnataka. *Karnataka Journal of Agricultural Sciences*, **22**(5): 1092-1093.

Joseph R 2008. Impact of Krishi Vigyan Kendra training programme on maize production. Evaluation capacity building in rural resources management: A Manual. Indian Agriculture Research Institute, Pusa, New Delhi, pp. 21-28.

Khajuria S, Rai A K, Kanak Lata, Raj Kumar and Jadav J K 2016. Frontline demonstrations: An approach for management of chilli thrips (*Scirtothrips dorsalis* Hood). *Indian Journal of Arid Horticulture*, **11**(1-2): 96-98.

Meena K C and Gupta I N 2016. Impact of K V K Training Programmes on Adoption of Garlic Production Technology. *Journal of Krishi Vigyan,* DOI: 124.253.136.240.

Morwal B R, Pagaria P, Choudhary H D and Das S 2019. Impact of interventions on knowledge and adoption of improved technologies in ber cultivation in western Rajasthan. *Indian Journal of Arid Horticulture*, **1**(1): 22-25.

Mundial B 2008. *Agriculture for development-2008,* World Development Report, Washington.

Nandal U and Ojha S N 2012. Role of farm women in additional income generation through secondary agriculture. In: *Proceedings of Global Conference on Women in Agriculture,* 13-15 March, 2012, NASC Complex, New Delhi, pp. 58-59.

Patel B I, Patel D B, Patel A J and Vihol K H 2009.Performance of mustard in Banaskantha district of Gujarat. *Journal of Oilseeds Research*, **26**(Special issue): 556-557.

Samui S K, Maitra S, Roy D K, Mandal A K and Saha D 2000. Evaluation of front line demonstration on groundnut. *Journal of Indian Society Costal Agricultural Research*, **18**(2): 180-183.

Sanyang S E, Te-Chen Kao and Wen-Chi Huang 2008. Comparative study of sustainable and non-sustainable interventions in technology development and transfer to the women's vegetable gardens in the Gambia. *Journal of Technology Transfer*, **34**: 59-75.

Singh A P, Vaid A and Mahajan V 2014. Impact of KVK Training programmes and frontline demonstrations on adoption of Pusa Basmati 1121 in Kathua district of Jammu and Kashmir. *Journal of Krishi Vigyan*, **2**(2): 44-48.

Tandel B M, Prabhu Nayaka, Shah K A and Timbadiya C K 2015. Knowledge level of sapota growers about scientific package of practice. *Agriculture Update*, **10**(1): 84-85

USDA 2016. *Quick stats.* USDA-NASS, Washington, DC.

Studies on variability, correlation coefficient and path analysis for yield associated traits in soybean [*Glycine max* (L.) Merrill]

SHRISHTI MEHRA*, M K SHRIVASTAVA, PAWAN K AMRATE AND R B YADAV

Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur-482 004, Madhya Pradesh

(Received: December 30, 2019; Revised: March 2, 2020; Accepted: March 6, 2020)

ABSTRACT

In the present study, genotypic and phenotypic variability, correlation coefficient and path analysis were worked out on forty six important soybean genotypes for yield and its attributing characters at JNKVV, Jabalpur. The highest per cent of PCV (37.69), GCV (37.48) and heritability (98.9) were found for number of pods/plant. The number of pods/plant was significantly correlated with number of seeds (0.7595) and seed yield/plant (0.6316). Path coefficient analysis also revealed, substantially higher positive direct effects of number of pods/plant (0.8364) and number of seeds/pod (0.5177) on seed yield/plant.

Keywords: Correlation and Path analysis, Genetic advance, Genetic variability, Heritability, Soybean

Soybean [*Glycine max* (L.) Merril] is considered as "Wonder Crop" of 20th century due to its dual qualities *viz.,* high protein (40%) and oil content (20%). In India, it is grown in 10.96 million hectare with production of 13.46 million hectare and productivity of 1228 kg/ha (Anonymous, 2018). The degree of genetic variability present in a population of any crop species is always crucial for crop improvement which must be exploited by plant breeders for enhancing yield as well as imparting resistance against various stresses. Knowledge of key genetic parameters is necessary for any crop improvement programme which provides precise information for selection of particular traits. Genetic parameters like genotypic (GCV) and phenotypic (PCV) coefficient of variation, heritability, genetic advance and path coefficient analysis are very useful biometrical tools for measuring variability present in genotypes. In this concern, under the present study, genetic background and breeding values of some important soybean genotypes were determined to find the suitability in inclusion for crop improvement programme.

Forty six genotypes including five checks JS 97 52, JS 20-29, JS 20-69, JS 20-34 and NRC 86 were evaluated in Randomized Block Design with three replications at All India Coordinated Research Project (AICRP) on Soybean, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur during *kharif* 2018. The genotypes JS 21-17, JS 21-71, JS 21-72, JS 21-73, JS 20-98, JSM 230, JSM 283, JS-10, JS-12, JS-11, JS-13, JS 13-01, JS12-01, JS10-01, JS-06, JS 11-01, JS 12-03, JS 12-02, JS 10-02, JS 10-03, CAT 142, SQL 8, SQL 31, SQL 89, AMS 19B, AMS 59, AMS 56, EC 383165, M 204, YOUNG, HARDEE, PC PGR BHATT, NRC 117, NRC 125, NRC 130, NRC 132, NRC 37, RSC 11-07, RSC 10-46, RVS 2002-4, and RVS 2001-18 collected from AICRP on Soybean, Jabalpur were included in the present study. Each of these genotypes was sown in three rows of 3m length with 40 cm row to row and 7 cm plant to plant spacing. Observations were recorded from five random competitively selected plants for twelve characters viz., days to flower initiation, days to 50% flowering, days to maturity, plant height (cm), number of primary branches, number of pods/plant, number of seeds/plant, number of seeds/pod, biological yield/plant (g), 100-seed weight (g), harvest index (%) and seed yield/plant (g). Phenological observations were taken on plot basis. Analysis of variance on different characters was carried out as per the standard procedure of Fisher (1963). Genotypic and phenotypic coefficients of variation were estimated according to Burton and Devane (1953). Heritability in broad sense and genetic advance were worked out as per Hanson et al. (1956) and Johnson et al. (1955), respectively. Phenotypic and genotypic correlation and path coefficients of variation were computed based on the method given by Dewey and Lu (1959).

The analysis of variance revealed that the mean squares were significant for all the twelve characters. The estimates of phenotypic coefficient of variation (2.71 to 37.69%) slightly higher than of genotypic coefficient of variation (2.64 to 37.48%) indicated less effect of environment in the expression of traits (Table 1). Highest PCV and GCV were recorded for number of pods/plant (37.69% and 37.48%) followed by number of seeds (35.99% and 31.82%), seed yield (35.47% and 34.348%) and biological yield/plant (32.54% and 31.9%) indicating a high variability and ample scope for selecting traits for development of varieties. Moderate (PCV and GCV) values were observed for 100 seed weight (19.34% and 18.96%), number of seeds/pod (18.77% and 16.73%), plant height (13.80% and13.23%), and low (PCV and GCV) values for phenological traits viz., days to flower initiation (6.67% and 6.55%), days to 50% flowering (5.63 % and 5.42%) and days to maturity (2.71% and 2.64%), respectively (Ghodrati *et al.,* 2013).

Table 1 Phenotypic and genotypic coefficients of variations (PCV & GCV), heritability [h^2b (%)] and genetic advance (GA) for twelve yield associated traits of soybean

Character	Mean	Range		PCV (%)	GCV (%)	h2b (%)	GA as % of mean 5%
		Min.	Max.				
Days to flower initiation	30.82	34.7	46.66	6.67	6.55	96.5	13.26
Days to 50% flowering	43.98	39.7	53.66	5.63	5.42	92.7	10.75
Days maturity	94.75	87.7	100.66	2.71	2.64	95.2	5.32
Plant height (cm)	57.26	29.3	71.42	13.8	13.23	92	26.13
Number of primary branches	5.75	3.83	8.01	21.58	18.78	75.8	33.68
Number of pods/plant	42.73	22	81.33	37.69	37.48	98.9	76.8
Number of seed/plant	102.3	45.3	186.67	35.99	31.82	78.2	57.97
Number of seed/pod	2.54	1.93	3.62	18.77	16.73	79.4	30.72
Biological yield/plant (g)	2329	11	42.83	32.54	31.9	96.1	64.45
100-seed weight	10.45	6.9	15.33	19.34	18.96	96.1	38.3
Harvest index (%)	45.3	16.9	60.97	23.44	23.08	97	46.82
Yield/plant (g)	10.41	3.11	19.61	35.47	34.34	93.8	68.51

Table 2 Genotypic (g) and phenotypic (p) correlation coefficients among twelve yield associated traits of soybean

Characters		Days to flower initiation	Days to 50 % flowering	Days to maturity	Plant height (cm)	Number of primary branches	Number of pods/plant	Number of seed/plant	Number of seed/pod	Biological yield/plant (g)	100 seed weight (g)	Harvest index (%)	Yield/ plant (g)
Days to flower initiation	g	1	0.899	0.378	0.2148	-0.146	0.1003	0.1359	0.2158	0.0611	0.1679	0.2846	0.2509
	p	1	0.8702 ***	0.3658 ***	0.1980 *	-0.1238	0.0995	0.1165	0.1816 *	0.0625	0.1578	0.2767 **	0.243
Days to 50% flowering	g		1	0.4555	0.1421	-0.1103	0.1573	0.2065	0.2033	0.0433	0.0262	0.2435	0.232
	p		1	0.4275 ***	0.1275	-0.1007	0.1484	0.1555	0.1864 *	0.041	0.021	0.2303 **	0.217*
Days to maturity	g			1	0.0741	0.0508	0.2373	0.2061	-0.2303	-0.0211	-0.2079	0.065	0.1042
	p			1	0.07	0.0222	0.2313 **	0.1857 *	-0.2066 *	-0.0203	-0.2048 *	0.0589	0.0932
Plant height (cm)	g				1	-0.1684	0.2303	0.1957	0.0667	0.1522	0.2237	0.34	0.3086
	p				1	-0.1327	0.2129 *	0.1680 *	0.0815	0.1389	0.2088 *	0.3160 ***	0.2775**
Number of primary branches	g					1	0.0877	0.1634	-0.0391	0.1322	-0.4639	-0.3185	-0.1361
	p					1	0.0854	0.115	-0.028	0.1245	-0.3907 ***	-0.2761 **	-0.1047
Number of pods/plant	g						1	0.8532	-0.2166	0.6027	-0.3291	0.1862	0.6501
	p						1	0.7597 ***	-0.1975 *	0.5905 ***	-0.3211 ***	0.1830 *	0.6316***
Number of seed/ plant	g							1	0.2569	0.6711	-0.2426	0.3841	0.879
	p							1	0.1682*	0.5762 ***	-0.2071*	0.3366***	0.7491***
Number of seed/pod	g								1	0.0476	0.3328	0.4702	0.4073
	p								1	0.0671	0.3040 ***	0.4383***	0.3956***
Biological yield/plant (g)	g									1	-0.0089	-0.2083	0.6447
	p									1	0.0054	-0.1949*	0.6505***
100 seed weight (g)	g										1	0.3632	0.2686
	p										1	0.3652***	0.2791***
Harvest index (%)	g											1	0.5868
	p											1	0.5886***
Yield/plant (g)	g												1
	p												1

High heritability coupled with genetic advance (percent of mean) were observed for plant height, number of primary branches, number of pods/plant, number of seeds/plant, number of seeds/pod, biological yield , 100-seed weight, harvest Index and seed yield/plant (Table 1). This suggested the preponderance of additive gene action with low environmental influence. Heritability estimates along with genetic advance are usually more helpful in predicting the genetic gain than heritability estimates alone (Johnson *et al.,* 1955). Similar results were obtained by Ramana et al. (2000) for plant height, number of branches/plant, number of pods/plant and seed yield/plant, Jain *et al.* (2017) and Neelima *et al.* (2018) for number of pods/plant, harvest index, plant height.

Genetic and phenotypic correlation coefficient showed the inherent association with the level of phenotypically expressed correlation which is influenced by the environment (Table 2). Days to 50% flowering recorded highly significant positive association with days to maturity (0.4275), harvest Index (0.2303) and seed yield/plant (0.2170). Similar positive associations were found for number of pods/plant with number of seeds/ plant (0.7595), seed yield/plant (0.6316), biological yield/plant (0.5909); Number of seeds/plant with seed yield/plant (0.7491), biological yield/plant (0.5762) and harvest index (0.3366); Number of seeds/pod with harvest index (0.4383), seed yield/plant (0.3956) and 100-seed weight (0.3040); Biological yield/plant with seed yield/plant (0.6505); 100-seed weight with harvest index (0.3652), seed yield/plant (0.2791) and harvest Index with seed yield/plant (0.5886) as has been reported earlier (Koraddi *et al.,* 2015).

Path coefficient analysis (Table 3) revealed, substantially higher positive direct effects for number of pods/plant (0.8364), number of seeds/pod (0.5177) and days to maturity (0.3035) on seed yield/plant. Contrary to this, negative direct effect was observed by number of seeds/plant (-1.5112) followed by days to flower initiation (-0.3445) and 100 seed weight (-0.2566) as also reported by Chavan *et al.* (2016) for 100-seed weight, number of pods/plant and days to maturity, Balla *et al.* (2017) for days to maturity, Dessia *et al.* (2018) for number of pods/plant, number of seeds/pod and biological yield/plant. The residual effect (0.2206) indicated that component characters under study were responsible for about 78% of variability in seed yield/plant.

On the basis of above findings, it is evident that substantial genetic variability was envisaged for yield and its component traits in most of the genotypes under study. Therefore, these traits governing genotypes should be considered while selecting superior and desirable plants for further evolving high yielding genotypes in soybean.

Table 3 Path coefficient analysis for seed yield per plant with its component characters in soybean

Characters	Days to flower initiation	Days to 50 per cent flowering	Days maturity	Plant height (cm)	Number of primary branches	Number of pods/ plant	Number of seed/ plant	Number of seed/ pod	Biological yield/plant (g)	100 seed weight (g)	Harvest index (%)
Days to flower initiation	-0.3445	-0.3096	-0.1302	-0.0740	0.0503	-0.0345	-0.0468	-0.0744	-0.0210	-0.0578	-0.0981
Days to 50 % flowering	0.1288	0.1434	0.0653	0.0204	-0.0158	0.0225	0.0296	0.0291	0.0062	0.0038	0.0349
Days to maturity	0.1147	0.1382	0.3035	0.0225	0.0154	0.0720	0.0626	-0.0699	-0.0064	-0.0631	0.0197
Plant height (cm)	-0.0381	-0.0252	-0.0132	-0.1776	0.0299	-0.0409	-0.0348	-0.0118	-0.0270	-0.0397	-0.0604
No. of primary branches	-0.0117	-0.0088	0.0041	-0.0134	0.0799	0.0070	0.0131	-0.0031	0.0106	-0.0370	-0.0254
No. of pods/plant	0.0839	0.1316	0.1985	0.1927	0.0734	0.8364	0.7136	-0.1812	0.5042	-0.2753	0.1558
No. of seeds/plant	-0.2053	-0.3121	-0.3115	-0.2957	-0.2470	-1.2893	-1.5112	-0.3883	-1.0142	0.3666	-0.5804
No. of seeds/pod	0.1117	0.1052	-0.1192	0.0345	-0.0202	-0.1121	0.1330	0.5177	0.0246	0.1723	0.2434
Biological yield/plant (g)	0.0876	0.0621	-0.0302	0.2183	0.1896	0.8644	0.9625	0.0683	1.4342	-0.0128	-0.2988
100 seed weight (g)	-0.0431	-0.0067	0.0534	-0.0574	0.1190	0.0844	0.0623	-0.0854	0.0023	-0.2566	-0.0932
Harvest index (%)	0.3669	0.3139	0.0838	0.4384	-0.4106	0.2401	0.4952	0.6063	-0.2686	0.4683	1.2893
Seed yield/plant (g)	0.2509	0.2320	0.1042	0.3086	-0.1361	0.6501	0.8790	0.4073	0.6447	0.2686	0.5868

R Square = 0.9513; Residual effect = 0.2206

REFERENCES

Anonymous 2018. *Directors Report,* Indian Institute of Soybean Research, Indore, pp. 327.

Balla M Y and Ibrahim S E 2017. Genotypic correlation and path coefficient analysis of soybean [*Glycine max* (L.) Merr.] for yield and its components. *Agricultural Research and Technology*, **7**(3): 99-103.

Burton G W 1952. Quantitative inheritance in grasses. *Proceedings of the 6th Grassland Congress*, **1**: 277-285.

Chavan B H, Dahat D V, Rajput H J, Deshmukh M P and Diwane S L 2016. Correlation and path analysis in soybean. *International Research Journal of Multidisciplinary Studies*, **2**(9): 1-5.

Desissa D H and Gemechu H L 2018. Correlation and path analysis studies among yield and yield related traits in soybean (*Glycine max* (L.) Merrill) varieties. *International Journal of Plant Breeding and Crop Science*, **5**(1): 352-360.

Dewey J R and Lu K H 1959. A correlation and path co-efficient analysis of components of crested wheat seed production. *Agronomy Journal*, **51**: 515-518.

Fisher R A and Yates F 1963. *Statistical tables for biological, agricultural and medical research*. Oliver and Boyd, London.

Ghodrati G R, Sekhavat R, Mahmood S H, Gholami A 2013. Evaluation of correlations and path analysis of components seed yield in soybean. *International Journal of Agriculturural Research and Review*, **3**(4): 795-800.

Hanson W D, Robinson H F and Comstock R E 1956. Biometrical studies of yield segregating population Korean lespandeza. *Agronomy Journal*, **48**: 268-272.

Jain R K, Joshi A, Chaudhary H R, Dashora A and Khatik C L 2017. Study on genetic variability, heritability and genetic advance in soybean [*Glycine max* (L.) Merrill]. *Legume Research*, DOI: 10.18805/LR-3874.

Johnson H W, Robinson H F and Comstock R E 1955. Estimate of genetic and environmental variability in soybean. *Agronomy Journal*, **47**: 314-318.

Koraddi S, Basavaraja G T, Immadi S and Vijaykumar A G 2015. Correlation and path coefficient analysis for yield and its components in soybean [*Glycine max* (L.) Merrill]. *The Bioscan*, **10**(4): 2065-2067.

Neelima G, Mehtre S P and Narkhede G W 2018. Genetic variability, heritability and genetic advance in soybean. *International Journal of Pure Applied Bioscience*, **6**(2): 1011-1017.

Ramana M V, Pramilarani B and Satyanarayana A 2000. Genetic variability, correlation and path analysis in soybean. *Oilseeds Research Journal*, **17**(1): 32-35.

Correlation and path coefficient analysis of seed yield and yield related characters in sesame (*Sesamum indicum* L.)

BABITA KUMARI, S R KUMHAR AND SUSHILA SIROHI

Agricultural Research Station, Mandor, Agriculture University, Jodhpur-342 304, Rajasthan

(Received: December 16, 2019; Revised: March 9, 2020; Accepted: March 12, 2020)

ABSTRACT

Correlation and path analysis were carried out to determine the effects of various traits as components of seed yield in 40 sesame genotypes. The genotypes were evaluated in RBD with three replications during *kharif* 2018 at the Research Farm of Agricultural Research Station, Agriculture University, Jodhpur, Rajasthan. Analysis of variance exhibited significant difference for all the characters suggesting the presence of inherent genetic variations among the genotypes studied. Correlation among the traits revealed that seed yield/plant was positively associated with number of capsules/plant, capsule bearing length, harvest index and number of primary branches at both genotypic and phenotypic levels, while, non-significant correlation with days to 50% flowering, days to maturity, plant height (cm), number of seeds per capsule and 1000-seed weight. The path coefficient analysis of different characters contributing towards seed yield/plant showed positive direct effect by number of capsules/plant. Capsule bearing length, harvest index, number of primary branches/plant, 1000-seed weight, plant height and days to 50% flowering showed considerable positive direct effect on seed yield. Indirect positive effect showed by days to 50% flowering via number of primary branches at genotypic level. These results indicated that number of primary branches/plant, number of capsules/plant, capsule bearing length and harvest index are the principal yield components, and selection for these traits may be useful in improving seed yield in sesame.

Keywords: Correlation and Path coefficient, Seed yield, Sesame

Sesame is cultivated worldwide in over 50 nations. India is regarded as the main centre of genetic diversity, although the crop originated in Africa (Maiti *et al*., 2012). Generally, sesame is a short-day plant that may grow in long-day areas as well. Sesame seeds contain 38-54% oil and 18-25% protein, and it is an oilseed crop with immense therapeutic uses. Sesame oil has significant resistance against oxidation as it contains endogenous antioxidants including lignins and tocopherols (Elleuch *et al.,* 2007; Lee *et al.,* 2008). Due to availability of only a few high yielding varieties/ cultivars and with limited resistance to major insect pests and diseases, the average productivity of sesame is low relative to other oilseed crops. Seed yield being a polygenic trait, depends on other ancillary characters, inherited quantitatively and highly influenced by the environment. Therefore, studies on correlation and path analysis allow breeders to understand the strength of the relationship between different characters as well as the direction of changes expected during selection. Moreover, identification of high yielding genotypes and the genotypes having superior performance for component characters which are positively associated with grain yield are also important because these may be used as parents in hybridization programme. The efficiency of selection, thus, can be increased if it is simultaneously practiced for characters which are positively correlated with yield. In the present study 40 genotypes of sesame were evaluated to assess the ancillary characters that influence the seed by adopting correlation as well as path coefficient analysis.

Corresponding author's E-mail: srkumhar@gmail.com

In the present investigation 40 genotypes of sesame were evaluated in a Randomized Block Design with three replications during *kharif* 2018; under rainfed conditions of Research Farm at Agricultural Research Station, Agriculture University, Mandor, Jodhpur, Rajasthan. The rainfall in *kharif* 2018 was very erratic, therefore, one life saving irrigation was provided to save the crop. Each genotype was sown in 4 m length of two rows with spacing of 30 cm between rows and 15 cm from plant to plant. The recommended agronomic practices were followed to raise a healthy crop. Observations were recorded on days to 50% flowering, days to maturity, plant height (cm), number of primary branches/plant, number of capsules/plant, number of seeds/capsule, capsule bearing length (cm), 1000-seed weight (g), harvest index (%), oil content (%) and seed yield/plant (g). Averages of the observations were used to compute the correlation and path analysis to know the magnitude of association between yield and its component traits and to assess the relative importance of their direct and indirect effects, thus providing an obvious understanding of their association with seed yield. Correlation coefficients were calculated at genotypic and phenotypic level as per suggested by Dewey and Lu (1959). Path coefficient analysis was carried out by taking seed yield/ plant (g) as dependent variable and other traits as contributing traits. The direct and indirect effects both at genotypic and phenotypic levels were estimated using path coefficient analysis as suggested by Wright (1921) and Dewey and Lu (1959).The estimates of correlation and path coefficient analysis were calculated by using software Windostat programme.

The potential productivity of any crop is basically valued in terms of seed yield/unit area. Its improvement by direct selection is generally difficult because yield is a complex polygenic trait, largely influenced by its various component characters as well as by the environmental factors. Besides, path coefficient analysis provides an efficient means of partitioning of correlation coefficient into direct and indirect effects of the component characters. Hence, it becomes essential to estimate association of seed yield with component characters and among themselves. The phenotypic and genotypic correlations between seed yield and its contributing traits as estimated with the 40 genotypes are presented in Table 1. In general, the genotypic correlation coefficients were higher than the respective phenotypic correlations which might be from the modifying effect of environment on the association of characters at phenotypic level. Therefore, knowledge of relation between yield and its components is essential and selection for one component may bring about a simultaneous change in the other. Therefore, for a rational approach to improve seed yield, it may be useful to collect information on character association.

Among the eleven characters studied, only four traits *viz.,* number of capsules/plant, harvest index, capsule bearing length and number of primary branches/plant exhibited significant positive association at both genotypic and phenotypic levels with seed yield/plant (Table 1). The correlations of seed yield/plant (g) with number of capsules/plant (0.500), harvest index (0.394), capsule bearing length (0.297), plant height (0.253) and number of primary branches/plant (0.231) were highly positive and significant at genotypic level. The correlations of seed yield/plant was positive and significant at phenotypic level with characters *viz.,* number of primary branches/plant (0.224), plant height (0.253) as already reported (Patil and Lokesha, 2018; Singh *et al.,* 2018), capsule bearing length (0.285) as documented earlier (Lalpantluangi *et al.,* 2018; Patil and Lokesha, 2018 and Abate, 2018) and harvest index (0.251) (Abate, 2018). The correlations of seed yield/plant was non-significant with days to 50% flowering, days to maturity, number of seeds/capsule and oil content (%). Days to maturity had positive and significant association with number of primary branches/plant (0.547) and days to 50% flowering (0.807). Plant height had non-significant association with all characters included except capsule bearing length as reported by Saxena and Bisen (2016).

The correlation of days to 50% flowering positively associated with days to maturity and number of primary branches/plant (0.350). Capsule bearing length (cm) had positive and significant association with number of capsules/plant (0.350) and oil content (0.403). Thus, the present study supports the earlier findings that selection for number of primary branches/plant, capsule bearing length (cm), number of capsules/plant and harvest index (%) may bring about simultaneous improvement in seed yield.

Table 1 Phenotypic and genotypic correlation coefficient between different characters in sesame

Characters	Level	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of primary branches/ plant	Number of capsules/ plant	Capsule bearing length (cm)	Number of seeds/ capsule	1000 seed weight (g)	Harvest index (%)	Oil content (%)	Seed yield/plant (g)
Days to 50% flowering	G	1.000	0.807**	-0.102	0.350**	0.077	-0.522**	0.097	-0.013	-0.130	-0.114	-0.001
	P	1.000	0.720**	-0.101	0.301**	0.067	-0.347**	0.133	-0.006	-0.049	-0.073	0.029
Days to maturity	G		1.000	0.130	0.547**	0.173	-0.258**	-0.058	0.067	-0.217*	-0.083	-0.014
	P		1.000	0.025	0.470**	0.166	-0.106	-0.039	0.028	-0.098	-0.077	0.036
Plant height (cm)	G			1.000	0.133	0.112	0.187*	0.141	0.120	-0.042	0.007	0.253**
	P			1.000	0.102	0.072	0.088	0.091	0.040	-0.064	-0.136	0.085
Number of primary branches/plant	G				1.000	0.501**	-0.238**	0.094	-0.039	-0.133	-0.179	0.231*
	P				1.000	0.446**	-0.113	0.040	-0.024	-0.004	-0.085	0.224*
Number of capsules/plant	G					1.000	0.350**	-0.218*	0.067	-0.024	0.183*	0.500**
	P					1.000	0.372**	-0.088	-0.039	0.057	0.170	0.428**
Capsule bearing length (cm)	G						1.000	-0.111	0.070	-0.088	0.403**	0.297**
	P						1.000	0.021	-0.050	0.028	0.244**	0.285**
Number of seeds/capsule	G							1.000	-0.387**	-0.092	-0.112	-0.024
	P							1.000	-0.311**	0.026	-0.139	0.022
1000 seed weight (g)	G								1.000	0.271**	0.168	0.136
	P								1.000	0.136	0.096	0.057
Harvest index (%)	G									1.000	-0.173	0.394**
	P									1.000	-0.068	0.251**
Oil content (%)	G										1.000	-0.164
	P										1.000	-0.095
Seed yield/plant(g)	G											1.000
	P											1.000

** = Significant at 1%., * = Significant at 5%

The correlation analysis provides information which is incomplete in the sense that it does not throw light on the underlying causes that are operative for the various interrelationships. A better picture of the contribution of each component building up the total genetic architecture of a complex character may be obtained through the analysis of causal schemes. Hence, in such a situation path coefficient analysis devised by Wright (1921) is useful in partitioning direct and indirect causes of association which allow a detailed examination of specific forces acting to produce a given correlation and measures the relative importance of each causal character. Such a study provides a realistic basis for allocation of weightage to each attribute in deciding a suitable criterion for genetic improvement. In the present study path coefficient analysis was computed both at genotypic and phenotypic levels for all the characters.

Results of path coefficient analysis (Table 2) of different characters contributing towards seed yield/plant showed that days to 50 per cent flowering (1.048) had the highest positive direct effect followed by capsule bearing length (0.802), number of primary branch/plant (0.522), harvest index (0.409), plant height (0.298), 1000 seed weight (0.159)and number of capsules/plant (0.034) at genotypic level. Whereas, days to maturity (-0.931) had the highest negative direct effect on seed yield/plant followed by number of seeds/capsule (-0.165) and oil content (-0.311) at genotypic level. These findings were supported by Patil and Lokesha (2018), Abate (2018) and Rehman *et al.* (2019). This indicated that seed yield was mainly a product of direct effects of number of capsules/plant but was also affected indirectly via capsule bearing length, number of primary branches/plant, days to 50% flowering, harvest index (%), plant height (cm) and 1000-seed weight (g). Direct negative effect on seed yield/plant was also observed for days to maturity, number of seeds/capsule and oil content. At genotypic level direct effect of all the characters was positive except days to maturity, number of seeds/capsule and oil content (%) which exhibited negative direct effect. At phenotypic level, the highest direct positive effect on seed yield/plant was observed for number of capsules/plant (0.306) followed by capsule bearing length (0.280), days to 50% flowering(0.206), harvest index (0.195), number of primary branches/plant (0.131), 1000-seed weight (0.081) and plant height (0.034). These findings are in line with the observations made earlier (Sumathi *et al.,* 2007; Kumar and Vivekanandan, 2009; Ibrahim and Khidir, 2012), Sivaprasad *et al.,* 2013; Abate *et al.,* 2015; Bamortiya *et al.,* 2016; Saxena and Bisen, 2016; Abhijatha *et al.,* 2017; Teklu *et al.,* 2017; Singh and Bisen, 2018; Patil and Lokesha, 2018; Abate, 2018 and Rhman *et al.* (2019).

Table 2 Path coefficient analysis showing direct (bold) and indirect effects of different characters on seed yield in sesame

Characters	Level	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of primary branches/plant	Number of capsules/plant	Capsule bearing length (cm)	Number of seeds/capsule	1000 seed weight (g)	Harvest index (%)	Oil content (%)	Correlation with seed yield/plant
Days to 50% flowering	G	1.048	-0.752	-0.030	0.183	0.003	-0.419	-0.016	-0.0002	-0.053	0.035	-0.001
	P	0.206	-0.140	-0.003	0.040	0.020	-0.097	-0.001	-0.0005	-0.010	0.014	0.029
Days to maturity	G	0.846	-0.931	0.039	0.285	0.006	-0.207	0.010	0.001	-0.089	0.026	-0.014
	P	0.148	-0.194	0.001	0.062	0.051	-0.030	0.0003	0.002	-0.019	0.015	0.036
Plant height (cm)	G	-0.107	-0.121	0.298	0.069	0.004	0.150	-0.023	0.002	-0.017	-0.002	0.253**
	P	-0.021	-0.005	0.034	0.013	0.022	0.025	-0.001	0.003	-0.013	0.026	0.085
Number of primary branches/plant	G	0.367	-0.509	0.040	0.522	0.017	-0.191	-0.016	-0.001	-0.054	0.056	0.231*
	P	0.062	-0.091	0.003	0.131	0.136	-0.032	-0.0003	-0.002	-0.001	0.017	0.224*
Number of capsules/plant	G	0.081	-0.161	0.033	0.261	0.034	0.281	0.036	0.001	-0.010	-0.057	0.500**
	P	0.014	-0.032	0.002	0.059	0.306	0.104	0.001	-0.003	0.011	-0.033	0.428**
Capsule bearing length (cm)	G	-0.548	0.241	0.056	-0.124	0.012	0.802	0.018	0.001	-0.036	-0.125	0.297**
	P	-0.071	0.021	0.003	-0.015	0.114	0.280	-0.0002	-0.004	0.005	-0.048	0.285**
Number of seeds/capsule	G	0.101	0.054	0.042	0.049	-0.007	-0.089	-0.165	-0.006	-0.038	0.035	-0.024
	P	0.027	0.007	0.003	0.005	-0.027	0.006	-0.007	-0.025	0.005	0.027	0.022
1000 seed weight (g)	G	-0.013	-0.063	0.036	-0.020	0.002	0.056	0.064	0.016	0.111	-0.052	0.136
	P	-0.001	-0.005	0.001	-0.003	-0.012	-0.014	0.002	0.081	0.026	-0.019	0.057
Harvest index (%)	G	-0.136	0.202	-0.013	-0.069	-0.001	-0.071	0.015	0.004	0.409	0.054	0.394**
	P	-0.010	0.019	-0.002	-0.001	0.018	0.008	-0.0002	0.011	0.195	0.013	0.251**
Oil content (%)	G	-0.119	0.077	0.002	-0.094	0.006	0.324	0.019	0.003	-0.071	-0.311	-0.164
	P	-0.015	0.015	-0.005	-0.011	0.052	0.068	0.001	0.008	-0.013	-0.195	-0.095

Note: Residual effect: Phenotypic = 0.31841 and Genotypic = 0.68614

The significant correlation of other character with seed yield/plant was due to the indirect effect through number of capsules/plant via capsule bearing length (cm), number of primary branches/plant, days to 50% flowering, harvest index (%), plant height (cm), days to maturity, 1000 seed weight (g), oil content (%)and number of seeds/capsule. This indicated that seed yield was a complex character and could be improved through number of capsules/plant via capsule bearing length, number of primary branches/plant, days to 50%flowering, harvest index (%), plant height (cm), 1000-seed weight (g) and number of seeds/capsule. Direct negative effect on seed yield/plant was also observed for days to maturity, number of seeds/capsule and oil content. These results are in corroboration with earlier reports (Sumathi *et al.*, 2007; Sumathi and Muralidharan, 2009; Sivaprasad and Yadavalli, 2012; Bamortiya *et al.,* 2016; Abhijatha *et al.,* 2017; Patil and Lokesha, 2018).

Path coefficient analysis revealed that, the highest positive direct effect on seed yield/ plant exerted by number of capsules/plant, followed by capsule bearing length, harvest index, number of primary branches/plant, 1000-seed weight, plant height and days to 50% flowering, and therefore these traits may be used for further improving yield attributes breeding programmes of sesame.

REFERENCES

Abate M 2018. Correlation and path coefficient analysis in mid-altitude sesame (*Sesamum indicum* L.) germplasm collection of Ethiopia. *African Journal of Agricultural Research*, **13**(46): 2651-2658.

Abhijatha A, Madhukar K and Arya K 2017. Evaluation of sesame (*Sesamum indicum* L.) genotypes to the shaded uplands of southern region. *International Journal of Current Microbiology and Applied Science*, **6**(7): 332-339.

Bamrotiya M M, Patel J B, Malav A, Chetariya C P, Ahir D and Kadiyara J 2016. Genetic variability, character association and path analysis in sesame (*Sesamum indicum* L.). *International Journal of Agriculture Sciences*, **8**(54): 2912-2916.

Dewey D R, and Lu K H 1959. A correlation and path coefficient analysis of components of crested wheat grass seed production. *Agronomy Journal*, **51**: 515-518.

Elleuch M, Besbes S, Roiseux O, Blecker C and Attia H 2007. Quality characteristics of sesame seeds and by-products. *Food Chemistry*, **103**: 641-650.

Ibrahim S E and Khidir M O 2012. Genotypic correlation and path coefficient analysis of yield and some yield components in sesame (*Sesamum indicum* L.). *International Journal of Agricultural Science*, **2**(8): 664-670.

Kumar K B and Vivekanandan P 2009. Correlation and path analysis for seed yield in sesame (*Sesamum indicum* L.). *Electronic Journal of Plant Breeding*, **1**: 70-73.

Lalpantluangi P C and Shah P 2018. Character association and path coefficient analysis in sesame (*Sesamum indicum* L.) genotypes under foothill condition of Nagaland. *The Pharma Innovation Journal*, **7**(5): 82-87.

Lee J Y, Lee Y S and Choe E O 2008. Effects of sesamol, sesamin and sesamol in extracted from roasted sesame oil on the thermal oxidation of methyl linoleate. *Food Science and Technology*, **42**: 1871-1875.

Maiti R, Satya P, Rajkumar D and Ramaswamy A 2012. Origin and development of crop anatomy. *Crop Plant Anatomy*, DOI: 10.1079/9781780640198.0000.

Patil M and Lokesha R 2018. Estimation of genetic variability, heritability, genetic advance, correlations and path analysis in advanced mutant breeding lines of sesame (*Sesamum indicum* L.). *Journal of Pharmacognosy and Natural Products*, **4**: 151.

Rhman R H A A, Salah A O, Ibrahim and Elareny M 2019. Correlation, path coefficient analysis and genetic variability for assessment of yield and its components in F_1 hybrid population of sesame (*Sesamum indicum* L.). *International Journal of Agriculture and Environmental Research*, **5**(1): 130-147.

Saxena K and Bisen R 2016. Genetic variability, correlation and path analysis studies for yield and yield component traits in sesame (*Sesamum indicum* L.). *International Journal of Agriculture Sciences*, **8**(61): 3487-3489.

Singh A, Bisen R and Tiwari A 2018. Genetic variability and character association in sesame (*Sesamum indicum* L.) genotypes. *International Journal of Current Microbiology and Applied Science*, **7**(11): 2407-2415.

Sivaprasad Y V N, Krishna M S R and Venkateswarlu Y 2013. Correlation, path analysis and genetic variability for economical characteristics in F_2 and F_3 generations of the cross AVT 3 × TC 25 in Sesame (*Sesamum indicum* L.). *Journal of Environmental and Applied Bioresearch Department of Agricultural Botany*, **1**(2): 14-18.

Sivaprasad Y V N and Yadavalli V 2012. Correlation, path analysis and genetic variability in F_2 and F_3 generations of cross Padma × JLSV 4 in sesame (*Sesamum indicum* L.). *International Journal of Agricultural Sciences*, **2**(12): 311-314.

Sumathi P, Muralidharan V and Manivannan N 2007. Trait association and path, coefficient analysis for yield and yield attributing traits in sesame (*Sesamum indicum* L.). *Madras Agricultural Journal*, **94**(7-12): 174-178.

Sumathi P and Muralidharan V 2009. Genetic analysis of the hybrids, involving monostem/shy branching genotypes in sesame (*Sesamum indicum* L.). *Electronic Journal of Plant Breeding*, **1**: 65-69.

Teklu D H, Kebede S A and Gebremichael D E 2017. Assessment of genetic variability, genetic advance, correlation and path analysis for morphological traits in sesame genotypes. *International Journal of Novel Research in Life Sciences*, **4**(2): 34-44.

Wright S 1921. Correlation and causation. *Journal of Agricultural Research*, **20**: 557-585.

Effect of nitrogen scheduling on nitrogen uptake pattern and seed protein yield, oil yield and oil quality of canola oilseed rape (*Brassica napus*) sown on different dates

LOVELEEN KAUR, VIRENDER SARDANA AND GURPREET KAUR

Punjab Agricultural University, Ludhiana-141 004, Punjab

(Received: December 17, 2019; Revised: March 23, 2020; Accepted: March 25, 2020)

ABSTRACT

A field experiment was conducted at the Punjab Agricultural University Ludhiana during *rabi* 2016-17 to study the effect of nitrogen (N) application dose and time on N uptake pattern, protein and oil yield and oil quality of canola oilseed rape (*Brassica napus*) under different sowing dates. The treatments comprised three sowing dates (15 October, 30 October and 15 November) in the main plots and seven combinations of dose (100 and 125 kg/ha) and time of application of N (two or three splits) in sub plots. Loamy sand soil of experimental field was low in organic carbon and available N in the upper 15 cm soil profile. The test variety GSC 7 was sown at spacing of 45 cm x 10-12 cm. Delay in sowing significantly reduced the N content and uptake by canola oilseed rape at all growth stages in different plant parts as well as in seed and stover at maturity except N content in stem at 80 DAS. The highest oil yield (941 kg/ha) obtained with 125 kg/ha of N applied as 50 kg at sowing + 50 kg at initiation of stem elongation + 25 kg at initiation of flowering was at par with application of 125 and 100 kg/ha of N in two equal splits at sowing and initiation of stem elongation. The highest protein yield (738 kg/ha) obtained with 125 kg/ha of N applied in three splits (50 + 50 + 25) was significantly higher than all other treatments. The highest oil yield produced by 15 October sown crop with application of 125 kg/ha of N in three splits (1056 kg/ha) was 7.3% and 40.4%% higher than application of 100 kg/ha of N in two equal splits and 6.7% and 35.9% higher than 125 kg/ha of N in three splits in 30 October and 15 November sown crop, respectively. Fatty acid composition of oil was not influenced by sowing dates and N scheduling.

Keywords: Nitrogen, Oil, Oilseed rape, Protein, Sowing dates, Yield

Rapeseed-mustard oil is the third major vegetable oil used for cooking in the world after soybean and palm oil and the major vegetable oil in India. Its de-oiled seed meal is primarily used as feed for livestock including poultry as a rich source of protein. The use of canola rapeseed-mustard oil in increasing globally as it contains oleic and essential fatty acids as well as anti-oxidants in desirable proportion and offers a cheaper source of quality oil than olive oil. Canola cultivars of rapeseed-mustard besides having low levels of saturated fatty acids (7-10%) and moderate levels of poly-unsaturated essential fatty acids such as linoleic acid (18-22%) and linolenic acid (8-12%) as that of non canola cultivars, possess extremely low levels of erucic acid (<2%), high level of mono unsaturated (oleic acid 60-65%) fatty acid in oil and low glucosinolates (<30 µmoles per gram) in the seed meal as compared to non canola cultivars in which generally contain more than 40% erucic acid in oil and more than 100 µmoles glucosinolates per gram of seed meal. As a result, the consumption of canola oil in India is also increasing rapidly. Canola cultivars of oilseed rape (*Brassica napus*) developed recently in India offer superior quality of oil and meal, white rust immunity, frost tolerance, higher yield potential as well as oil content.

Sowing at optimum time ensures optimal use of resources through better harmony between plant and prevailing weather conditions which is essential to achieve potential productivity of a cultivar.

Nitrogen (N) is the key input for field crops including oilseeds. Knowledge about its judicious application in optimum amounts and at times synchronous with its peak demand is imperative to achieve higher N use efficiency (Ferguson *et al.,* 2002; Grant *et al.,* 2012; Ma *et al.,* 2015). The present research was carried out to study the effect of sowing time and, N dose and its time of application on the N uptake pattern, oil and protein yield and oil quality of canola oilseed rape.

The field experiment was conducted at the research farm of Punjab Agricultural University, Ludhiana (30°54" N latitude, 75°48" E longitude, 247 m msl) during *rabi* 2016-17 on loamy sand soil of neutral pH (6.9), low organic carbon content (0.28%) and potassium permanganate available nitrogen (171 kg/ha), rich in sodium bicarbonate extractable available phosphorus (24.1 kg/ha) and low in ammonium acetate extractable available potassium (75 kg/ha) at the depth of 0-15 cm. Treatments comprising three sowing dates (15 October, 30 October and 15 November) allocated to main plots and seven treatments of dose (100 and 125 kg/ha) and time of application of nitrogen (two or three splits) to sub plots were replicated thrice as per split plot design. Variety GSC 7 was sown at row spacing of 45 cm with plant spacing within row of 10-12 cm maintained by thinning at about 20 days after sowing (DAS). Nitrogen as per treatments was applied through urea. Phosphorus @ 30 kg P_2O_5/ha in the form of single super phosphate and potassium @ 15 kg K_2O/ha in the form of muriate of potash were applied at sowing. Gross plot size was 20.25 m^2. All other recommended cultivation practices were adopted.

Nitrogen content in different plant parts at 40, 80 and 120 DAS, seed and stover at harvest was determined by modified micro-Kjeldahl method (Subbiah and Asija, 1956). Protein content in seed was calculated by multiplying the N content in the seed by a factor of 6.25 and expressed in percentage. The oil content in seed was determined with MQC benchtop Nuclear Magnetic Resonance (NMR) Analyser (Oxford instruments, UK) as suggested by Alexander *et al.* (1967). Nitrogen uptake by different plant parts at different growth stages, seed and stover at harvest was determined by multiplying per cent N content in the plant part, seed and stover with respective dry matter, seed and stover yields. Protein and oil yields were calculated by multiplying the protein and oil content in the seed sample of each treatment with respective seed yield. Fatty acids in oil were trans-esterified and analyzed by gas liquid chromatography (GLC) using standard method of trans-esterification developed by Appleqvist (1968).

Delay in sowing significantly reduced the N content at all growth stages in different plant parts as well as in seed and stover at maturity except in stem at 80 DAS (Table 1). Crop sown on 15 October and 30 October registered similar N content at 40 DAS whereas, 15 October sown crop attained significantly higher N content in leaves at 80 DAS and in leaves, stems and siliquae at 120 DAS over 30 October sowing date. Both these sowing dates (15 and 30 October) registered significantly higher N content in plant at 40 DAS, in leaves at 80 DAS and in leaves, stems and siliquae at 120 DAS than 15 November sowing date. Nitrogen content in seed of 15 October sown crop (4.77%) was 6.5% and that of stover (1.53%) was 2.0% more than 30 October sown crop (Table 1). Crop sown on 30 October registered 3.2% and 22.9% more N content in seed and stover, respectively over 15 November sown crop. Kaur (2000) and Kaur (2015) reported reduction in N content in seed of *Brassica carinata* from 3.17% to 2.93% with delay in sowing from 15 November to 15 December under similar conditions.

Differences in N content in different plant parts due to N application dose and time were significant except in stem at 80 DAS (Table 1). At 40 DAS, application of 125 kg/ha of N in two equal splits at sowing and initiation of stem elongation and 100 kg/ha in three splits (50 + 25 + 25 or 25 + 50 + 25 at sowing, initiation of stem elongation and initiation of flowering) resulted in similar N content which was significantly higher than all other treatments (Table 1). This may be ascribed to increased supply and availability of N for longer duration with its split application. Application of 100 kg/ha of N in two equal splits resulted in significantly lowest N content (1.23%). At 80 DAS, the highest N content in leaf obtained with 100 kg/ha of N applied in two equal splits (2.52%) was at par with 125 kg/ha of N applied in three splits as 50 + 50 + 25 (2.31%) and significantly higher than all other treatments of N application dose and time. Increased N dose at sowing and initiation of stem elongation increased vegetative growth and leaf area of crop and thus resulted in more leaf N uptake. Nitrogen content in leaf (2.92%), stem (0.99%) and siliqua (1.94%) at 120 DAS and in seed (4.89%) and stover (1.65%) at maturity obtained with 125 kg/ha of N applied in three splits was significantly higher than their respective content except over seed N content (4.70%) obtained with application of 125 kg/ha of N in two equal doses (Table 1). Ghanbari (2010) reported maximum N content (3.02%) with N application in 4 splits (25% at sowing + 25% at stem elongation + 25% beginning of flowering + 25% at end of flowering) and minimum (2.44%) with N application in 2 splits (50% at sowing + 50% at stem elongation) in canola *Brassica napus*.

With successive delay in sowing, there was significant reduction in N uptake by different plant parts at different growth stages and in seed and stover at maturity (Table 2). The highest N uptake at 40 DAS by the crop sown on 15 October (21.1 kg/ha) was 21.9% more than that of 30 October sown crop whereas 30 October sown crop recorded 63.2% more N uptake than 15 November sown crop. Similarly at 80 DAS, N uptake by leaves (51.6 kg/ha) and stems (49.4 kg/ha) and total (101 kg/ha) of 15 October sown crop was 34.0% more for leaves, 36.1% more for stems and 35.0% more for total N uptake than crop sown on 30 October. Crop sown on 30 October in turn registered 32.3% more N uptake by leaves, 1.4% by stem and 15.1% by total (leaf + stem) than 15 November sown crop. It indicated consistent and significant reduction in N uptake by leaves due to delay in sowing from 15 October to 30 October to 15 November but such differences for N uptake by stems were narrow between 30 October and 15 November sowing dates. At 120 DAS, crop sown on 15 October recorded significantly higher N uptake by leaves (53.6 kg/ha), stems (62.5 kg/ha), siliquae (108.4 kg/ha) and total i.e. leaf + stem + siliqua (224.5 kg/ha) which was 19.6% more in leaf, 38.8% more in stem, 16.6% more in siliqua and 22.8% more for total (leaf + stem + siliqua) N uptake than 30 October sown crop. Crop sown on 30 October registered 15.5%, 45.6%, 34.4% and 31.5% more N uptake by leaves, stems, siliquae, and total, respectively than 15 November sown crop. Timely sown crop (15 October) registered significantly higher N uptake by seed (118.3 kg/ha), stover (145.4 kg/ha) and total (263.7 kg/ha) which exceeded by 10.7%, 40.9% and 26.3% for seed, stover and total N uptake, respectively over 30 October sown crop (Table 2). Crop sown on 30 October registered 40.9% more

N uptake in seed, 52.9% more in stover and 46.4% more of total N uptake than 15 November sown crop. Mukherjee (2014) reported significant reduction in N uptake by Indian mustard with delay in sowing from 30 October to 30 November. Keerthi *et al.* (2017) also reported higher N uptake by *Brassica juncea* in 15 October than 15 November sown crop.

Differences in N uptake by different plant parts due to N application dose and time were significant except in stem at 80 DAS (Table 1). At 40 DAS, the highest N uptake (20.0 kg/ha) obtained with 125 kg/ha of N applied in two equal splits was significantly higher than all other treatments of N application (Table 2). At 80 DAS, N uptake by leaf (47.8 kg/ha) and total i.e. leaf + stem (85.9 kg/ha) obtained with 100 kg/ha of N applied in two equal splits was at par with 125 kg/ha of N applied in three splits (47.3, 92.8 kg/ha) and significantly higher than all other treatments. At 120 DAS, significantly highest N uptake in leaf (70.8 kg/ha), stem (64.1 kg/ha) and siliqua (112.2 kg/ha) and total i.e. leaf + stem + siliqua (247.1 kg/ha) was obtained with 125 kg/ha of N applied in three splits over all other treatments. Application of 125 kg/ha of N in two equal splits also resulted in significantly higher N uptake in all plant parts over 100 kg/ha of N applied in different splits. Application of 100 kg/ha of N in two splits (25 + 75) or in three splits (50 + 25 + 25) resulted in statistically similar N uptake with each other in all plant parts and total N uptake and was also at par with 34 + 33 + 33 applied at sowing, initiation of stem elongation and initiation of flowering for leaf and stem N uptake but registered significantly lower N uptake than other treatments at 120 DAS. Increase in DMA by leaf, stem and siliqua with higher dose of N and its increased number of splits increased the uptake in these plant parts at different growth stages.

The highest N uptake by seed (118.0 kg/ha), stover (134.1 kg/ha) and total i.e. seed + stover (252.1 kg/ha) at maturity was also obtained with 125 kg/ha of N applied in three splits which was significantly higher than all other treatments (Table 2). This increase accrued from higher seed and stover yields as well as N content in them with same dose (125 kg/ha of N in three splits) compared to all other treatments of N management. Similarly application of 125 kg/ha of N in two equal splits resulted in significantly higher N uptake in seed, stover as well as seed + stover than all other treatments. Reager *et al.* (2006) reported maximum uptake of N (93.9 kg/ha) in Indian mustard with split application of nitrogen as ⅓ basal + ⅓ 30 DAS + ⅓ 60 DAS and minimum N uptake (66.2 kg/ha) with N applied as ½ basal + ½ at 30 DAS.

Crop sown on 15 October and 30 October resulted in significantly higher oil content than 15 November sown crop (Table 3). Increased temperature during oil synthesis and reduced reproductive period of the late sown crop might be the reason for reduction in oil content than early sown crop. Similar reduction in oil content with delayed sowing was reported by Jain *et al.* (1989) and Keerthi *et al.* (2017) in *Brassica juncea* and by Malik (1994) in *Brassica carinata.* The oil yield produced by 15 October (969 kg/ha) and 30 October (942 kg/ha) sown crop was similar but significantly higher (45.3% and 41.2%) than 15 November sown crop (Table 3). Such improvement in oil yield in early sowing dates was mainly the result of the significant increase in seed yield.

An analysis of fatty acid profile of oil indicated that the fatty acid profiles (palmitic, stearic, oleic, linoleic, linolenic, eicosenic and erucic acids) were not influenced by sowing dates (Table 4).

Higher temperatures (more than 24-25°C) during seed filling stage in general, reduced oil content in seeds. (Hang and Gilliland, 1984; Ozer, 2003). Malik (1994) reported significant reductions in oil content in *Brassica carinata, Brassica juncea* and *Brassica napus* with delay in sowing from 10 November to 25 November and 9 December. Alam *et al.* (2014) from Bangladesh reported similar reductions in oil content with delay in sowing of *Brassica juncea, Brassica napus* and *Brassica campestris* from 25 November to 15 December. Similar reductions in oil content with delay in sowing from optimum times have been reported by Pramanik *et al.* (1996) and Kumar (2000) in *Brassica carinata,* Dinda *et al.* (2015) and Keerthi *et al.* (2017) in Indian mustard.

The effect of N dose and its application time on oil content was non-significant (Table 3). It varied in a narrow range of 38.6% to 39.5% under different treatments. Application of 125 kg/ha of N (mean over time of application) resulted in 11.4% higher oil yield than application of 100 kg/ha of N (830 kg/ha). Oil yield increased due to similar increase in seed yield with increase in N dose. The highest oil yield (941 kg/ha) obtained with 125 kg/ha of N applied as 50 kg at sowing + 50 kg at initiation of stem elongation + 25 kg at initiation of flowering was at par with application of 125 kg/ha (913 kg/ha) and 100 kg/ha of N (918 kg/ha) in two equal splits at sowing and initiation of stem elongation (Table 3). With application of 100 kg/ha of N, oil yield decreased significantly when lower amount of N was applied at sowing or initiation of stem elongation in comparison to its application in two equal splits at sowing and initiation of stem elongation. However additional application of 25 kg/ha of N at flowering initiation increased the oil yield by 2.5% over application of 100 kg/ha in two equal splits. The effect of dose and time of application of N on fatty acid composition of oil was non-significant (Table 4).

Shahraki *et al.* (2007) from Iran reported highest oil content in *Brassica napus* with application of N in 2 splits as ½ at sowing + ½ at stem elongation stage whereas, Ghanbari (2010) also from Iran reported highest oil content (38%) in canola *Brassica napus* with N applied in 3 splits (25% at sowing + 50% at stem elongation + 25% at start of flowering) and lowest oil content with N applied in 4 splits (25% at sowing + 25% at stem elongation + 25% at start of flowering + 25% at end of flowering). Cheema *et al.* (2010) from Pakistan also obtained highest oil (44.9%) content in *Brassica napus* with application of N in 2 splits as ½ at sowing + ½ at flowering. Seymour *et al.* (2013) recorded reduction in oil content of *Brassica napus* with application of N near flowering.

There was significant reduction in seed protein content with each successive delay in sowing (Table 3). Seed protein content of 15 October (29.8%) sown crop was 3.8% more than that of 30 October sowing whereas 30 October sown crop registered 5.5% more protein in seed than 15 November sown crop. This increase may be ascribed to more time available for growth and development and subsequently enhanced uptake of N by early sown crop. Ozer (2003) reported reduction in protein content in rapeseed with delay in sowing from 30 October to 10 November.

Seed protein yield decreased with delay in sowing from 15 October to 30 October and further to 15 November (Table 3). Seed protein yield (740 kg/ha) produced by 15 October sown crop was 10.8% more than that obtained from 30 October sown crop which in turn out yielded 15 November sown crop by a margin of 40.9%. Such an increase accrued from higher seed yield and protein content in early sown crop in comparison to its delayed sowing.

Increase in N dose to 125 kg/ha increased protein content in seed (28.8%) in comparison to 100 kg/ha of N (27.9%). The highest protein content (30.6%) obtained with 125 kg/ha of N applied in three splits was significantly more than all other treatments of dose and time of application of N (Table 3). Application of 100 kg/ha of N in three splits as 50 + 25 + 25 resulted in significantly more seed protein content (29.1%) than application of 100 kg/ha of N as 25 + 50 + 25 (27.2 %) or 125 kg/ha of N in two equal splits (27.1%). Cheema *et al.* (2010) obtained highest protein (23.7%) content in *Brassica napus* with application of N in 2 splits as ½ at sowing + ½ at flowering.

Application of 125 kg/ha of N (mean over time of application) increased the seed protein yield by 15.9% over 100 kg/ha of N (601 kg/ha). The highest protein yield (738 kg/ha) obtained with 125 kg/ha of N applied in three splits (50 + 50 + 25) was significantly higher than all other treatments. Addition application of 25 kg/ha of N at flowering initiation increased the seed protein yield by 11.7% over application of 100 kg/ha in two equal splits and 12.3% over application of 125 kg/ha of N in two equal splits. Application of lower dose of N (25 kg) at sowing or initiation of stem elongation or at flowering initiation significantly reduced the seed protein yield in comparison to application of 100 kg/ha of N in two equal splits. This was due to higher seed yield and protein content with application of N in two equal splits.

Table 1 Effect of dates of sowing and nitrogen management on nitrogen content (%) of canola oilseed rape at different growth stages

Treatments	40 DAS	80 DAS		120 DAS			At maturity	
		Leaf	Stem	Leaf	Stem	Siliqua	Seed	Stover
Date of sowing								
15 October	1.68	2.42	1.56	2.23	0.91	1.65	4.77	1.53
30 October	1.62	1.98	1.53	2.05	0.78	1.54	4.48	1.50
15 November	1.22	1.67	1.67	1.88	0.62	1.45	4.34	1.22
SEm±	0.05	0.20	-	0.02	0.03	0.02	0.10	0.02
CD (p=0.05)	0.10	0.40	NS	0.04	0.06	0.04	0.20	0.03
Dose (per ha) and time of application of nitrogen								
50* + 50**	1.23	2.52	1.55	1.84	0.79	1.63	4.53	1.25
25* + 75**	1.52	1.74	1.61	1.72	0.69	1.28	4.49	1.28
50* + 25** + 25***	1.59	2.06	1.53	1.88	0.64	1.25	4.65	1.40
25* + 50* + 25***	1.62	1.99	1.54	2.30	0.70	1.82	4.35	1.28
34* + 33** + 33***	1.48	1.67	1.67	1.70	0.78	1.21	4.47	1.24
62.5* + 62.5**	1.66	1.90	1.50	2.00	0.79	1.69	4.70	1.54
50* + 50** + 25***	1.44	2.31	1.70	2.92	0.99	1.94	4.89	1.65
SEm ±	0.02	0.05	-	0.01	0.02	0.02	0.03	0.02
CD (p=0.05)	0.11	0.31	NS	0.08	0.04	0.04	0.20	0.10

* = Sowing, ** = Initiation of stem elongation, *** = Initiation of flowering

Table 2 Effect of dates of sowing and nitrogen management on the nitrogen uptake (kg/ha) of canola oilseed rape at different growth stages

Treatments	40 DAS	80 DAS			120 DAS				At maturity		
		Leaf	Stem	Total	Leaf	Stem	Siliqua	Total	Seed	Stover	Total
Date of sowing											
15 October	21.1	51.6	49.4	101.0	53.6	62.5	108.4	224.5	118.3	145.4	263.7
30 October	17.3	38.5	36.3	74.8	44.8	45.0	93.0	182.8	106.8	102.0	208.8
15 November	10.6	29.1	35.8	65.0	38.8	30.9	69.2	139.0	75.8	66.7	142.6
SEm+	1.1	5.1	2.5	5.1	2.7	1.8	1.5	5.4	2.9	3.1	3.6
CD (p=0.05)	2.1	10.2	5.0	10.1	5.4	3.5	3.0	10.7	5.7	6.1	7.2
Dose (per ha) and time of application of nitrogen											
50* + 50**	13.8	47.8	38.1	85.9	44.4	48.2	96.1	188.8	105.7	88.4	194.2
25* + 75**	16.8	33.2	42.1	75.3	35.2	41.5	78.8	155.5	92.6	93.6	186.2
50* + 25** + 25***	15.6	39.7	38.7	77.5	35.0	39.6	77.8	152.4	94.1	101.4	195.4
25* + 50* + 25***	15.6	39.2	37.9	77.1	48.7	36.7	104.8	190.3	89.2	100.2	189.4
34* + 33** + 33***	16.4	32.0	41.0	73.0	36.1	41.8	66.4	144.5	99.6	92.0	191.6
62.5* + 62.5**	20.0	38.8	41.4	80.1	49.7	51.1	95.3	196.1	103.1	123.2	226.3
50* + 50** + 25***	16.1	47.3	45.4	92.8	70.8	64.1	112.2	247.1	118.0	134.1	252.2
SEm+	0.5	1.2	-	1.7	0.7	0.4	1.1	1.3	1.3	1.5	2.1
CD (p=0.05)	3.0	7.3	NS	10.3	3.9	2.6	6.5	7.9	7.9	9.2	12.6

* = Sowing, ** = Initiation of stem elongation, *** = Initiation of flowering

Table 3 Effect of dates of sowing and nitrogen management on oil content, oil yield, protein content, protein yield of canola oilseed rape

Treatments	Oil content (%)	Oil yield (kg/ha)	Protein content (%)	Protein yield (kg/ha)
Date of sowing				
15 October	39.1	969	29.8	740
30 October	39.6	942	28.0	668
15 November	38.1	667	27.2	474
SEm+	0.2	14	0.5	18
CD (p=0.05)	0.4	29	1.0	36
Dose (per ha) and time of application of nitrogen				
50* + 50**	39.5	918	28.3	661
25* + 75**	39.0	801	28.1	579
50* + 25** + 25***	38.7	782	29.1	588
25* + 50* + 25***	38.9	794	27.2	558
34* + 33** + 33***	38.9	865	28.0	623
62.5* + 62.5**	38.6	913	27.1	644
50* + 50** + 25***	39.1	941	30.6	738
SEm+		8	0.2	8
CD (p=0.05)	NS	46	1.4	50

* = Sowing, ** = Initiation of stem elongation, *** = Initiation of flowering

Table 4 Effect of dates of sowing and nitrogen management on fatty acid composition of canola oilseed rape

Treatments	Palmitic (16:0)	Stearic (18:0)	Oleic (18:1)	Linoleic (18:2)	Linolenic (18:3)	Eicosenoic (20:1)	Erucic (22:1)
Date of sowing							
15 October	4.0	1.7	69.3	15.2	8.6	0.2	0
30 October	4.1	1.6	68.8	15.3	8.8	0.2	0.5
15 November	4.5	1.8	67.9	15.8	8.9	0.6	0.7
SEm±	-	-	-	-	-	-	-
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS
Dose (per ha) and time of application of nitrogen							
50* + 50**	4.2	1.7	68.6	15.3	8.9	0.2	0
25* + 75**	4.3	1.7	68.1	15.4	8.6	0.3	0
50* + 25** + 25***	4.2	1.6	68.9	15.4	8.8	0.2	0
25* + 50* + 25***	4.3	1.7	69.0	15.0	8.8	0.1	0
34* + 33** + 33***	4.3	1.7	69.2	15.4	8.5	0.5	0.1
62.5* + 62.5**	4.3	1.7	68.6	15.6	8.5	0.4	0.2
50* + 50** + 25***	4.0	1.7	68.2	15.8	8.2	0.2	0.1
SEm ±	-	-	-	-	-	-	-
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS

* = Sowing, ** = Initiation of stem elongation, *** = Initiation of flowering

Table 5 Interactive effect of dates of sowing and nitrogen management on oil yield (kg/ha) of canola oilseed rape

Dose (per ha) and time of application of nitrogen	Date of sowing		
	15 October	30 October	15 November
50* + 50**	1019	984	752
25* + 75**	959	844	599
50* + 25** + 25***	904	918	526
25* + 50* + 25***	872	950	559
34* + 33** + 33***	964	934	697
62.5* + 62.5**	1009	972	758
50* + 50** + 25***	1056	990	777
SEm ±		7	
CD (p=0.05)		79	

Interaction between dates of sowing and N dose and its application time for oil yield was significant (Table 5). Oil yield decreased with each successive delay in sowing with all N treatments except with 100 kg/ha of N applied in three splits as 50 + 25 + 25 or 25 + 50 + 25 at sowing, initiation of stem elongation and initiation of flowering) where 30 October sowing was at par with 15 October sowing date. Application of 125 kg/ha of N in three splits as 50 + 50 + 25 resulted in highest oil yield in all sowing dates and, in each respective sowing date, it was on par with 100 or 125 kg/ha of N applied in two equal splits. In all sowing dates, it was significantly higher than 100 kg/ha of N applied as 25 + 75. The highest oil yield produced by 15 October sown crop with application of 125 kg/ha of N in three splits (1056 kg/ha) was also at par with 30 October sown crop with application of 100 kg/ha of N in two equal splits or 125 kg/ha of N in three splits as 50 + 50 + 25.

Delay in sowing from 15 October to 30 October to 15 November significantly reduced the nitrogen (N) content and uptake by canola oilseed rape at all growth stages in different plant parts as well as in seed and stover at maturity except N content in stem at 80 DAS. Crop sown on 15 October registered 21.9%, 35.0%, 22.8%, 10.7% and 40.9% more N uptake than 30 October sown crop which in turn registered 63.2%, 65.1%, 31.5%, 40.9% and 52.9% more N uptake than 15 November sown crop at 40, 80 and 120 DAS, seed and stover, respectively. The oil and seed protein yield from 15 October sown crop were 2.9% and 10.8% higher than 30

October sown crop which in turn out yielded 15 November sown crop by a margin of 41.2 and 56.1%. Differences in N content and uptake in different plant parts due to N application dose and time were significant except in stem at 80 DAS. Application of 125 kg/ha of N increased the oil yield by 11.4% and protein yield by 15.9% over 100 kg/ha of N. The significantly highest oil and protein yields were obtained with application of 125 kg/ha of N in three splits as 50 kg at sowing + 50 kg at initiation of stem elongation + 25 kg at initiation of flowering than all other treatments except the oil yield over 125 and 100 kg/ha of N in two equal splits.

REFERENCES

Alam M M, Begum F and Roy P 2014. Yield and yield attributes of rapeseed-mustard (*Brassica*) genotypes grown under late sown condition. *Bangladesh Journal of Agricultural Research*, **39**: 311-336.

Alexander D E, Silvela L, Collins S F I and Rodgers R C 1967. Analysis of oil content in maize by wide line NMR. *Journal of American Oil Chemist Society*, **44**: 555-558.

Appleqvist L A 1968. Rapid methods of lipid extraction and fatty acid ester preparation for seed and leaf tissue with special remarks on preventing the accumulation of lipid contaminants. *Ark Kenci*, **28**: 351-370.

Cheema M A, Saleem M F, Muhammad N, Wahid M A and Baber B H 2010. Impact of rate and timing of nitrogen application on yield and quality of canola (*Brassica napus* L.). *Pakistan Journal of Botany*, **42**: 1723-1731.

Dinda N K, Ray M and Sarkar P 2015. Effect of sowing date *vis-a-vis* variety of rapeseed and mustard on growth, yield and aphid infestation in Gangetic plains of West Bengal. *The Ecosan*, **9**: 21-24.

Ferguson R B, Hergert G W, Schepers J S, Gotway C A, Cahoon J E and Peterson T A 2002. Site-specifc nitrogen management of irrigated maize: yield and soil residual nitrate effects. *Soil Science Society of America Journal*, **66**: 544-553.

Ghanbari A 2010. Effects of nitrogen rates and splitting on oil content and seed yield of canola (*Brassica napus* L.). *American Eurasian Journal of Agriculture and Environmental Sciences*, **8**: 161-166.

Grant C, Wu R, Selles F, Harker K N, Clayton G W, Bittman S, Zebarth B J and Lupwayi N Z 2012. Crop yield and nitrogen concentration with controlled release urea and split applications of nitrogen as compared to non-coated urea applied at seeding. *Field Crops Research*, **127**: 170-180.

Hang N and Gilliland G C 1984. Planting date effects on yield and quality of oilseed *Brassica* spp. Research Bulltein, Agriculture Research Centre, Washington State University, pp. 1-12.

Jain V K, Chauhan Y S, Khandekar M P and Jain P C 1989. Effect of sowing dates and genotypes on yield and yield attributing traits in Indian mustard. *Madras Agricultural Journal*, **76**: 241-246.

Kaur H 2015. Physiological implications of determinate plant growth habit in Ethiopian mustard (*Brassica carinata* A. Braun) under different dates of sowing. M. Sc. Thesis, Punjab Agricultural University, Ludhiana, Punjab.

Kaur N 2000. Nitrogen requirement of seeded and transplanted African sarson (*Brassica carinata* A. Braun). M.Sc. Thesis, Punjab Agricultural University, Ludhiana, Punjab.

Keerthi P, Pannu R K and Dhaka A K, Daniel J and Yogesh 2017. Yield, nitrogen uptake and nutrient use efficiency in Indian mustard (*Brassica juncea* L.) as affected by date of sowing and nitrogen levels in western Haryana, India. *International Journal of Current Microbiology and Applied Science,* **6**: 1168-1177.

Kumar D 2000. Nitrogen requirement of transplanted hybrid gobhi sarson (*Brassica napus* L.) in relation to age of seedling. M. Sc. Thesis, Punjab Agricultural University, Ludhiana, Punjab.

Ma B L, Biswas DK, Herath A W, Whalen J K, Ruan S Q, Caldwell C, Earl H, Vanasse A, Scott P and Smith D L 2015. Growth, yield and yield components of canola as affected by nitrogen, sulphur and boron fertilization. *Journal of Plant Nutrition and Soil Science*, **178**: 658-670.

Malik R S 1994. *Brassica carinata*: a potential oilseed crop for late sowing. *Annals of Agricultural Research*, **65**: 478-482.

Mukherjee D 2014. Influence of date of sowing and nutrient management practices on sustainable production of Indian mustard (*Brassica juncea*) under sub-temperate condition of eastern Himalaya. *Research on Crops*, **15**: 122-128.

Ozer H 2003. Sowing date and nitrogen rate effects on growth, yield and yield components of two summer rapeseed cultivars. *European Journal of Agronomy*, **19**: 453-463.

Pramanik S C, Singh N P, Singh S and Garnayak L M 1996. Irrigation and nitrogen effects on oil yield and nitrogen uptake by Ethiopian mustard (*Brassica carinata*). *Indian Journal of Agronomy*, **41**: 101-107.

Reager M L, Sharma S K and Yadav R S 2006. Yield attributes, yield and nutrient uptake of Indian mustard (*Brassica juncea*) as influenced by nitrogen levels and its split application in arid western Rajasthan. *Indian Journal of Agronomy*, **51**: 213-216.

Seymour M, Sprigg S, French B, Malik R, Bucat J and Harries M 2013. Timing of nitrogen for canola in lower rainfall areas in Western Australia Department of Agriculture and Food, Western Australia. Grains Research and Development Corporation, Western Australia.

Shahraki A D, Kashani A, Mesgarbashi M, Mamghani R and Nabipour M 2007. The effect of planting density and time of nitrogen application on some agronomical characteristic of rapeseed (*Brassica napus* L.). *Genetics and Breeding*, **2**: 389-392.

Subbiah B V and Asija G L 1956. A rapid procedure for estimation of available nitrogen in soils. *Current Science*, **25**: 259-266.

MEETING REPORT

National Seminar on

"Technological Innovations in Oilseed Crops for Enhanced Productivity, Profitability and Nutritional Security" held at PJTSAU Auditorium, Hyderabad during February 7-8, 2020

Preamble

There is a huge demand-supply gap in vegetable oils and India is importing vegetable oils worth ₹.69,024 crores (2018-19). In order to reduce the imports and to increase domestic availability of vegetable oils, achieving quantum jump in oilseeds productivity through development of innovative, sustainable and profitable technologies and their adoption is crucial. Concerted efforts of NARS along with its partners and other stakeholders has resulted in development of several technologies, that need upscaling along with strategic policy to achieve higher adoption and self-sufficiency in vegetable oil requirement in the short to medium term.

Status

India is among the largest vegetable oil economies in the world next to only USA, China, Brazil and Argentina. Oilseeds are the second largest agriculture commodity in India after cereals occupying about 13-14% of gross cropped area. They account for 7% of value of all agricultural products. About 14 million farmers are involved in oilseeds production and a million in processing. The diverse agro-ecological conditions in the country are favorable for growing nine annual oilseed crops, considered as the primary source of vegetable oil that include seven edible (groundnut, rapeseed & mustard, soybean, sunflower, sesame, safflower and niger) and two non-edible/industrial oilseeds (castor and linseed). The nine annual oilseeds are cultivated in 25.51 million ha with a production of 32.24 million tonnes with a productivity of 1264 kg/ha (2018-19). In addition, the non-conventional oil sources including rice bran oil, cottonseed oil and corn oil along with perennial oil bearing crops such as oil palm and coconut and several oil bearing tree species of forest origin *viz*., pongamia, jatropha, neem, mahua, etc. collectively called secondary sources of oil, contribute nearly a third to vegetable oil kitty of the country. Paradoxically, despite having the highest acreage under oilseeds and maintaining steady increase in oilseeds production and productivity, it is not matching the pace of increase in population and *per capita* consumption of vegetable oils (18 kg in 2018) driven by population growth with a higher standard of living, price elasticity and industrial needs. Currently, the vegetable oil needs of the country is being met from more than 60% imports (15 million t.) at a cost of Rs. 69, 000 crores on import bill (2018-19). Globally, the new dimension of demand for vegetable oil comes from the unlimited demand for biofuel due to the commitments under UN Kyoto protocol for binding emission reduction. Oilseeds are the most sought renewable source of vegetable oil for biofuel production.

Considering the complexity of vegetable oils sector in India, comprising primarily oilseed growers, processors and many stakeholders with diverse interests, it was considered to deliberate on achieving significant enhancement of oilseeds and vegetable oil production through productivity improvement under the prevailing growing conditions, quicker technology transfer and concerns of decelerating area, addressing issues of the processing industry, favourable policy framework of import and domestic marketing/procurement and pricing interventions, quality and blending, crop diversification/replacement of area under rice, area expansion in rice fallows, public awareness for moderation in edible oil consumption in tune with WHO recommendations. The national seminar on "**Technological Innovations in Oilseed Crops for Enhanced Productivity, Profitability and Nutritional Security**" (**NOS-2020**) at Hyderabad during February 7-8, 2020 under the aegis of Indian Society of Oilseeds Research, provided a common platform for convergence of all stakeholders engaged in oilseed supply and value chain to address the issues and foster viable partnerships.

The Seminar

The seminar was attended by 477 delegates representing scientific, extension, industry and developmental agencies. The National seminar provided an opportunity to review, share and discuss the opportunities and alternatives for overcoming the barriers for increasing the productivity and profitability of oilseeds cultivation and vegetable oil industry in India.

Inaugurating the seminar Dr. Trilochan Mohapatra, Secretary, DARE and Director General, ICAR, New Delhi and President, ISOR invited the participants of the national seminar to discuss threadbare, the issues concerning all aspects of oilseeds and vegetable oils to curtail the imports. From the demand side, he called for moderation in oil consumption for better health of the citizens. He stressed on the need to address issues to achieve quantum jump in oilseeds and vegetable oil production through research and technology (higher use of genomic resources and systematic incorporation in varietal development, integrated crop management and achieve higher input and resource use efficiency, effective and eco-friendly pest and disease management, etc.) across crops and states for achieving higher vegetable oil production and export. He appreciated the initiative for establishing 35 oilseed seed hubs for meeting the supply of quality seed supply as a significant step towards achieving higher VRR and SRR to aid in increasing oilseeds production. He reiterated on the need to adopt modern breeding techniques such as genome editing, speed breeding, marker assisted breeding and also to continue the research efforts for value addition in crops like castor, reducing gap from lab to land with better out-reach activities; and higher value chain from seed to Industry etc. to break the intrinsic yield barriers in oilseed crops.

Dr. A. Vishnuvardhan Reddy, Director, ICAR-IIOR, Hyderabad and Vice-President, ISOR, provided the status and background of vegetable oils in the country. The significant achievement of increase in oilseeds production by 5.5 times to reach to 32 million tonnes from a mere 6 million tonnes in sixties was commendable given the background of predominantly (>70%) rainfed ecosystem, small farm holdings and unfavourable market environment.

Dr. V. Praveen Rao, Vice-Chancellor, PJTSAU, Rajendranagar, Hyderabad stressed the need for clear policy framework for adopting precision agriculture practices and gadgets such as sensors and use of drones for spraying and data acquisition. He highlighted the experience of Telangana State in identifying efficient crop ecological zones as crop colonies for focused development and stressed the need for valuing ecosystem services of oilseeds cultivation beyond yield and profits.

Dr. Mangala Rai, Former Secretary, DARE & DG, ICAR, recapped the progressive increase in oilseeds production, the reasons for oil import due to the dynamic policy decisions affecting domestic vegetable oil production and import requirement and tariffs. He emphasized the importance of value addition in oilseeds and promoting valuable by-products (cake, meal, fibre etc.) as main products in crops like soybean, linseed, etc. He exhorted to provide more emphasis on achieving higher resource use efficiency of water, continued soil health especially with respect to the soil micro-organisms, for a sustainable oilseeds production system. The need to embrace cutting edge technologies and tailoring genotypes to varied growing situations and stresses was emphasized for achieving quantum increase in production.

Dr. Panjab Singh, former Secretary, DARE & DG, ICAR opined that enabling policy in conjunction with the technological development is essential for achieving higher oilseeds production to meet the growing demand. He suggested that moderating the quantum of consumption coupled with infusion of technology for increasing production will provide surplus for export in long term. Dr. Singh informed that oilseed crops help in diversification of cropping systems without disturbing existing main crops to fit as efficient either preceding or succeeding or intercrops. He proposed that policy decision to keep a ceiling on growing of cereals like rice/wheat in best ecologies and encouraging oilseeds need to be emphasized and supported including value addition for increasing much needed boost in the oilseed production.

During the two day Seminar, in-depth discussions were held under seven themes *viz* Accelerated breeding and boosting crop yields through genetic improvement, Conservation agriculture and enhancing resource use efficiency in production systems, Stress management and climate change; Processing, value addition, specialty oils and secondary sources of oil; Knowledge management and technology transfer for reaching farmers and consumers; Marketing, Policy support and Consumer awareness; and Agri-Innovation and entrepreneurship opportunities. Thus, all aspects of productivity enhancement, crop management, processing, value addition, market chain, and the complete value chain were discussed. In each of the sessions, there were key note addresses by pioneers in the respective areas, and lead lectures by the experts in each of the domains that flagged the recent developments as well as the issues and challenges that need to be addressed.

THE RECOMMENDATIONS FROM THE SEMINAR

RESEARCH FRONT

Crop Improvement

- Focused attention is required on germplasm enhancement and pre-breeding.
- Systematic efforts are needed to collect, conserve, regenerate the local landraces and wild relatives and establishment of 'International nursery' for oilseeds.
- Emphasis be given for trait discovery, identification of markers linked to economically important traits and establishment of phenotyping facilities for oilseed crops.
- Besides attempting for resistance to biotic and abiotic stress, there is a need to breed for hauling in the genes for yield *per se.* A collection of stocks with crop-wise yield QTLs be made, subjected to meta-analysis and used further. Genes be supplemented as per the need of mega-environment for which the breeding strategy is applied.
- Specialty varieties are to be developed and commercialized as the vehicles of commerce in agriculture towards farm-prosperity.
- Focus to be given for value addition in castor to increase export of value added products as well as in reducing the gap in industry – academia linkage in upscaling the value chain.
- Value addition in oilseeds and promoting valuable by-products (cake, meal, fibre etc.,) in crops like soybean, linseed, etc. must be given importance to increase profitability.
- While resorting to speed breeding, appropriate glasshouse or controlled environment (photoperiod, temperature, and humidity) chambers be made for each oilseed crop to enable 4-5 generations of advancement each year *eg*. short-day oilseeds like soybean, black-out arrangement, specific pots/trays for density increase, drying etc., may be needed.
- Fast-forwarding the genetic gain be carried out by combining accelerated breeding with single seed descent, marker-assisted selection, doubled haploid and genomic selection (GS) methods.
- Breeding for climate-change resilience will need (i) strategic crossing of complementary physiological traits based on phenomics and metabolomics profiling, and (ii) phenotyping and remote-sensing platforms for large-scale screening. These need to be adopted.
- Translational research be carried out for speedy outcomes utilizing the plurality and breadth of the Indian agricultural R&D system.
- Improvement of traits such as seed dispersal, oil content and quality, plant architecture, reduction/ removal of allergens in oilseeds may be attempted through genome editing approach.

Crop Production

- The developments in sensor technology and IT tools (data analytics, remote sensing, geo/plant referencing with micro-irrigation systems need to be integrated.
- There is an urgent need to adopt, scale up and capacity building of conservation agriculture technologies – focusing on oilseed based cropping systems in the changing climatic scenario for enhanced productivity, carbon sequestration and sustainability.
- Small implements and machinery for complete value chain for oilseed crops for attending to the timely farm operations, reducing the cost of cultivation, drudgery by small holding farmers must be developed.
- Village/block level clusters to promote and foster cultivation under Good Agricultural Practices (GAP) to be established.

Stress Management

- Intensive efforts to be made on developing of resistant cultivars to insect vectors of important viral diseases in oilseed crops through application of molecular biology

- Need to strengthen research activities on understanding climate change effects on crop pests and natural enemies to gear up for managing pest outbreaks
- Importance to be given for development of location specific forecasting services to farmers about insect pests and diseases by deployment of wireless sensor networks (WSN) and decision support system (DSS) development
- Intensive research efforts to be made to study, understand and make use of crop specific soil microbiome in crop health management
- Need to explore and identify abiotic stress tolerant beneficial microbial endophytes for deployment in stressed ecosystems
- Specific need is to have resistance to necrosis of sunflower, phytoplasma in sesame, aphids in safflower, and rugose whitefly an invasive in oil palm etc. Need to understand the basis of resistance by adopting basic research.

Processing, Value addition, Specialty Oils and Secondary Sources of Oils

Oil Palm

- Genetic improvement of the plant bearing material to be given the highest priority to increase the oil yield.
- Appropriate cropping systems for increasing the farmers' income besides reducing the negative externalities on the ecological front need to be identified and adopted.
- Appropriate institutional arrangements and policy environment favouring oil palm for sustained oil production and its by-product utilization through value addition to be developed.

Coconut

- Focus to be given for developing varieties/ hybrids of very short to short type and bearing more number of nuts and replacement of old and senile palms in traditional areas.
- Virgin Coconut Oil (VCO) holds high promise for domestic and export market. Technologies developed by CSIR, ICAR-CPCRI should be commercially utilized by entrepreneurs, SHG's/FPO's with technical / financial support.
- Promotion of value added products *viz*., milk based products and activated carbon for domestic and export market to be explored.

Olive

- Mapping of suitable agro-ecological regions for area expansion should primarily focus on "Chilling requirement and Critical range of temperature" besides other associated soil and climatic factors
- Ecological mapping is a pre-requisite for the genotype evaluation for development / refinement of the production technology. This must be given a priority.

Soybean

- Greater penetration of specialty products through technology licensing must be explored.
- Public Private Partnership for niche product development to be encouraged.

Linseed

- A suitable action plan for area expansion in convergence with Bharathi Vidhyapeeth and FPO's/NGO's should be developed for enhancing the availability of omega 3 present in linseed

Sesame

- High oil yield genotypes with emphasis on low peroxide value and low free fatty acid must be given priority.

Bioenergy

- Integration of oilseed with bio energy research programmes for increasing the domestic production of edible oils needs to done.

- Area expansion of the identified (by Ministry of Energy and Petroleum) 2 million ha with suitable technology transfer mechanism of oil bearing plant material.
- A brainstorming session on using plant remains for bioethanol production is to be conducted.

EXTENSION AND KNOWLEDGE MANAGEMENT

- All the developed interactive mobile apps, DSS and other ICT approaches must reach farmers for bridging the gap between attainable yields with improved technologies compared to farmers' practices.
- Wider adoptability of improved technologies, there is a need for convergence of the activities being carried out by different extension agencies including corporate company led efforts is to be ensured.

DATA ANALYSIS

- The available data over the decades and across the country is to be utilized through the data analytics tools which would help in pinpointing corrective/promotive measures to achieve the goals quickly and efficiently.
- Crop profitability index in each potential areas of oilseed cultivation is to be worked out so that places where oilseed has a competitive edge could be identified for growing oilseed crops.
- Available data must be analyzed thoroughly to assess the amount of water that is required to produce one unit of oil.

POLICY ISSUES

- Public acceptance and regulatory policy are critical for promoting the use of CRISPR technology in crops and efforts must be made to formulate measures to ensure these.
- Edible oil policy is skewed in favour of consumers rather than producers and therefore, creative disruptive policy instruments need to be introduced to reverse the trends and insulate the domestic oilseeds economy.
- On the consumption front, skewness in per capita availability (PCA) (ranging from 9-11 kg/annum in low income group and between: 22-24 kg/annum in high income group) needs to be reduced by subsidizing edible oils under PDS to advance nutritional security to the low income groups. This can be clubbed with procurement of oilseeds at MSP.
- Oilseeds Crushing Industry Modernization Fund is to be created to increase the efficiency.
- Partial imports of oilseeds instead of wholesale import of vegetable oils is to be adopted for better capacity utilization of the processing sector besides providing employment and generating income by selling oil / cake / meal to feed industry and for export purpose.
- There is a need to impose quantitative restrictions on import of edible oil since the excessive, speculation driven, unrestrained vegetable oil imports tend to suppress domestic oilseed prices. Measures to impose annual ceiling on import volume; close monitoring of import; quarterly reviews; dynamic tariffs and most importantly reducing the credit period would provide an impetus to the domestic oilseeds farmers
- Backward integration by setting up processing facilities especially in backward areas/ non-traditional areas with a view to improve processing activities besides reducing the length of supply chain is needed if crop diversification is to be taken up seriously.
- Price tracking mechanism has to be intensified and farmers should be made aware of the market intelligence by appropriate capacity building of farmers.
- Promotion of oil palm in eastern India which would bring higher production need to be given impetus.
- Policy decision to keep a ceiling on growing of cereals like rice/wheat in best ecologies and encouraging oilseeds need to be emphasized and supported including value addition for increasing much needed oilseed production.

- Supportive rural infrastructure for storage including cold chains need to be established.
- Robust procurement systems to be implemented - Ensuring MSP implementation through increased procurement of the oilseeds.
- Enabling and stable policy environment is the key to scale up micro-irrigation systems for higher water use efficiency and enhancing oilseed productivity in the country. This needs to be effected.
- There is an urgent need to encourage and support the local grassroots innovators by all relevant stakeholders for due recognition and to develop them as entrepreneurs.
- Policy decision is urgently needed on the issues such as use of GM crops (*e.g*. Bt genes, gene silencing etc.) which can play a major role in organic agriculture and sustainable management of pests
- Stringent quarantine system and policy to manage invasive pests and vectors are to be executed. Often, time is wasted in not admitting the presence of invasive pests which favours the dispersal of the invasive.
- Government support to be given for establishing local enterprises for production of some important components of IPM like bio-agents and other inputs used in organic agriculture
- Fixing Standard Input Output Norms for duty/tax free import of low-cost crude edible oils against matching export of refined oils would enable complete utilization of the existing installed capacity of the country. This needs to be put in place.

A.Vishnuvardhan Reddy, Vice-President, ISOR, V. Dinesh Kumar, Programme Committee Convener, NOS and Editor, JOR, M. Sujatha, General Secretary, ISOR, and GD Satish Kumar, Treasurer, ISOR

INDIAN SOCIETY OF OILSEEDS RESEARCH

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

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

General

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

Manuscript

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

Full-length Articles

Organization of the Manuscript

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

Full-length article comprises the following sections.

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

Guidelines for each section are as follows:

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

Short Title

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

Title

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

Author/Authors

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

Institution and Address

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

Abstract

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Rao C R 1968. *Advances in Statistical Methods in Biometrical Research*, pp.40-45, John Wiley & Sons, New York.

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

Figures

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

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

Expression of Plant Nutrients on Elemental Basis

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

SI Units and Symbols

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

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

Names and Symbols of SI Units

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

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

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

Some applications along with symbols

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

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

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

Special Instructions

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

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

III. A sentence should not begin with an abbreviation.

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

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

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

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

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

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

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

Details of the peer review process

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

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

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

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

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

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

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

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

Important Instructions

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

SPECIAL ANNOUNCEMENT

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

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

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

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

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

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

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

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

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

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

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

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

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

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

o0o