ISSN 0970-2776
Volume 39 Number 2 June, 2022

Journal of Oilseeds Research

Indian Society of Oilseeds Research
ICAR-Indian Institute of Oilseeds Research
Rajendranagar, Hyderabad-500030, India

THE INDIAN SOCIETY OF OILSEEDS RESEARCH

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

EXECUTIVE COUNCIL FOR 2022-2024

Editorial Board

MEMBERSHIP TARIFF

(w.e.f. 01.06.2014)

Life Membership	**Annual Subscription**		**India**	**Abroad**
Individual : Rs.5000/- + Admn. Fee Rs.50/-	Individual	:	Rs. 1000/- + Admn. Fee Rs.50/-	US$ 100 Ordinary
	Institutions	:	Rs. 6000/-	US$ 200 Institutions
	Students	:	Rs. 500/- + 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 **4.59** by National Academy of Agricultural Sciences (NAAS) from January 1, 2021

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

JOURNAL OF OILSEEDS RESEARCH

Previous Issue : Vol. **39**, No. 1, pp. 1-65

Vol. **39**, No. 2 June, 2022

CONTENTS

Short Communications

Review

Weed management in sunflower: A review on challenges and opportunities

A SOLAIMALAI, M JAYAKUMAR[1*], V SANJIV KUMAR, S MANOHARAN,
K BASKAR AND G RAVINDRA CHARY[2]

*AICRP on Dryland Agriculture, Agril. Research Station, Tamil Nadu Agril University, Kovilpatti-628 501, Tamil Nadu

((Received: October 25, 2021; Revised; May 24, 2022; Accepted: June 13, 2022)

ABSTRACT

Weed management is a science-based decision-making process that coordinates the use of macro and micro-environment information, weed biology and ecology, and all available technologies to control weeds by the most economical and ecologically viable methods. The concept of weed management is not new and many advances have been made in recent years in India. Weeds compete with crop plants for nutrients, soil water, space and sunlight causing poor growth and yield losses. The extent of yield losses caused by weeds depends up weed density and type of weed flora. The age old practice of controlling weeds in sunflower by hand weeding and hoeing is time consuming, more expensive and tedious although it is more effective. However, timely weed management may not be possible manually due to non-availability of labourers and high rate of wages during peak farm operation. Under such condition, use of herbicides is the need of the hour for crop production. Therefore, use of newly introduced pre-emergence and post emergence herbicides along with cultural and mechanical methods is needed for effective weed management and increase the productivity of sunflower.

Keywords: Allelopathy, Critical weed competition period, IWM, Sunflower, Yield losses, Weed flora

Sunflower (*Helianthus annuus* L.) is one of India's most important oilseed crops, ranking third in terms of edible oil production behind soybean and peanuts. Because of its short duration, photo insensitivity, better yield potential, and adaptability to a variety of soil and agro-climatic conditions, it has potential as an edible oilseed crop. It is rich in polyunsaturated fatty acids and vitamin E and may be grown at any time of year. The sunflower crop was introduced to India in 1969 as a supplementary oilseed crop to fill the void left by the shortage of edible oil. Commercial sunflower production began in 1972-73 with a few imported types from the Soviet Union and Canada. The crop has well accepted by the farming community because of its desirable attributes. India has emerged as second major sunflower producing country in Asia after China. In India, sunflower is cultivated in 0.28 million hectare with a production of 0.22 million tonnes and productivity of 782 kg/ha (Anonymous, 2019). The cultivation of sunflower is mainly confined to Southern India comprising the states of Karnataka, Maharashtra, Andhra Pradesh and Tamil Nadu. There are various factors responsible for low yield in sunflower.

Despite decades of use of modern weed management methods, weeds continue to represent a significant threat to the long-term viability of sunflower production. The emergence of herbicide-resistant weeds and weed shifting demonstrate the ineffectiveness of modern agro-technical solutions. Integrated Weed Management (IWM) is a long-term approach to weed control that incorporates all available weed control techniques, such as preventative measures, crop rotations, tillage, crop competition, mechanical and physical control, herbicide rotation, herbicide mixtures, biological control, nutrition, irrigation, flaming and so on, while minimizing economic, health and environmental risks (Swanton *et al*., 2008).

It is well known that the weeds interfere with crops causing serious impacts through either competition (for light, water, nutrients and space) and/or allelopathy. Weed infestation removed 48.2 kg N, 14.4 kg P/ha in sunflower (Wanjari *et al*., 2001). Weeds cause great reduction of sunflower yield ranges from 18.6-36.3% (Jat and Giri, 2000; Singh and Giri, 2001). Accordingly, it is essential to control weeds in sunflower fields. Herein, agricultural methods of weed control, such as intercropping are considered the best, especially after the contraction of herbicides compounds volume because they have negative environmental effects, but it is indispensable. Intercropping patterns are more effective than monocropping in suppression of weeds, but their effectiveness varies greatly (Girjesh and Patil, 1991). CHEN Yuan-quan *et al*. (2012) results demonstrated that maize-sunflower is most effective on weed suppression and that it also has a more competitively inhibitory effect on Xanthium compared with the other patterns by evaluating the Xanthium density and dry weight under different intercropping systems with maize. Maize-peanut, maize-alfalfa and maize-sweet potato intercrops have no apparent inhibitory effect on weeds. To further investigate

[1]Central Coffee Research Institute, Coffee Research Station, Chikmagaluru-577 117, Karnataka; [2]AICRP on Dryland Agriculture, CRIDA, Santosh Nagar, Hyderabad-500 059, Telengana;
Corresponding author's E-mail: agrokumar2013@gmail.com

the effect of maize-sunflower on weed control, indoor pot experiments were conducted by determining the effect of extractions on germination rate (GR), root vigor, MDA (malondialdehyde), SOD (superoxide dismutase) and POD (peroxidase) content of Xanthium. The results better prove that maize-sunflower extractions have more significant inhibitory effect on GR and young root vigor of Xanthium than maize monocrop extractions.

Many investigators have been confirmed that hoeing twice is the most effective weed control practice for diminishing the weed dry matter accumulation in sunflower-soybean cropping systems (Samui and Roy 1990; Devidayal and Reddy 1991; Bochare *et al.,* 1992; Giri *et al.,* 1998; Jan *et al.,* 2000; Kushwah and Vyas, 2005; Vyas *et al.,* 2000). With all of the above-mentioned in mind, the goal of this research is to analyze and recommend sustainable production technology of sunflower in intercropping systems. Krishnaprabu (2018) revealed that adoption of sunflower + green gram cropping system produced the highest seed yield of 1486 kg/ha during summer season, which has followed by sunflower + sesame than sole sunflower crop recorded the lowest seed yield of 1379 kg/ha during summer season. The research considered sunflower as the main, cash crop, and investigated different legumes as complementary crops, with living mulch as the soil cover. In order to achieve the stated advantages of this production method, the research focused on defining the most suitable legumes for intercropping with sunflower (Jensen *et al.,* 2020).

Furthermore, butralin herbicide effectively controls grasses and some broad-leaf weeds (Hassall, 1990), while prometryn controls annual broad-leaved and some grasses (WSSA, 1994). The major effect of dinitroanilines (e.g. butralin) is on the growth of roots, the shoots that emerge often appear quite normal, but soon die because of failure of secondary root development. Prometryn is absorbed through roots from soil application and translocated to shoots, and inhibits photosynthesis resulting in blocking electron transport leading to stopping CO_2 fixation and production of ATP and $NADPH_2$. So, the integration between the two complementary herbicides- butralin and prometryn is expected to broaden the spectrum of controlled weed species, in addition to reducing the dosage of each to 50% of their recommended rates. Hereof, both of environmental pollution and weed control costs will be decreased. In this respect, successful integrated chemical weed control results in sunflower and soybean were observed by Giri *et al.* (1998) and Behera *et al.* (2005).

Crop rotation is an essential part of weed control. Crop selection and sequencing have an impact on long-term weed population dynamics and, as a result, weed control. Rotations of crops with various life cycles were an important component of weed management in traditional farming. Farmers have additional opportunity to prevent plant establishment or seed production by weeds by planting and harvesting these crops at different times. The successful inclusion of oilseed crops in cereal-based cropping systems has been shown to have positive agronomic and economic impacts. Genetic improvement in oilseed crop yields will continue to make them economically competitive with cereals (Johnston *et al.,* 2002). Lafond *et al.* (1993), Dhuyvetter *et al.* (1996) and Zentner *et al.* (2002) explained that where oilseeds are adapted, their inclusion in rotation with cereals could increase net inversion return and reduce risk through improved production stability. The highest sunflower seed yields and economics were obtained from the rapeseed-common vetch + sunflower-wheat and a fodder pea + sunflower-wheat fodder pea + sunflower crop rotation systems under rainfed conditions. These crop rotation systems were found the best crop rotation systems under rainfed conditions of Southern Marmara region of Turkey (Dogan *et al.,* 2008).

On the other hand, 1st rotation system (wheat-chickpea-sunflower) of the trials consisting of sunflower as main crop was also profit rotation because chickpea was a cash crop in agricultural marketing. Differences in net return were affected by crops in rotation, weather conditions and crop prices. In similar studies, the highest net income was obtained from the rice-potato-sunflower sequence (Jaiswal *et al.,* 1993) and sunflower-groundnut rotation (Reddy and Sudhakara Babu, 2003). In addition, Nel and Loubser (2004) reported that dry bean and soybean improved net returns and reduced risk while sunflower was the most effective in reducing risk with little effect on the net return.

Application of butralin+prometryn or hoeing twice rid the sunflower plants of weed competition early and the mortality impact of such treatments on weeds remains along the critical period of weed competition, until the plants cover the soil surface. This enables sunflower plants to make good use of the environmental resources, reflecting in improving yield and its components. These results are in harmony with those obtained by El-Bially and Abd-El-Samie (1997) and Giri *et al.* (1998). The lowest attained values of seed weight/plant and 1000-seed weight recorded when sunflower was grown more closely with soybean (in side: side pattern) might be due to the more intensive competition imposed by either sunflower plants itself or by soybean ones, i.e. intra and inter-specific competition, respectively. Similar findings were obtained by Sarkar *et al.* (2003). On the other hand, the increments in sunflower oil yield. Among them, weeds are major threat resulting in seed yield loss. Suryavanshi *et al.* (2015) reported that heavy weed infestation was the dominant reason for low yield of sunflower. Under the superior weeded treatments (especially butralin+prometryn combination) or with solid sunflower over the intercropping patterns might be attributed to enhancing seed yield. Successful integrate chemical weed control in sunflower was recorded by Jat and Giri (2000). Keeping these points of view, this investigation was planned to study the effect of weeds on sunflower.

Critical period of weed competition: Burnside *et al.* (1998) mentioned that research was needed to determine the critical period for control in any field crop is usually done by (1) keeping the crop free from weeds until certain predetermine times and then allowing weeds to grow and (2) allowing the weeds to emerge and grow with the crop for certain predetermined times, after which all weeds are removed in a timely manner until the end of growing season, Singh *et al.* (1996), pointed out that the time interval between (1) and (2) is the critical period for weed control. Historically critical periods have been calculated by mean separations (hereafter referred to as the classical approach) in experiments that evaluated the impact time of weed emergence and time of removal on crop yields (Zimdahl, 1988). The competition of weeds affected crop growth due to minimizing the availability of nutrients, water and sunlight. Meanwhile, on the other side, weed competition during the whole crop life cycle caused reduction of growth characters and recorded with highest density of weeds (Durgan *et al.,* 1990; Onofri and Tei, 1994; Carranza *et al.,* 1995; Berti *et al.,* 1996; Lehoczky *et al.,* 2006) reported who that the plants growth was affected by weed competition.

Gowda *et al.* (1985) discovered that sustaining weed-free conditions up to 60 DAS resulted in the highest yield in sunflower. According to Singh *et al.* (1992), a weed-free period of 30 to 45 days before to planting correlated to optimal sunflower yield. The critical period of weed competition determined to be between the 3 and 7 weeks after sunflower sowing and 2 to 8 weeks after planting in both seasons reported by (Carranza and Savedra, 1995; Mukhtar *et al.,* 2018). Critical period of weed competition between 30 to 45 days after sowing of sunflower (CPG, 2016). Seed yield of sunflower increased significantly with the increase in initial duration of weed-free condition up to harvest. Critical period of weed competition was found to be 20 to 49 (Wanjari *et al.,* 2001). Shahverdi *et al.* (2002) results showed a critical period of weed control based on 5% and 10% of acceptable yield loss from 10-43 and 18-33 days after emergence.

The key time of weed competition in Sunflower, according to Malliswara Reddy *et al.* (2008), was between 20 and 40 DAS. Igor elezovic *et al.* (2012) revealed that only two weeks of weed competition after sunflower emergence decreased yield by 6 per cent. Selvakumar *et al.* (2018) found that weed competition was one of the major biotic constraints in reducing sunflower productivity under irrigated condition due to wider spacing and application of higher dose of fertilizer. The level of weed infestations the sunflower differed over location and directly affected the intensity of the competitive relationships between crops and weeds which resulted in greater yield losses.

Yield losses due to weeds: Yield losses as a consequence of weeds have been reported by many researchers with a wide range of degrees. Kondap *et al.* (1983) identified that yield losses in sunflower due to weeds ranged from 26 to 50%. Covarelli and Tei (1984) found that the severe weed competition reducing the yield up to 83%. Bochare *et al.* (1992) indicated that the yield losses caused by weeds were to the extent of 76 % in *kharif* sunflower crop.

The increase in yield induced by weed removal treatments may be due to control of annual weeds at the critical early period, consequently the competition between sunflower plant and associated weeds was decreased and giving good chance for sunflower growth and improve the filling of grains resulting heavier grains (Durgan *et al.,* 1990; Onofri and Tei , 1994; Berti and Zanin, 1994; Carranza *et al.,* 1995; Sattin *et al.,* 1996); Weed competition losses in sunflower crops ranged from 19 to 56% of weed free yields (Carranza *et al.,* 1995). Mishra (1997) revealed that seed yield loss due to weeds were around 30 to 60% in case of sunflower crop. Renukaswamy *et al.* (2012); Azadbakht *et al.* (2012); Heydarian *et al.* (2012) stated that the weed competition reduces the sunflower seed yield by 33.5%. Lehoczky *et al.* (2006) reported that, the reduction in seed and seed oil yields due to increasing of competition with associated weeds that decreased weight of seeds per head and simultaneously increased the dry matter production of weeds and weed density. Narender *et al.* (2017) reported that weeds compete with crop plants for nutrients, soil, moisture, space and sunlight causing poor growth and yield losses. Uncontrolled weed growth caused enormous loss of nutrient, which in turn reduced the yield of sunflower crop with an extant of 64%.

Nutrient losses due to weed competition: According to Jat and Giri (2000), unchecked weed development resulted in massive nutrient losses, which in turn lowered sunflower seed yield. Wanjari *et al.* (2000) found that weed-infested sunflower crops lost 124.2 kg N, 49.9 kilogramme P_2O_5, and 129.2 kg K_2O/ha, compared to 160.5 kg N, 63.3 kg P_2O_5, and 171.0 kg K_2O/ha in weed-free conditions. According to Leela (2002), weeds with a higher overall weed density and dry weight remove more nutrients. According to Sumathi *et al.* (2009), unweeded sunflower fields eliminated NPK at rates of 93, 91, and 90%, respectively, higher than weed-free fields. According to Tadavi *et al.* (2017), the weeds check treatment produced the highest levels of NPK uptake by weeds. The unweeded control treatment had the largest weed density, maximum nutrient removal by weeds, a low weed control index, and the lowest growth and yield attributes and sunflower yield (Kalaiyarasan and Vaiyapuri, 2016; Kalaiyarasan *et al.,* 2019).

Hand weeding: Because of reduced weed competition, Basavarajappa (1992) found that manual, mechanical, and herbicidal weed management methods enhanced capitulum diameter, test weight, and number of seeds per capitulum

when compared to weedy control. In plots where hand weeding was done, the highest grain yield of 2274 kg/ha was achieved (Hafeez *et al.,* 2001). Hoeing was the most effective treatment for increasing seed yields in the sunflower + soybean intercropping system in Cairo (Egypt) (Saudy and El-Metwally, 2009). Hand weeding twice on 20 and 40 DAS resulted in a higher sunflower yield of 1288 kg/ha (Bhuvaneshwari *et al.,* 2010). Hand weeding twice at the 20 and 40 DAS reported the highest weed control efficacy, according to Siva sankar and Subramanyan (2011). According to Tadavi *et al.* (2017), treatment weed-free conditions with three hand weedings at 15, 30, and 45 DAS resulted in a greater seed production of 1022 kg/ha. Narender *et al.* (2017) found that weed-free conditions, such as hand weeding from 15 DAS to till harvest at 15-day intervals, resulted in greater seed and stalk yields.

Mulching: Bhan and Khan (1980) reported that application of paddy straw and sugarcane trash mulch at 2.5 t/ha enhanced the sunflower yield by about 2 q/ha over no mulch. At the rows @ 7 t/ha and hand weeding twice at 30 and 45 DAS was effective in controlling of weeds. Application of eucalyptus leaf mulch on the soil surface between lower weed density, weed dry weight eventually resulting in higher yield of sunflower and compared with other mulches *viz.,* mango leaves, tamarind leaf mulch @ 4 t/ha and neem leaves mulch @ 2.5 t/ha than the unmulched plot (Vidyashree *et al.,* 2019).

Allelopathy weeds management: Allelopathic techniques, such as the use of weed-smothering crops for weed management and agricultural sustainability, are one of the options for overcoming these challenges. Importantly, this type of weed control will not affect the environment or raise the expense of weed management. In some agricultural systems, such as organic farming, allelopathic weed control can be used as a single technique. It can also be used in conjunction with other approaches to produce integrated weed control. The allelopathic potential of crops is managed in allelopathic weed control such that the allelochemicals from these crops limit weed competition. Allelopathic activity is expressed by the exudation of allelochemicals by living plants or their dead components. Root exudation, leaching from dead or alive plant tissues, and volatilization from aboveground plant parts are the methods through which allelochemicals are exuded. Allelochemicals are transported to target species via a number of factors. Allelopathic transporters such as soil hyphae are significant. Arbuscular mycorrhizal fungi, according to Achatz and Rillig (2014), are involved in aiding the transport of below-ground allelochemicals. The presence of soil hyphae during the application of allelochemicals from *Juglans regia* L. stunted the tomato test crop's growth. In the presence of soil hyphae, juglone allelochemical transmission was enhanced.

Allelopathic weed control can be implemented by growing allelopathic plants in close proximity to weeds which promote production of these chemicals (Tesio and Ferrero, 2010); or by placing the allelopathic materials obtained from dead plants in close proximity to weeds. The decomposing plant material releases allelochemicals which are absorbed by the target weeds. The most important example for such cases includes the use of allelopathic plant residues for weed control (Tabaglio *et al.,* 2008). Allelopathic weed control can also be implemented by growing allelopathic plants in a field for a certain period of time, in order for their roots to exude allelochemicals. Crop rotation is the most important example for such allelopathic weed control (Farooq *et al.,* 2011). Another way to control weeds through allelopathy includes obtaining allelochemicals in a liquid-solution by dipping the allelopathic chaff in water for a certain period of time. Several researchers have advocated using this way of weed control either alone or in combination with other methods of weed control (Jabran *et al.,* 2010; Khan *et al.,* 2012; Razzaq *et al.,* 2010, 2012). Recent research indicates that allelopathic plants not only suppress weeds but can have positive effects on the soil environment, that is, improved nutrient availability to crop plants through and enhanced soil microbial activities (Wang *et al.,* 2013; Zeng, 2014). The allelopathic wheat cultivar 22 Xiaoyan was found to have higher concentrations of microorganisms and enzyme (catalase and urease) activity (Zuo *et al.,* 2014). The authors argued that the allelopathic wheat cultivars exuded carbon and nitrogen, which improved the allelopathic effects of soil microorganisms in the rhizosphere. Hence, the allelochemicals excreted from the microorganisms further helped to suppress crop weeds and diseases (Zuo *et al.,* 2014).

Chemical method of weed control: Singh *et al.* (1991) found that weed free plot recorded 100% (WCE) followed by pendimethalin @ 1.5 l/ha and one hand weeding over weedy check. Pannacci *et al.* (2007) stated that the weed control was important for increase the yield of sunflower. Applications of single herbicides are not control all the weed species due to their selectivity of species. Pre-emergence herbicides will be effective against the germinating weeds but in order to minimize the second flush of weeds, it is important to apply post emergence herbicide (Walia *et al.,* 2007).

Jat and Giri (2000) reported that application of pendimethalin recorded the maximium leaf area, seed filling, test weight, number of seeds per captitulam, seed weight, seed and biomass yield and oil content of sunflower. At Tirupati (Andhra Pradesh), higher seed yield and maximum economic returns in *rabi* sunflower were obtained with pre-emergence application of pendimethalin 1 kg/ha followed by propaquizafop 60 g/ha applied at 20 DAS, besides obtaining broad spectrum weed control throughout

the crop growth period (Sankar and Subramanyam, 2011). Weed free check has recorded significantly lowest weed density and weed dry weight which was closely followed by pendimethalin @ 1.0 kg/ha as pre emergence + hand weeding on 30 DAS. However, unweeded control recorded more total weed density. Quizalofop ethyl, propaquizafop, fenoxoprop ethyl are the group of aryloxyphenoxy propionate herbicides which has the inhibitors of acetyl CoA carboxylase mode of action which is selective for the control of annual and perennial grassy weeds in broad leaved crops (Sitangshu Sarkar, 2006; Dixit *et al.,* 2012).

Table 1 Weed flora diversity in sunflower

Weed species	References
Grasses like *Eleusine aegypticum*, *Aerachme resemosa, Eragrostis lenella*, sedges such as *Cyperus rotundus* and broad leaved weeds *viz., Heliothropium eichvaldii, Portulaca oleracea, Tribulus terrestris, Amaranthus viridis* and *Chenopodium album*	Gill *et al.* (1984)
The predominant weed species infesting *kharif* sunflower were *Cyperus rotundus, Dactiloctinum aegyptium, Digitaria sanguinalis, Cynodon dactylon, Amaranthus viridis, Commenlina benghalensis, Euphorphia hirta* and *Parthenium hysterophorus*	Suresh and Reddy (1994)
Cynodon dactylon, Digitaria marginata, Dactiloctinum aegyptium, Chloris barbata among monocots, dicot weeds like *Acanthospermum hispidum, Euphorphia hirta, Mollugo ceriana, Amaranthus retroflexues, Portulaca olereca* and sedge like *Cyperus rotundus*	Basvarajappa *et al.* (1996)
Heliotropium eichvaldii, Melilotus indica, Chenopodium album and *Cyperus rotundus* were dominant weed species in spring sunflower crop	Wanjari *et al.* (2000)
At Perambalur (Tamil Nadu), *C. dactylon, P. repens, C. barala, C. rptimdis, T. portulacastrum* and *D. arvensis* were the dominant weed flora in sunflower	Baskaran and Kavimani (2014)
At Bangalore (Karnataka), *D. marginala, E. colonum, C. rotundus* and *P. niruri* were observed as major weed species in sunflower	Nanjunda Reddy *et al.* (2005)
At IARI, New Delhi. *C. rotundus, T. porulaeastrum, D. arvensis, D. agyptium, D. sanguinalis, E. colonum, T. terrestris* and *C. benghalensis* were common in sunflower crop	Wanjari *et al.* (2005)
Echinochola crusgalli, Digitaria sanguinalis, Setaria sp, sedges like *Cyperus rotundus* and broad leaved weeds such as *Portulaca oleracea* and *Amaranthus viridis* were common in the field under temperate condition of Kashmir valley	Singh and Singh (2006)
At Annamalai Nagar (Tamil Nadu) *E. colonum, C. rotandu, C. viscose, T. portulacastrum, E. alba* and *P. niruri* were important weed flora in sunflower crop	Sylaja and Sundari (2008)
At Tripati (Andhra Pradesh), *B. hispida, D. sanguinalis, D. aegyptium, C. rotundu, C. viscosa* and *E. hirta* were noticed in sunflower	Sumathi *et al.* (2009)
C. dactylon, C. rotundus, C. argentia and *D. arvensis* were observed in the crop	Nagamani *et al.* (2011)
At Burdwan (West Bengal), *C. dactylon, D. aegyptium, D. sanguinalis, E. indica, C. rotundus, C. esculentus, C. benghalensis, D. arvensisi* and *E. alba* were the dominant weed flora in sunflower crop	Soumen Bera *et al.* (2018)
At Hyderabad (Andhra Pradesh), weeds such as *C. rotundus, C. difformis, T. indium, C. benghalensis, E. hirita, D. arvensis., C. viscosa, C. monophylla, C. dactylon* and *C. barbata* were recorded in sunflower field	Siva Sankar and Subramanyan (2011)
At TNAU, Coimbatore, the predominant grassy weeds were *Cyanadon dactylon* (L.), *Dactyloctenium aegyptium* (L.), and *Echinochloa colona* (L.). *Cyperus rotundus* (L.) was the only sedge weed was found and among the broad-leaved weeds *Trianthema portulacastrum* (L.), *Digera arvensis* (Forsk.) and *Parthenium hysterophorus* (L.) were the dominant ones. Dicot weeds were predominant than the monocot and sedges and among the dicots *Trianthema portulacastrum* (L.)	Selvakumar *et al.* (2018)
At Coimbatore, (Tamil Nadu), the pre-dominant weed species of grasses were *Echinochloa colonum, Cyandon dactylon, Dactyloctenium aegyptium, Chloris barbata* and *Panicum repens,* sedges like *Cyperus rotundus* and broad leaved weeds like *Trianthema portulacastrum, Parthenium hysterophorus, Digera arvensis* and *Datura meta*	Vidyashree *et al*. (2019)

Janaki *et al.* (2015) reported that due to acute labour shortage and relatively tender nature of the sunflower, adopting the hand weeding or mechanical weeding circumvented the chemical weed control as the only available option. Crop injury rate of 5-15% was recorded after application of flurochloridone and acetochlor. For flurochloridone, the phytotoxicity increased due to irrigation after herbicide application. The highest sunflower injury rate (27-35%) was recorded after application of oxyfluorfen (Jursík *et al.,* 2015).

At Bangaluru (Karnataka), nutrient uptake by crop was significantly higher in pendimethalin 38.7 CS 1.0 kg a.i /ha as pre-emergence + quizalofap ethyl 10 EC 37.5 g a.i/ha at 17 DAS directed on weeds (75.63, 26.91 and 69.48 kg N P K/ha) and farmers practice (intercultivation at 20 and 40 DAS = HW on 30 DAS) (83.15, 31.63 and 75.68 kg N P K/ha) which was on par with weed free (three HW on 15, 30 and 45 DAS) (78.67, 28.98 and 71.47 kg N P K/ha) whereas uptake was lower in unweeded control (38.52, 10.36 and 30.43 kg N P K/ha) (Meti *et al.,* 2017). Sujith *et al.* (2017) reported that application of pendimethalin @1.0 kg a.i /ha as pre-emergence spray + quizalofopethyl 10 EC @ 37.5 g ai /ha post emergence spray on weeds at 15 - 20 DAS recorded reduced total weed population and dry weight compared to all other treatments with higher weed control efficiency (80.38 %) and thus considered for weed management options in sunflower. Tadavi *et al.* (2017) found that the best treatment among the herbicidal treatment in respect of controlling weeds was pre-emergences application of pendimethalin @ 1 kg a.i/ha followed by post emergence spraying of fenoxoprop ethyl @ 37.5 g a.i /ha. Whereas in this experimental site broad leaved weeds are dominant, so these chemicals are not having significant effect on controlling weeds. However application of post-emergence herbicides did not control the weeds effectively and it accordance with the findings of (Singh *et al.,* 2018).

Selvakumar *et al.* (2018) found that Pre emergence application of pendimethalin @ 1 kg ai/ha followed by one hand weeding at 30 DAS is the best IWM practice for getting effective and economical weed control in irrigated sunflower. Combinations of pre emergence herbicide pendimethalin and post emergence herbicides *viz.,* quizalofop ethyl, propaquizofop and fenoxyprop ethyl was not effective against broad leaved weeds infested field in sunflower, though they were not were phytotoxic to sunflower.

At Raichur (Karnataka), application of pendimethalin @ 0.75 kg a.i./ha (pre) followed by propaquizafop @ 37.5 g a.i./ha (post) at 20-25 days after sowing recorded significantly higher yield components *viz.,* capitulum diameter (16.93 cm), seed yield (1924 kg/ha) and harvest index (0.40) as compared to all other herbicide treatments and it was on par with pendimethalin @ 0.75 kg a.i./ha (pre) followed by one intercultivation at 30 DAS (Amrullah Rahil *et al.,* 2019).

Integrated weed management: Fluchloralin administered 0.75 kg a.i/ha as pre-plant inclusion supplemented with on hand weeding at 30 DAS resulted in enhanced seed output of sunflower, according to (Jayakumar *et al.,* 1988). In sunflower, Girijesh and Patil (1991) found that pre-emergence application of pendimethalin 0.75 kg a.i/ha combined with one intercultivation resulted in fewer dicot weeds, weed biomass, and weed index, as well as a higher weed control efficiency (86.94%) that was comparable to hand weeding three times on 15, 30, and 45 DAS. Legha *et al.* (1992) indicated that higher seed yields could be obtained by pre-emergence application of pendimethalin at 1.0 kg/ha followed by one hand weeding at 40 days after sowing than pendimethalin alone even with increased doses. At Coimbatore (Tamil Nadu), Nalayini and Sankaran (1992) reported that pre-emergence application of pendimethalin 1.0 kg a.i/ha followed by hand weeding at 40 DAS was found effective in recording maximum head diameter and seed yield which was on par with twice hand weeding at 20 and 40 DAS. Balyan (1993) noticed that fluchloralin applied 0.5 kg a.i/ha as pre-plant incorporation + hand weeding at 40 DAS decreased weed population and biomass with higher weed control efficiency over rest of the treatments in sunflower. Patel *et al.* (1994) found that application of oxyfluorfen 0.3 kg a.i/ha as pre-emergence recorded higher seed yield than twice hand weeding at 20 and 40 DAS. Pradeep and Sunderam (1996) observed that pre-emergence application of pendimethalin 1.0 kg a.i/ha followed by hand weeding at 30 DAS recorded maximum head diameter and seed yield which proved equally effective as twice hand weeding at 20 and 30 DAS in sunflower based intercropping situation under rainfed condition. Kumar *et al.* (1998) observed that application of pendimethalin 1.0 kg a.i/ha as pre-emergence coupled with intercultivation at 35 DAS resulted in higher plant height and seed yield of *rabi* sunflower. Chandranath *et al.* (1999) noted that pre-emergence application of pendimethalin or pre-plant incorporation Fluchloralin @ 1.0 kg a.i/ha as + hand weeding and intercultivation at 35 DAS was found effective in suppressing the weeds in sunflower under irrigated condition. Wahab *et al.* (2000) reported that pre emergence application of oxyfluorfen at 0.3 kg /ha followed by hand weeding at 30 DAS recorded the lowest weed dry matter production and showed better WCE in sunflower. At Annamalai nagar (Tamil Nadu), application of fluchloralin @ 1.5 kg a.i/ ha with one HW at 30 DAS proved better with weed control efficiency, 96.58% and 97.04% and it reduced the weed density m^2 and weed biomass respectively. It also favoured the improvement in growth attributes *viz.,* plant height, leaf area index, dry matter production and seed yield (1388.44 and 1401.20 kg/ha) of sunflower in summer and *kharif* seasons respectively (Balasubramanian *et al.,* 2001).

Sridhar (2002) found that higher 100 seed weight and seed yield with pre-emergence application of pendimethalin

1.0 kg a.i/ha followed by hand weeding at 45 DAS were on par with two intercultivation and twice hand weeding at 25 and 45 DAS. Fluchloralin applied 0.5 kg a.i/ha as pre-plant incorporation + hand weeding at 30 DAS produced higher seed yield of sunflower in black gram + sunflower intercropping system (Vedharethinam *et al.,* 2004). Bhan and Kolhe (2008) found that application of pendimethalin 1 kg a.i/ha as pre-emergence + hand weeding at 50 DAS reduced weed dry matter and resulted in higher seed yield of sunflower. Shylaja and Sundari (2008) reported that application of pendimethalin 1 kg/ha + hand weeding at 30 DAS gave the higher number of seeds per head and 100 seed weight in sunflower. Sumati *et al.* (2010) reported that pre-emergence application of pendimethalin 1.0 kg /ha followed by one hand weeding on 40 DAS recorded bigger capitulum with more seeds per capitulum and test weight in sunflower.

Nagamani *et al.* (2011) reported that the lowest total weed density and biomass accumulation of all categories of weeds were recorded with pendimethalin 1 kg/ha hand weeding 30 DAS. Baskaran and Kavimani (2014) resulted that the treatment pre-emergence application of pendimethalin at 1 kg/ha + hand weeding on 40 DAS recorded the highest seed yield of sunflower. Parmar *et al.* (2014) reported that pre-emergence pendimethalin at 1 kg/ha+ hand weeding at 20 and 40 DAS recorded the lowest weed index in sunflower. Suryavanshi *et al.* (2015) reported that pre-emergence application of pendimethalin 38.7 CS at 0.75 kg/ha+one hand weeding at 40 DAS gave higher value of all yield attributes and yield of sunflower during both the year highly effective weed control method. Selvakumar *et al.* (2018) concluded that pre-emergence application of pendimethalin at 1.0 kg/ ha followed by one hand weeding at 30 DAS was the best IWM for getting effective and economical weed control in irrigated sunflower. Kayamarsi *et al.* (2018) reported that critical period of red root pigweed in normal irrigation with accepting 5 per cent yield loss in sunflower was 35-86 DAP in the first year and 49-94 DAP in second year. At Annamalai nagar (Tamil Nadu), sunflower + green gram intercropping system produced higher seed yield of 1486 kg/ha during summer season whereas pre-sowing soil incorporation of Pendimethalin @ 0.75 kg/ha + one hand weeding at 30 DAS was more beneficial with high productivity (Krishna Prabu, 2018).

Economics: Pre-emergence application of pendimethalin 1 kg a.i/ha + manual weeding at 30 DAS resulted in a higher benefit-to-cost ratio in sunflower agriculture (Pradeep and Sunderam, 1996a). Higher net returns and seed yield of irrigated *rabi* sunflower were achieved by using a 45 x 30 cm planting pattern and managing related weeds with hand weeding twice at 20 and 40 DAS or pre-emergence application of pendimethalin at 1 kg/ha (Sumathi *et al.,* 2010a). According to Baskaran and Kavimani (2014), a pre-emergence application of pendimethalin at 1 kg/ha followed by one hand weeding at 40 DAS resulted in a net return of ₹36333/ha and a B:C ratio of 2.72. Narendar *et al.* (2017) found that pre-emergence spraying of oxyflurofen @ 150 g a.i/ha followed by hand weeding at 25 DAS resulted in a greater B:C ratio (2:3).

At Dholi (Bihar), weed-free treatment (twice hand weeding at 20 and 40 DAS) produced significantly greater yield (22.51q/ha), but treatment combining pendimethalin @ 1 kg a.i. as pre-emergence with propaquizofop @ 62 a.i./ha at 20 DAS produced significantly higher net yields and B:C ratio (Vikram *et al.,* 2020; Hansraj *et al.,* 2018). Total nutrient uptake by crop, maximum gross monetary returns (₹34704/ha), net monetary returns (₹17999/ha), and B:C ratio (2.08) were all found to be highest in the weed-free treatment (3 hand weeding at 15, 30 and 45 DAS) (Tadavi *et al.,* 2017).

From this review it can be concluded that, application of weed management through hand weeding, mulching, cultural, biological, mechanical and chemical method is promising method of control weeds and enhance crop production. However, fine tuning of the available technologies are needed to make the available technologies suit to the location specific needs to farmers in India.

REFERENCES

Achatz M, Rillig M C 2014. *Arbuscular mycorrhizal* fungal hyphae enhance transport of the allelochemical juglone in the field. *Soil Biology Biochemistry*, **78**: 76e82.

Altieri M A, Lana M A, Bittencourt H V, Kieling A S, Comin J J, Lovato PE 2011. Enhancing crop productivity via weed suppression in organic no-till cropping systems in Santa Catarina, Brazil. *Journal of Sustainable Agriculture*, **35**: 855e869.

Amrullah Rahil U K, Shanwad B G, Koppalkar B K, Desai and Mallikarjun Kenganal 2019. Effect of pre and post emergent herbicides on growth and yield of sunflower (*Helianthus annuus* L.). *Journal of Farm Science*, **32**(1): 22-26.

Anonymous 2019. *Agricultural statistics at a glance 2019.* Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, Krishi Bhavan, GOI, New Delhi.

Balasubramanian V, Anbumani S and Panneerselvam P 2001. Effect of weed control methods on growth and yield of sunflower. *Agricultural Science Digest*, **21** (1): 31-33.

Balyan RS 1993. Integrated weed management in oilseed crops in India. In: *Proceeding of International symposium. Indian Journal Weed Science*, **1**: 317-323.

Basavarajappan D N 1992. Integrated weed management in sunflower cultivars. M.Sc.(Agri) Thesis, University of Agricultural Sciences, Bangalore, India.

Baskaran R and Kavimani R 2014. Integrated weed management in maize - sunflower cropping system. *Indian Journal of Weed Science*, **46**(4): 330-332.

Basvarajappa D N, Nanjappa H V and Ramachandrappa N K 1996. Nutrient uptake crop and weeds as influenced by integrated

weed control in sunflower hybrids. *Journal of Oilseeds Research*, **13**(2): 245-247.

Bedmar F, Leaden M T and Eytherabide J J 1989. Evaluation of different combinations of acetachlor with linuron and fluchloride for weed control in sunflower. *Annals of Applied Biology*, **114**: 94-95.

Behera U K, Singh U and Singh YV. 2005. Influence of weed-control on productivity of soybean (*Glycine max*) in Vertisol of central India. *Indian Journal of Agronomy*, **50** (3): 221-224.

Bernstein ER, Stoltenberg DE, Posner JL, Hedtcke JL 2014. Weed community dynamics and suppression in tilled and no-tillage transitional organic winter rye-soybean systems. *Weed Science*, **62**: 125e137.

Berti A, Zanin G 1994. Density equivalent: a method for forecasting yield loss caused by mixed weed populations. *Weed Research*, **34**: 327-332.

Berti A, Dunan C M, Sattin M, Zanin G, Westra P 1996. A new approach to determine when to control weeds. *Weed Science*, **44**: 496- 503.

Bhan A and Kolhe SS 2008. Impact of integrated weed management on the performance of sunflower, weed dynamics and soil microflora. *Indian Journal Weed Science*, **40** (1&2): 111 - 112.

Bhan S and Khan SA 1980. Effect of frequency and method of irrigation and application of surface mulch on sunflower. *Indian Journal of Agronomy*, **25**(4): 645 - 650.

Bochare PA, Shelke DK, Bhosle RH, Jadhav NS and Salunke VD. 1992. Weed management in kharif sunflower. *Journal of Maharashtra Agricultural University*, **17** (3): 503- 504.

Bochare PA, Shelke DK, Bhosle RH, Jadhav MS and Salunke VD 1992. Weed management in *kharif* sunflower. *Journal of Maharashtra Agricultural University*, **17** (3): 502 - 503.

Burnside O C, Wiens MJ, Holder B J, Weisberg S, Ristau EA, Johnson MM, Cameron JH 1998. Critical periods for weed control in dry beans (*Phaseolus vulgaris*). *Weed Science*, **46** (3):301-306.

Carranza PP, Saavedra M and Garcia Torres L 1995. Competition between *Radolfia segetun* and sunflower. *Weed Research*, **35**: 369 - 375.

Chandranath HT, Suriyanarayan guggari AK and Nadagoud VB 1999. Integrated weed management in sunflower. *Journal of Oilseeds Research*, **16** (2): 350 - 353.

Channappagoudar BB, Biradar NR, Bharamagoudar TD and Rokhade CJ 2008. Physiological studies on weed control efficiency of different herbicides in sunflower. *Karnataka Journal of Agricultural Science*, **21** (2): 165 - 167.

CHEN Yuan-quan, SUI Peng, LUAN Chen and SHI Xue-peng 2012. Xanthium Suppression Under Maize-Sunflower Intercropping System. *Journal of Integrative Agriculture*, **11**(6): 1026-1037.

Covarelli G and Tei F 1984. Competition between sunflower and *Sinapsis arvensisi* at different level of infestation. EWRS: 323 - 330.

Crop production guide, 2016. *Crop production guide for field crop.* Published by Tamil Nadu Agricultural University, Coimbatore & State Agriculture Dept. Chennai, Tamil Nadu.

Devidayal and Reddy PS 1991. Effect of intercropping sunflower in different patterns of groundnut on yield and economics in Saurashtra region of Gujarat. *Indian Journal Agricultural Science*, **61**: 490-492.

Dhuyvetter KC, Thompson CR, Norwood CA, Halvorson AD 1996. Economic of dryland cropping system in the Great Plains. *A Review Journal of Production Agriculture*, **9**: 216-222.

Dixit JP, Harvendra Singh and Bhadauria SKS 2012. Quizalofop ethyl: An effective post emergence herbicide to control grassy weeds of Groundnut. *Annals of Plant and Soil Research*, **14** (1): 22-24.

Dogan R, Goksoy TA, Yagdi K, Turan MZ 2008. Comparison of the effects of different crop rotation systems on winter wheat and sunflower under rainfed conditions. *African Journal of Biotechnology*, **7**(22): 4076-4082.

Dube E, Chiduza C, Muchaonyerwa P, Fanadzo M, Mthoko T 2012. Winter cover crops and fertiliser effects on the weed seed bank in a low-input maize-based conservation agriculture system. *South Africa Journal Plant Soil*, **29**: 195-197.

Durgan BR, Dexter AG, Miller SD 1990. Kochia (*Kochia scopaia*) interference in sunflower (*Helianthus annuus*). *Weed Technology*, **4**: 52-56.

El-Bially ME and Abd-El-Samie FS 1997. Integrated weed management in sunflower. *Annals of Agricultural Science,* Ain Shams Univ., Cairo, **42** (1): 147-158.

Elezovic I, Datta A, Vrbnicanin S, Glamoclija D, Simic M, Malidza G and Knezevic SZ 2012. Yield and yield components of imidazolinone- resistant sunflower (*Helianthus annuus* L.) are influenced by pre-emergence herbicide and time of post-emergence weed removal. *Field Crops Research*, **128**: 137 - 146.

Farooq M, Jabran K, Cheema ZA, Wahid A, Siddique KH 2011. The role of allelopathy in agricultural pest management. *Pest Management Science*, **67**: 493e506.

Gill HS, Brar LS and Paul S 1984. Investigation on weed control in sunflower. *Pesticides*, **18** (2): 8 - 11.

Giri AN, Bhosle RH and Lokhande OG 1998. Performance of cultural, chemical and integrated weedcontrol methods in sunflower (*Helianthus annuus*). *Indian Journal of Agronomy*, **43** (1): 143-148.

Girijesh GK and Patil TV 1991. Weed management studies in groundnut and sunflower intercropping system. *Journal of Oilseeds Research*, **8**: 7 - 13.

Gowda KTK, Muniyappa TV and Venkataramu MN 1985. Weed control in sunflower through mechanical, chemical and cultural methods. *Indian Journal Weed Science*, **8** (2): 16 - 25.

Hafeez U, Gulzar A and Zar Q 2001. Effect of weed control treatments on the performance of sunflower. *Journal of Biological Science*, **1**: 132 - 133.

Hansraj H, Vikram B, Dwivedi D K and Sandeep patil 2018. Effect of different pre and post-emergence herbicides on crop growth and yield in sunflower. *Trends in Biosciences*, **11**(19): 2808 - 2810.

Halkier BA, Gershenzon J 2006. Biology and biochemistry of glucosinolates. *Annual Review Plant Biology*, **57**: 303e333.

Haramoto ER, Gallandt ER 2004. Brassica cover cropping for weed management: A review. *Renewable Agricultural Food System*, **19**: 187e198.

Hassall KA 1990. *The Biochemistry & Uses of Pesticides*. 2nd Ed. Macmillan Press Ltd., London.

Heydarian H, Hadi MRHS, Mohmoodabad HS and Kalateh MN 2012. Competitive effects of red root pig weed (*Amaranthus retroflexus*) on three sunflower (*Helianthus annuus*) cultivars. *International Journal of Agriculture and Crop Sciences*, **4** (9): 525-528.

Inayat ullah Awan, Mohammad Azam Khan, Muhamed Zareef and Ejaz Khan 2009. Weed management in sunflower with allelopathic water extract and reduced doses of an herbicide. *Pakistan Journal of weed Science Research*, **15**(1): 19-30.

Jabran K and Farooq M 2013. *Implications of Potential Allelopathic Crops in Agricultural Systems, Allelopathy.* Springer Berlin Heidelberg, pp. 349-385.

Jaiswal V P, Singh J P, Karamjit S, Shekhawat G S, Khuran S M P, Pandey S K, Chandla V K 1993. Production potential and profitability of some potato based cropping sequences in north-western plains. Potato: present and future. *Proceedings of the National Symposium held at Modipuram.* pp. 101-105.

Jan V K, Chauhan Y S, Bhargava M K and Sharma A K 2000. Chemical weed control in soybean (*Glycine max*). *Indian Journal of Agronomy*, **45** (1): 153-157.

Janaki P, Chinnusamy C, Sakthivel N and Nithya C 2015 Field dissipation of pendimethalin and alachlor in sandy clay loam soil and its terminal residues in sunflower (*Helianthus annuus* L.). *Journal of Applied and Natural Science*, **7**(2): 709-713.

Jat R and Giri G 2000. Influence of nitrogen and weed-control measures on weed growth, and seed and oil yields of sunflower (*Helianthus annuus*). *Indian Journal of Agronomy*, **45**(1): 193-198.

Jayakumar R, Premsekar M, Kempuchetty N and Subramanian S 1988. Effect of integrated weed management on yield and quality of sunflower. *Madras Agricultural Journal*, **75**(3&4): 85-88.

Jensen E S, Carlsson G and Hauggaard-Nielsen H 2020. Intercropping of grain legumes and cereals improves the use of soil N resources and reduces the requirement for synthetic fertilizer N: A global-scale analysis. *Agronomy for Sustainable Development*, **40**(1): 5.

Johnston A M, Tanaka D L, Miller P R, Brandt S A, Nielsen D C, Lafond G P, Riveland N R 2002. Oilseed crops for semiarid cropping system in the Northern Great Plains. *Agronomy Journal,* **94**: 231-240.

Jursík M, Soukup J, Holec J and Hamouzová K 2015. Efficacy and selectivity of pre-emergent sunflower herbicides under different soil moisture conditions. *Plant Protection Sciences*, **51**: 214-222.

Kalaiyarasan and Vaiyapuri V 2016. Integrated weed management in Sunflower. *Life Sconce Leaflets*, **77**: 85-91.

Kalaiyarasan C, Vaiyapuri V, Suseendran K and Jawahar S 2019. Response of sunflower to integrated nutrient and weed management practices on weeds, growth and yield, quality and nutrient uptake. *Plant Archives*, **19**(1): 526-533.

Kayamarsi Z, Kazemeini SA and Hamzehzarghani H 2018. Impact of water deficit on critical period of pigweed (*Amaranthus retroflexus* L.) in sunflower. *Iran Agricultural Research*, **37**(2): 27-34.

Khan M B, Ahmad M, Hussain M, Jabran K, Farooq S, Waqas-Ul-Haq M 2012. Allelopathic plant water extracts tank mixed with reduced doses of atrazine efficiently control *Trianthema portulacastrum* L. in *Zea mays* L. *Journal of Animal Plant Science*, **22**: 339-346.

Kondap M S, Narasima murthy Y V and Venugopal P 1983. More oilseeds through weed management. *Indian Farming*, **33**(1): 24-25.

Krishna Prabu S 2018. Weed management studies in sunflower based intercropping system. *International Journal of Pure Applied Bioscience*, **6**(6): 407-410.

Kumar K A, Reddy M D and Krishna A 1998. Integrated weed management in *rabi* sunflower. *Journal of Oilseeds Research*, **15**(1): 109-114.

Kumara O, Venugopal N and Reddy S S 2003. Effect of nitrogen levels and weed management on yield of sunflower. *Karnataka Journal of Agricultural Science*, **20**(1): 10-20.

Kushwah S S and Vyas M D 2005. Herbicidal weed control in soybean (*Glycine max*). *Indian Journal of Agronomy*, **50**(3): 225-227.

Lakhpat Singh Rawat R K, Maikhuri, Yateesh M, Bahuguna N K, Jha and Phondani P C 2017. Sunflower allelopathy for weed control in agriculture systems. *Journal of Crop Science and Biotechnology*, **20**: 45-60.

Lafond G P, Zetner R P, Geramia R and Derksen D A 1993. The effects of tillage system on the economic performance of spring wheat, winter wheat, flax and field pea production in east-central Saskatchewan. *Canadian Journal of Plant Science*, **73**: 47-54.

Leela C 2002. Weed dynamics and crop Productivity as influenced by Preparatory tillage and weed management methods in sunflower - maize cropping system. M.Sc. (Ag) Thesis, Tamil Nadu Agricultural University, Coimbatore.

Legha P K, Malik R K and Faroda A S 1992. Weed management in *kharif* sunflower. *Crop Research*, **5**: 376-379.

Lehoczky E, Reisinger P, Komives T and Szalai T 2006. Study on the early competition between sunflower and weeds in field experiments. *Journal of Plant Diseases and Protection*, **20**: 935-940.

Malidza G S, Vrbnicanin S, Bozic S and Jocic S 2016 Integrated weed management in sunflower: challenges and opportunities. ISC, 90.

Malliswara Reddy A, Reddy G P, Reddy D S and Reddy K B 2008. Determination of critical period of crop weed competition in hybrid sunflower. *Indian Journal of Weed Science*, **40** (1&2): 90-93.

Meti R N, Geetha K N, Shankar A G, Prathima A S and Prakash 2017. Weed management practices for improving productivity and nutrient uptake of sunflower (*Helianthus annuus* L.) in alfisols. *Environment and Ecology*, **35**(4): 2801-2805.

Mishra J S 1997. Critical period of weed competition and losses due to weeds in major field crops. *Farmer and Parliament,* **33**(6): 19-20.

Mirsky S B, Ryan M R, Teasdale J R, Curran W S, Reberg-Horton C S, Spargo J T, Wells M S, Keene C L and Moyer J W 2013. Overcoming weed management challenges in cover crop-based organic rotational no-till soybean production in the eastern United States. *Weed Technology*, **27**: 193-203.

Mukhtar A M, Gamar Elniaama A I, Salah E E and Babiker M M 2018. Critical period for weed control in sunflower (*Helianthus annuus* L) in Dongola locality, Northen State, Sudan. SUST *Journal of Agricultural and Veterinary Sciences*, **19**(1): 34-40.

Nagamani C, Naidu S M M and Subramanyam D 2011. Weed dynamics and yield of sunflower as influenced by varied planting patterns and weed management practice. *Indian Journal of Weed Science*, **43**(1&2): 101-104.

Nalayini P and Sankaran S 1992. Effect of moisture regimes and weed control on sunflower. *Indian Journal Weed Science*, **24** (3&4): 1-5.

Nanjunda Reddy H, Nanjappa H V and Ramachandrappa B K 2005. Effect of manures on weed dynamics yield and economics of sunflower - fodder maize crop sequence. *Mysore Journal of Agricultural Science*, **39**(3): 289-293.

Narender J, Padmaja J, Srinivas A and Sailaja V 2017. Evaluation of efficacy of different herbicides for efficient weed control in sunflower (*Helianthus annuus* L.). *International Journal of Pure and Applied Bioscience*, **5**(4): 1576-1581.

Nel A A, Loubser H L 2004. The impact of crop rotation on profitability and production risk in the Eastern and North Western Free State. *Agrekon*, **43**(1): 101-111.

Norsworthy J K, McClelland M, Griffith G, Bangarwa S K and Still J 2011. Evaluation of cereal and *Brassicaceae* cover crops in conservation-tillage, enhanced, glyphosate-resistant cotton. *Weed Technology*, **25**: 6-13.

Norsworthy J K and Meehan J T 2005. Use of isothiocyanates for suppression of Palmer amaranth (*Amaranthus palmeri*), pitted morningglory (*Ipomoea lacunosa*), and yellow nutsedge (*Cyperus esculentus*). *Weed Science*, **53**: 884-890.

Onofri A, Tei F 1994. Competitive ability threshold levels of three broadleaf weed species in sunflower. *Weed Research*, **34**: 471-489.

Pannacci E, Graziani F and Covarelli G 2007. Use of herbicide mixtures for pre and post-emergence weed control in sunflower (*Helianthus annuus*). *Crop Protection*, **26**:1150-1157.

Parmar V T, Patel J G and Vasave J B 2014. Efficiency of different herbicides in sunflower under south Gujarat condition. *Trends in Biosciences*, **7**(14): 1624-1629.

Patel Z G, Parmar N D and Raj V C 1994. Effect of weed control methods on yield and yield attributes of sunflower. *Indian Journal of Agronomy*, **39**(2): 330-331.

Pradeep K S and Sunderam V S S 1996. Effect of planting geometry, intercropping and weed management on rainfed sunflower. *Madras Agricultural Journal*, **83**(1): 664-665.

Pradeep K S and Sunderam V S S 1996a. Economics of chemical weed control in sunflower based intercropping situation under rainfed conditions. *Madras Agricultural Journal*, **83**(1): 665-666.

Razzaq A, Cheema Z, Jabran K, Hussain M, Farooq M and Zafar M 2012. Reduced herbicide doses used together with allelopathic sorghum and sunflower water extracts for weed control in wheat. *Journal of Plant Protection Research*, **52**: 281-285.

Razzaq A, Cheema Z A, Jabran K, Farooq M, Khaliq A, Haider G and Basra S M A 2010. Weed management in wheat through combination of allelopathic water extracts with reduced doses of herbicides. *Pakistan Journal of weed Science Research*, **16**: 247-256.

Reddy B N and Sudhakara B S N 2003. Sustainability of sunflower-based crop sequences in rainfed Alfisols. *Helia*, **26**(39): 117-124.

Renukaswamy N S, Kusagur P and Jayaprakash R 2012. Effect of chemical weed management on growth traits and its influence on performance of sunflower. *International Journal of Food, Agriculture and Veterinary Sciences*, **2**(1): 80-86.

Samui R C and Roy A 1990. Possibilities of increasing production of oilseeds through intercropping system. *Journal of Oilseeds Research,* **7**: 14-21.

Sankar S K and Subramanyam D 2011. Weed flora and yield of sunflower (*Helianthus annuus* L.) as influenced by pre and post-emergence application of herbicides. *Indian Journal of Weed Science,* **43**(1 & 2): 105-109.

Sarkar R K, Goswami S and Pal P K 2003. Production potential and economic feasibility of sunflower (*Helianthus annuus*) and pigeonpea (*Cajanus cajan*) intercropping system on rainfed upland condition. *Indian Journal of Agronomy*, **48**(4): 263-266.

Sattin M, Berti A, Zanin G 1996. Crop yield loss in relation to weed time of emergence and removal: analysis of the variability with mixed infestations. *Proceedings of the Second Int. Weed Control Congress*, Copenhagen. pp. 67-72.

Saudy H S and El-Metwally I M 2009. Weed management under different patterns of sunflower-soybean intercropping. *Journal of Central European Agriculture*, **10**(1): 41-52.

Selvakumar T, Srinivasan K and Rajendran L 2018. Performance of chemical weed management in irrigated sunflower. *International Journal of Agriculture Sciences*, **10** (20): 7395-7397.

Sharma S and Satsangi G P 2014. Potential Allelopathic Influence of sunflower (*Helianthus annuus* L.) on germination and growth behavior of two weeds *in vitro* condition. *International Journal of Biotechnology and Bioengineering Research*, **4**(5): 421-426.

Shahverdi M, Hejazi A, Rahimian Mashhadi H and Torkamani A 2002. Determination of the critical period for weed control in sunflower (*Helianthus annuus*). *Iranian Journal of Crop Sciences*, **4**(3): 152-162.

Shylaja R and Sundari A 2008. Weed management in sunflower (*Helianthus annuus* L). *Indian Journal of Weed Science*, **40**(2): 94-95.

Singh D K and Singh K N 2006. Weed control in sunflower (*Helianthus annuus*) under temperate condition of Kashmir valley. *Indian Journal of Agronomy*, **51**(3): 225-227.

Singh G, Ram I C and Singh D 1991. Crop weeds competition in green gram. *Tropical Pest Management*, **37**:144-148.

Singh M, Saxena M C, Abu-Irmaileh A B E, Al-Thabbi S A and Haddad N I 1996. Estimation of critical period of weed control. *Weed Science Society of America*, **44**: 273-283.

Singh G, Virk H K and Khanna V 2018. Pre- and post-emergence herbicides effect on growth, nodulation and productivity of green gram. *Journal of Crop and Weed*, **14**(2): 162-167.

Singh V B and Giri G 2001. Influence of intercropping and weed-control measures on suppression of weeds and productivity of spring season sunflower (*Helianthus annuus*) and groundnut (*Arachis hypogaea*). *Indian Journal of Agronomy*, **46**(3): 440-444.

Singh D, Dagar J C and Gangwar B 1992. Infestation of weeds and their management in oilseed crops-a review. *Agricultural Reviews*, **13**(3): 163-175.

Singh M, Vats O P and Brar L S 1997. Crop - weed competition in spring sunflower. *Indian Journal of Weed Science*, **29**: 90-91.

Sitangshu Sarkar 2006. Weed management in jute (*Corchorus olitorius* L.) by post emergence herbicides. *Journal of Tropical Agriculture*, **44**(1-2): 71-73.

Sivasankar K and Subramanyam D 2011. Weed flora and yield of sunflower (*Helianthus annuus* L.) as influenced by pre and Post - emergence application of herbicides. *Indian Journal of Weed Science*, **43**(1&2): 105-109.

Soumen Bera, Sibajee Banerjee and Chaitan sorean 2018. Performance of sunflower as influenced by established technique and weed management. *International Journal of Current Microbiological Applied Science*, **7**(8): 3193-3198.

Sridhar V 2002. Effect of herbicides and their integration with cultural practices on weed control and yield of sunflower. *Journal of Oilseeds Research*, **19**(2): 239-241.

Sujith G M, Geetha K N and Shadakhari Y A 2017. Effect of different herbicides and cultural practices on weed dynamics and productivity of sunflower (*Helianthus annuus* L.) grown on alfisols of Rastren dry zone of Karnataka. *International Journal of Advanced Biological Research*, **7**(3): 595-599.

Sumathi V, Subramanyam D, Koteswara Rao D S and Reddy D S 2010a. Effect of planting pattern and weed management on weed flora and yield of *rabi* sunflower. *Indian Journal of Weed Science*, **42** (3&4): 212-216.

Sumathi V, Koteswara Rao D S, Subramanyam D and Reddy D S M 2010. Effect of planting pattern and weed management on nutrient uptake and economics of Rabi sunflower and its associated weeds. *Indian Journal of Weed Science*, **42**(3): 65-70.

Suresh G and Reddy N V 1994. Weed management studies in *kharif* sunflower. *Journal of Oilseeds Research*, **11** (2): 297-299.

Suryavanshi V P, Suryawanshi B and Jadhav K T 2015. Influence of herbicides on yield and economics of *kharif* sunflower. *Journal Crop and Weed*, **11**(1): 168-172.

Tabaglio V, Gavazzi C, Schulz M and Marocco A 2008. Alternative weed control using the allelopathic effect of natural benzoxazinoids from rye mulch. *Agronomy for Sustainable Development*, **28**: 397-401.

Tesio F, Ferrero A 2010. Allelopathy, a chance for sustainable weed management. *International Journal of Sustainable Development World Ecology*, **17**: 377-389.

Tadavi A G, Chorey A B, Gaikwal G S and Sawadhkar 2017. Integrated weed management in sunflower. *International Journal of Current Microbiological Applied Science*, **6**(9): 1080-1088.

Tripathi S S and Vivek 2001. Critical period of weed competition in spring sunflower. *Indian Journal of Weed Science*, **33**: 212-214.

Vedharethinam R, Sundari A, Kalaisudarson S and Suresh kumar S M 2004. Economics of integrated weed management practices in sunflower based intercropping system. *Indian Journal Weed Science*, **36**(3&4): 308-309.

Vidyashree B S, Arthanari P M and Somasundaram E 2019. Effect of biomulches on weed flora on irrigated sunflower. *Journal of Pharmacognosy and Phytochemistry*, **8**(3): 441-443.

Vikram B, Kiran Kumar S, Prasad S S, Singh U K, Hansraj H and Dwivedi D K 2020. Effect of integrated weed management in sunflower (*Helianthus annuus* L.) in Bihar. *Journal of Pharmacognosy and Phytochemistry*, **SP6**: 356-359.

Vyas M D, Singh S and Singh P P 2000. Weed management in soybean [*Glycine max* (L. Merill.] *Annals of Plant Protection Science*, **8**(1): 76-78.

Wahab K, Kathiresan K, Anbhazhagan R and Thirumurugan M 2000. Influence of phosphobacteria and weed management practices on weed biometrics and yield of sunflower. In: *Proceeding of National Seminar on the Sustainability of Weed Control Options for the New Millennium.* December 20-21, 2000. Annamalai University, Annamalai Nagar, Tamil Nadu, India. p.38.

Walia U S, Surjit Singh and Buta Singh 2007. Integrated approach for the control of hardy weeds in groundnut (*Arachis hypogaea* L.). *Indian Journal of Weed Science*, **39**(1&2), 112-115.

Wang P, Zhang X and Kong C 2013. The response of allelopathic rice growth and microbial feedback to barnyard grass infestation in a paddy field experiment. *European Journal of Soil Biology*, **56**: 26-32.

Wanjari R H, Yaduraju N T and Ahuja K N 2001. Nutrient uptake by sunflower (*Helianthus annuus*) and associated weeds during rainy season. *Indian Journal of Agronomy*, **46**(3): 541-546.

Wanjari R H, Yaduraj N R and Ahuja K N 2000.Critical period of crop weed competition in spring sunflower. *Indian Journal Weed Science*, **32**: 17-20.

Wanjari R H, Yaduraja N T and Ahuja K N 2001. Critical period of crop-weed competition in rainy-season sunflower (*Helianthus annuus*). *Indian Journal of Agronomy*, **46**(2): 309-313.

WSSA 1994. Weed Science Society of America. *Herbicide Handbook.* 7th Ed. Champaign, Illinois, USA.

Yadav S K, Singh S P and Bhan V M 1983. Performance of herbicides for weed control in groundnut. *Indian Journal of Weed Science*, **15**: 58-61.

Zeng R S 2014. Allelopathy-the solution is indirect. *Journal of Chemistry Ecology*, **40**: 515-516.

Zimdahl R L 1988. The concept and application of the critical weed-free period. In: Altieri, M A and M Liebmann eds. *Weed Management in Agroecosystems: Ecological Approaches,* pp. 145-155. CRC Press, Boca Raton. Florida, USA.

Zuo S, Li X, Ma Y, Yang S 2014. Soil microbes are linked to the allelopathic potential of different wheat genotypes. *Plant Soil,* **378**: 49-58.

Zentner R P, Wall D D, Nagy C N, Smith E G, Young D L, Miller P R, Campbell C A, Campbell B G, Brandt S A, Lafond G P, Johnston A M and Derksen D A 2002. Economics of crop diversification and soil tillage opportunities in the Canadian prairies. *Agronomy Journal*, **94**: 216-230.

Characterization of diverse sesame (*Sesamum indicum* L.) panel through morphological and molecular marker analysis

VIVEK KUMAR, SIMA SINHA*, SWETA SINHA AND S N SINGH

Bihar Agricultural University, Sabour, Bhagalpur-813 210, Bihar

(Received: May 25, 2022; Revised: June 14, 2022; Accepted: June 16, 2022)

ABSTRACT

Sesame is one of the most important and ancient oilseeds crop with high and good quality oil content. Present investigation was carried out for the assessment of the genetic diversity using 33 sesame genotypes through morphologically and 21 SSR markers. In the morphological diversity analysis, nine clusters were observed with 33 genotypes using all phenological, yield and its contributing attributes. Among the 9 clusters, cluster II had maximum number of genotypes (14) followed by cluster III (6), cluster IV (5), cluster I (3), cluster V, VI, VII, VIII and IX had one genotype to each cluster. The highest inter-cluster distance was observed between cluster VI and I (386.70), which indicates maximum diversity between the genotypes of these clusters, could be further used in crossing programme. However, SSR markers grouped 33 genotypes into six clusters at 0.51 dissimilarity index. In which cluster V had maximum (7) genotypes and cluster VI had minimum (3) genotypes. The results of genetic diversity tallied with the morphological diversity, such as BRT-04 are the farthest from BRT-08, BRT-09 and BRT-10, however BRT-08, BRT-09 and BRT-10 are in the same cluster in both morphological and molecular diversity analysis. The UPGMA dendrogram was constructed using Jaccard's dissimilarity coefficients based on SSR markers score on thirty-three genotypes. Polymorphism information content (PIC) value varied between 0.15 and 0.36 with an average of 0.27. The genotypes from the distinct clusters can be utilized for hybridization programme to recover heterotic pools.

Keywords: Cluster distance, Genetic divergence, Multivariant analysis, Sesame, SSR

Oilseeds constitute second largest agricultural commodity after cereals in India occupying 13% of gross cropped area. In India, seven edible oils (soybean, groundnut, rapeseed-mustard, sunflower, niger, sesame and safflower) and two nonedible oilseeds (castor and linseed) are cultivated. Sesame is botanically named as *Sesamum indicum* L. and belongs to Pedaliaceae family. The major growing sesame states of the country are Gujarat, Rajasthan, Andhra Pradesh. India has achieved independency in production of cereal crops like wheat, paddy, maize etc. in the last fifty years. On the other hand, the production of oilseeds has largely been stagnant. However, the consumption of oilseeds has been on the rise. The oilseed crop sesame, which has high remunerative price and medicinal value, which can help in reduction of gap between supply and demand. Sesame oils apart from being a good source of carbohydrates, it also helps in maintaining cholesterol levels and reduces risks of cardiovascular diseases. Sesame has good quality of oil along with high oil content. Hence, it has been given the name "Queen of oilseeds". Sesame having sesamin, sesamolin and sesamol, nutrients which help in cholesterol (MUFA, PUFA) reduction. It also has high antioxidant value. Despite being one of the oldest oilseed crops, it has been largely neglected in research. Sesame bears 50-60% oil and can play a significant role in satisfying the exponentially increasing demand for edible oil in India. Further, it is a very rewarding crop for the farmers as it has high-cost benefit ratio.

Corresponding author's E-mail: simasinha11@gmail.com

Genetically diverged genotypes are a treasure of genes which plays an important role in the breeding programmes for development of high yielding genotypes with non-shattering capsules. Genetic diversity measures distances among genotypes, inter cluster and intra cluster. It provides an opportunity to the plant breeder to develop a desirable genotype. The genotype has been developed from widely diverged clusters are likely to produce heterotic genotypes and wide segregating generation (Rao, 1952). Characterization of genetic diversity using agro-morphological and molecular markers is one of the effective methods for diversity analysis in sesame. Where, large variability among different potential parents is always desirable that can be used in future breeding program and also significant to improve sesame varieties (Rajitha *et al.*, 2021). A number of agro-morphological traits base analysis showed a high genetic diversity in sesame populations (Begum *et al.,* 2011; Parameshwarappa *et al.,* 2012; Jadhav and Mohrir, 2013, Tripathi *et al.,* 2014; Soundharya *et al.,* 2017; Swathy *et al.,* 2018; Kumhar and Rajani, 2021). Several DNA based molecular markers have been developed to identify genetic variability within species. Recently more advance in molecular genetics is the introduction of microsatellite markers to identify the genetic diversity among the genotypes. In sesame, the genetic diversity analysis has

been done by several DNA markers such as AFLP (Laurentin and Karlovsky, 2006; 2007), SRAP (Zhang *et al.,* 2011; 2012), RAPD (Bhat *et al.,* 1999, Ercan *et al.,* 2004; Salazar *et al.,* 2006) and ISSR (Kim *et al.,* 2002, Kumar *et al.,* 2012). SSR markers have advantages of simplicity, effectiveness, transferability to close species, multiallelic nature, abundance, reproducibility, codominant inheritance and high genomic coverage. Due to this flexible property, SSR markers are very useful for study of genetic divergence in sesame. The aims of the present investigation were to evaluate genetic relationships among 33 sesame genotypes collected from different institute and local races from different corner of Bihar.

MATERIALS AND METHODS

Experimental materials and phenotyping: The study was carried out in the Research Farm of Bihar Agricultural University Sabour, Bhagalpur, Bihar in the year 2019-20. Sabour farm is geographically situated between 25°15'40"N latitude to 87°2'42"E longitude at 46 m above mean sea level. The experiment consists of thirty-three genotypes including three checks namely GT-10, TKG-22 and JTS-8 (Table 1). The experiment was laid in randomized block design in three replications. Plot area was 3.6 m^2 having distance between rows were 30 cm and plant to plant distance was 10 cm. Data were recorded on five plant basis for days to 50% flowering, number of productive branches, plant height (cm), height of 1^{st} capsule bearing node (cm), number of capsules per plant, number of seeds per capsule, capsule length (cm), inter node length (cm), days to maturity, 1000-grain weight (g), percent of oil and yield per hectare (kg).

DNA isolation: Genomic DNA was isolated from fresh leaf tissue of each sesame genotype using the modified CTAB method as described by Doyle and Doyle (1990). DNA precipitate with equal volume of Phenol: Chloroform: Isoamyl alcohol mixture (25:24:1) further precipitation by 2/3rd volume of chilled isopropanol was added and mixed gently by inversion and then kept in -20°C. Supernatant was discarded and DNA pellet was washed twice with 75 % ethanol (200 µl) and then final wash with 100 % ethanol. The alcohol was decanted and DNA pellet was air dried. Then, in 100 µl of 10 mM Tris, DNA pellet was dissolved and stored at -20°C. The quality of DNA was checked by 0.8% agarose gel electrophoresis.

PCR amplification and gel analysis: After quantification, the DNA was diluted to a concentration of 50 ng/µl for SSR analysis. The cocktail for the amplification (10 µl) was prepared in 0.2 ml PCR tubes, 8 ng/µl Template DNA (2.0 µ$MgCl_2$ (1.0 µl), 0.2 mM dNTPs (0.2 µl), 0.2 µM Primer (0.2 µl forward and reverse each), 0.5 U Taq DNA Polymerase (0.5 µa short spin for thoroughly mixing of the cocktail components. At that point, 0.2 ml PCR tubes were loaded on to a thermal cycler (BIO-RAD iCycler, BIO-RAD laboratories, Inc.). The program was set up as follows: denaturation at 95°C for 5 min, followed by 35 cycles of 95 ? for 45 s, 45 s at 53 to 57°C depending on annealing temperature of the primer and finally extension at 72°C for 5 min. Agarose gel electrophoresis (2.5%) stained with ethidium bromide was carried out to separate the amplified products. A 100 base pair ladder marker (StepUp™ 100 bp DNA Ladder, GeNei™) was used to estimate PCR fragments size.

Genetic diversity analysis

Molecular analysis: A total of 21 SSR primers were used for the analysis in which five primers showed polymorphism (Table 2). The clear and distinct bands amplified by SSR primers were scored visually for their presence (1) or absence (0) of the corresponding band among the 33 sesame genotypes. The Polmorphic Information Content (PIC) values of each primer were computed using the formula:

$$PIC = 1 - \sum_{i=1}^{n} p_i^2 - \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} 2p_i^2 p_j^2$$

where, n=number of alleles, p_i and p_j = alleles frequency in population *i* and *j* respectively (Botstein *et al*., 1980). The binary data scored was used to construct a dendrogram. Dissimilarity matrix was generated using the SIMQUAL programme of NTSYS-pc software, version 2.2 (Rohlf, 1998). The dissimilarity co-efficient were used for cluster analysis and dendrogram was constructed by the Under weighted Pair Group method (UPGMA) (Sneath and Sokal, 1973).

Morphological analysis: The morphological data of all the traits were put in Canonical Roots Analysis (P. C. A.) in order to distinguish the varieties. Genetic diversity analysis was estimated by Mahalanobis (1936) D^2 statistic methods and clustered the genotypes on the basis of Mahalanobis Euclidean distance by Tocher method (Windostat V 9.3).

RESULTS AND DISCUSSION

Morphological diversity: In order to assess the morphological diversity, a set of 33 seasame genotypes were evaluated which revealed a significant difference for most of the traits and found marked divergence. Cluster analysis of genotypes was based on mean performance of individual genotype for all of the twelve traits by using Tocher's variance method. On the basis of cluster analysis, genotypes were divided into nine clusters (Table 3; Fig. 1 and 2). Among all the nine clusters, cluster II had maximum number of genotypes (14) followed by cluster III (6), cluster IV (5),

cluster I (3), cluster V, VI, VII, VIII and IX (1 each). The intra and inter cluster average distances among nine clusters were variable, the result presented in Table 4. The intra-cluster distance ranged from 0.00 to 38.30. The highest intra-cluster distance was recorded for cluster-IV (38.30) followed by cluster II (34.74) followed by cluster III (32.20) then cluster I (20.87). Genotypes from these clusters could be utilized as parental lines for hybrid programmes owing to their higher mean performance within group. Lowest intra-cluster distance was recorded for cluster V, VI, VII, VIII and IX (0.000) means monogenotypic cluster. The inter-cluster distance ranged from 28.66 to 386.70 between cluster VII and VI and cluster VI and I respectively. The highest inter-cluster distance was observed between cluster VI and I (386.70), followed by cluster VII and I (313.59), cluster V and I (271.39), cluster IX and VI (233.50), cluster VI and IV (228.27), cluster III and I (217.14) indicating wider genetic diversity among the genotypes between these groups. Begum *et al.* (2011) grouped 50 genotypes of sesame into 5 clusters and reported that Clusters I and II should be preferred for selecting parents for hybridization resulting in producing new recombination with acceptable characters. Parameshwarappa *et al.* (2012) used 131 germplasm for assessment and grouped into eight clusters. Maximum intra cluster distance was shown by cluster IV while cluster II and VI showed highest inter cluster distance suggesting wide diversity. Jadhav and Mohrir (2013) grouped 31 genotypes into seven clusters and cluster I (10) was largest, followed by cluster II (8), cluster III (7) and cluster V (3), while clusters IV, VI and VII were solitary. Inter cluster distance ranged from 51.96 (between clusters V and VII) to 423.26 (between clusters II and VII), while maximum intra cluster distance observed within cluster V (48.03). Tripathi *et al.* (2014) reported that maximum inter cluster distance was observed between cluster VI and cluster XI (134.72) followed by clusters V and XI (124.23) while, lowest divergence was noticed between cluster IV and V (9.37). Soundharya *et al.* (2017) evaluated 62 genotypes and grouped into 6 clusters where, cluster I was largest containing 44 genotypes followed cluster II with twelve genotypes, cluster VI with three genotypes and cluster III, V, VI having solitary genotypes. The inter cluster distance was maximum between cluster IV and VI, minimum between cluster I and III, suggesting makeup of germplasm lines included in these clusters. Swathy *et al.* (2018) evaluated 90 genotypes and grouped into nine cluster. Of these clusters, cluster IX and V showed highest inter cluster distance indicating that they are the most diverse cluster whereas clusters VIII and II were the least diverse as indicated by the inter cluster distance.

The mean value of nine clusters for twelve characters has been presented in Table 5 and considerable difference has been found among cluster mean values. This study revealed that cluster V had highest mean values for days to 50 percent flowering (45.67), plant height (110.23 cm), height of 1st capsule bearing node (28.47 cm), inter node length (5.59 cm), days to maturity (98.67), whereas cluster I had highest mean values for number of productive branches (6.04), number of seeds per capsule (65.26) and yield Kg/ha (1414.37). The mean values for capsule length (3.01cm), percentage of oil (49.8) has been observed the highest in cluster VII, however, the highest mean values for number of capsules per plant (112.71) was observed in cluster IV and for 1000-grain weight (3.45 g) was the highest mean value in cluster VIII.

In genetic diversity experiment, the highest contribution was recorded for seed yield followed by oil content, days to 50% flowering, number of productive branches, 1000-grain weight, number of capsules per plant and inter node length however, rest of the traits have had meager contribution towards divergence. The present findings were partially in accordance with the findings of Kumhar and Solanki (2009), Narayana and Murugan (2013), Abate and Mekbib (2015) and Gogoi *et al.* (2015), where seed yield, days to 50 percent flowering, number of capsules per plant and plant height were observed as the major contributor towards total genetic divergence whereas Parameshwarappa *et al.* (2012) and Bamrotiya *et al.* (2016) observed that plant height, seeds per capsule and seed yield were the major contributors while as height of first capsule exhibited maximum genetic divergence respectively.

Molecular diversity: The molecular diversity of the sesame genotypes was assessed with the help of SSR markers. Twenty-one SSR primers were tested on 33 genotypes, out of which five were found to be polymorphic. The highest PIC value was observed in primer SSR-ES-12 (0.36) and the lowest PIC values were observed in primer CUSSR1 (0.15) (Table:6). PIC value was obtained between 0.15 to 0.36 with an average of 0.27 which is comparatively low as compared to polymorphism information content reported by Sapandana *et al.* (2012) (average PIC=0.77), Badri *et al.* (2014) (PIC= 0.298-0.912) and Iqbal *et al.* (2018) (PIC=0.36 to 0.82). The dendrogram of 33 genotypes of sesame was constructed using 5 polymorphic loci generated by SSR markers. UPGMA method was used for dendrogram construction using Jaccard's dissimilarity coefficients. The dissimilarity coefficients ranged from 0 to 1. The largest dissimilarity coefficient value 1 between the genotype TKG-15-01 and PC-14-1, BRT-04; Suparva and PC-14-1, BRT-04 and Suparva, JLS-408-2, OSM-170. The phylogenetic tree grouped the genotypes in six clusters at 0.51 dissimilarity index. In which cluster V had maximum (7) genotypes and cluster VI had minimum (3) genotypes. In cluster II, III, and IV had 6 genotypes in each group while cluster I had 5 genotypes (Fig. 3). Gogoi *et al.* (2018) grouped 33 sesame genotypes into three major clusters which further subdivided

into several sub clusters. Iqbal *et al.* (2018) used 35 SSR molecular markers for diversity analysis of 70 sesame genotypes and cluster analysis revealed five major clusters and further this major cluster was sub divided into sub clusters.

Table 1 List of genotypes used in the study

Sl. No.	Entry	Source	Sl. No.	Entry	Source
1	JLS-120	ORS, Jalgaon, MH	18	RAMA	IAS, Kolkata, West Bengal
2	AT-255	ARS, Amreli, Gujarat	19	AT-324	ARS, Amreli, Gujarat
3	TKG-523	AICRP, Tikamgarh, MP	20	SHT-01	RARS, Assam
4	TKG-525	AICRP, Tikamgarh, MP	21	KALIKA	OUAT, Bhubaneswar, Odisha
5	AT-337	ARS, Amreli, Gujarat	22	OSM-170	OUAT, Bhubaneswar, Odisha
6	AT-331	ARS, Amreli, Gujarat	23	Suprava	IAS, Kolkata, West Bengal
7	TKG-15-01	AICRP, Tikamgarh, MP	24	CUHY-57	IAS, Kolkata, West Bengal
8	DS-17-28	UAS, Dharwad, Karnataka	25	JCS2696	AICRP, Jagtial, Telangana
9	JCS-DT-26	AICRP, Jagtial, Telangana	26	BRT-04	Bihar
10	AT-336	ARS, Amreli, Gujarat	27	BRT-06	Bihar
11	TKG-518	AICRP, Tikamgarh, MP	28	BRT-08	Bihar
12	JLS-408-2	ORS, Jalgaon, MH	29	BRT-09	Bihar
13	JLS-708	ORS, Jalgaon, MH	30	BRT-10	Bihar
14	EC-370840	PC Unit, Jabalpur, MP	31	GT-10(NC)	ARS, Amreli, Gujarat
15	PC-14-1	PC Unit, Jabalpur, MP	32	TKG-22(NC)	AICRP, Tikamgarh, MP
16	AT-287	ARS, Amreli, Gujarat	33	JTS-8(ZC)	AICRP, Tikamgarh, MP
17	OSM-22	OUAT, Bhubaneswar, Odisha			

Table 2 List of twenty one Primers, Primer sequence (5'- 3')

Primer code	Source	Forward	Reverse
SSR-GN-03	Pandey *et al*., 2015	F: CCCAACTCTTCGTCTATCTC	R: TAGAGGTAATTGTGGGGGA
SSR-GN-06	Pandey *et al*., 2015	F: CCATTGAAAACTGCACACAA	R: TCCACACACAGAGAGCCC
SSR-GN-07	Pandey *et al*., 2015	F: TCTTGCAATGGGGATCAG	R: CGAACTATAGATAATCACTTGGAA
SSR-ES-12	Pandey *et al*., 2015	F: GCTGAGGAGTCTTGAAGCAGA	R: CAAAATCCCCCAACTCGATA
SSR-ES-14	Pandey *et al*., 2015	F: AAACCCGCTAAGGGACTCAT	R: CATGGCTTCTGGCTTTCTTC
SSR-ES-15	Pandey *et al*., 2015	F: TGCAGGAATGAACTCAAGGA	R: ACCTTATTCCCAGCCCACTT
CUSSR1	Bhattacharjee *et al.,* 2018	F: CAAGCGTAGAAACAAATCAAC	R: AGCTCCCAATCTATTCACTTC
CUSSR16	Bhattacharjee *et al.,* 2018	F: TTGTGGATTGTAAGCTATTCC	R: GTGACAATTCTTGCTCGTAAT
CUSSR17	Bhattacharjee *et al.,* 2018	F: CTGCTTCTCTCTCATGCATAC	R: AACATGATCGAAAAGAAAACC
CUSSR30	Bhattacharjee *et al.,* 2018	F: AGGAGAAAACACTCAAAGAGG	R: GTTTTGCAGAGCAGAGTAGAA
CUSSR18	Bhattacharjee *et al.,* 2018	F: CAAAACCCCCATCTATCTATC	R: TTAGTAGGACGTGGGTGAATA
CUSSR13	Bhattacharjee *et al.,* 2018	F: AGAGGAATTCACAGTCCTTTC	R: CTTGTGTGCTTCTTTTTGAGT
CUSSR3	Bhattacharjee *et al.,* 2018	F: TAACACTTCCACACACACACA	R: CACATGACCTTTCACCATAAT
CUSSR27	Bhattacharjee *et al.,* 2018	F: AAGAAGAAAGCAAACCTTGAC	R: TATTCAGCATATTCCCTCTCC
SSR 10	Bhattacharyya *et al.,* 2014	F: TCTTGCAATGGGGATCAG	R: CGAACTATAGATAATCACTTGGAA
SSR 19	Bhattacharyya *et al.,* 2014	F: CTCATCTACCCACACCATCTA	R: CACCAATTCTTTTGTGTCTT
SSR 28	Bhattacharyya *et al.,* 2014	F: CTCCCTCTTCCTCTTCTTCTT	R: CGAGCCATTCATAGATACAAC
SSR 33	Bhattacharyya *et al.,* 2014	F: ACAATCGTAGTCCTTTCTTGA	R: GCAAAGGTTGTTGTTGTCTC
SSR 46	Pandey *et al.,* 2015	F: GCAAACACATGCATCCCT	R: GCCCTGATGATAAAGCCA
CUESSR 02	Iqbal *et al.,* 2018	F: AAGAAAGCTAAGAAGGCAGAG	R: GCTTGATAGAGAAGTTACGACA
CUESSR 06	Iqbal *et al.,* 2018	F: TGTTATACTCAGCCAGTCACC	R: TGGTTGGGTTGATATAGTAGG

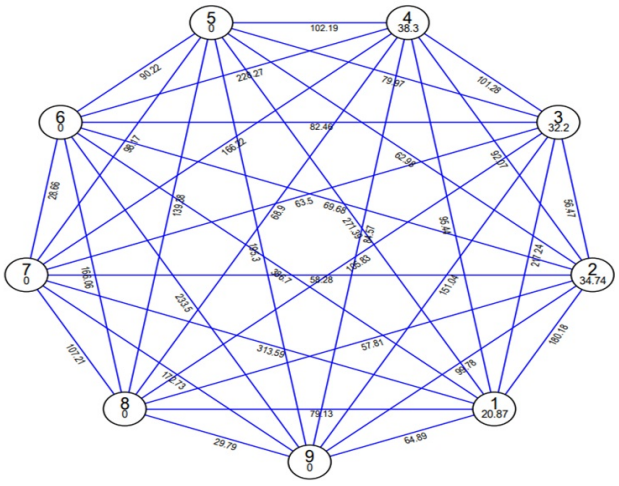

Fig. 1. Mahalanobis Euclidean Distance

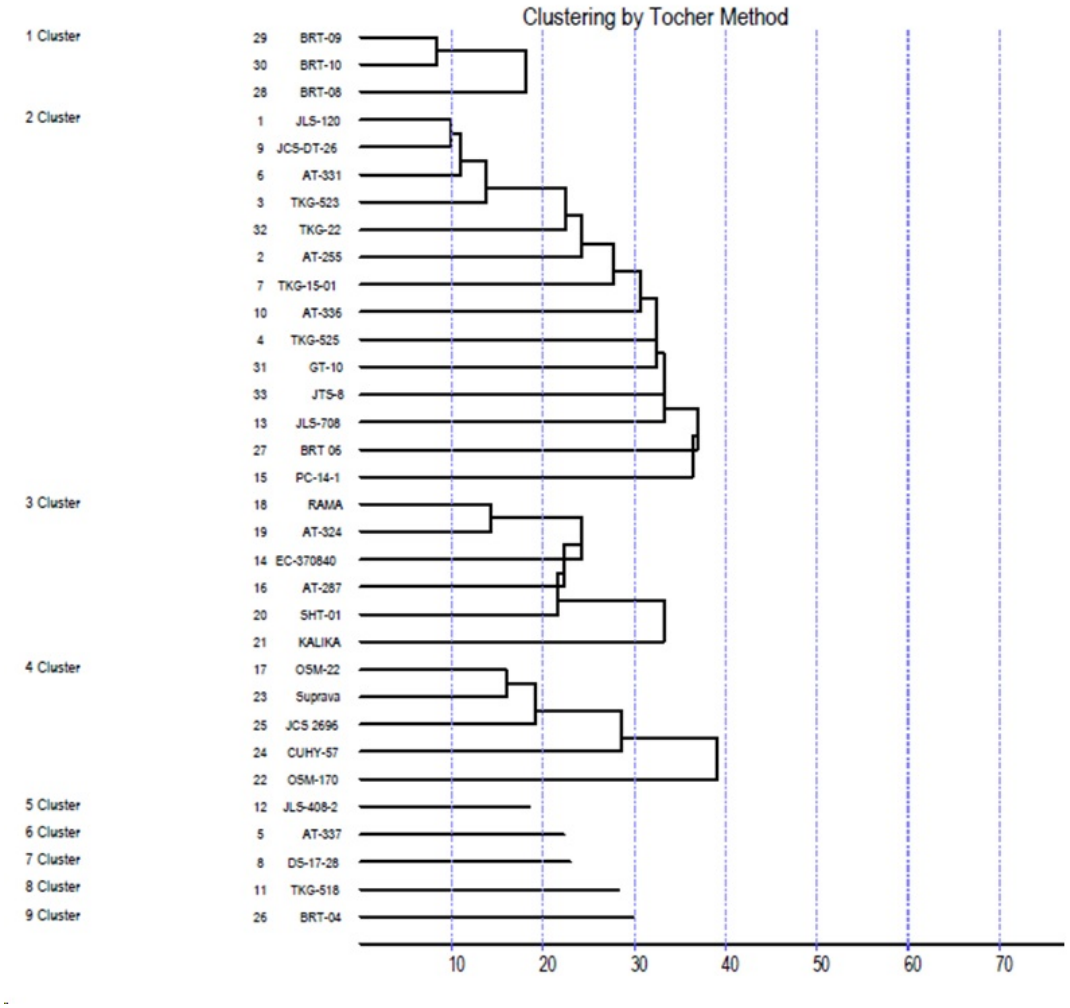

Fig. 2. Dendrogram of 33 sesame genotypes by Tocher Method

Table 3 Composition of clusters based on Tocher's Variance of thirty three sesame genotypes

Cluster No.	No. of genotypes	Name of genotypes
I	3	BRT-09, BRT-10, BRT-08
II	14	JLS-120, JCS-DT-26, AT-331, TKG-523, TKG-22, AT-255, TKG-15-01, AT-336, TKG-525, GT-10, JTS-8, JLS-708, BRT-06, PC-14-1
III	6	RAMA, AT-324, EC-370840, AT-287, SHT-01, KALIKA
IV	5	OSM-22, Suprava, JCS 2696, CUHY-57, OSM-170
V	1	JLS-408-2
VI	1	AT-337
VII	1	DS-17-28
VIII	1	TKG-518
IX	1	BRT-04

Table 4 Inter and intra cluster distance of thirty three sesame genotypes by Tocher's Method

Cluster Distances	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI	Cluster VII	Cluster VIII	Cluster IX
Cluster I	20.87	180.18	217.24	95.44	271.39	386.7	313.59	79.13	64.89
Cluster II		34.74	56.47	92.07	62.98	69.68	58.28	57.81	99.78
Cluster III			32.2	101.28	79.97	82.46	63.5	105.83	151.04
Cluster IV				38.3	102.19	228.27	166.22	68.9	84.57
Cluster V					0	90.22	98.17	139.38	195.3
Cluster VI						0	28.66	166.06	233.5
Cluster VII							0	107.21	172.73
Cluster VIII								0	29.79
Cluster IX									0

Table 5 Percentage contribution of each character towards total genetic divergence in thirty three sesame genotypes

Source	Times Ranked 1st	Contribution %
Days to 50% flowering	88	16.67%
No. of productive branches	62	11.74%
Plant height	1	0.19%
Height of 1st capsule bearing node	2	0.38%
No. of capsules per plant	17	3.22%
No. of seeds per capsules	0	0.00%
Capsule length	1	0.19%
Inter node length	13	2.46%
Days to maturity	2	0.38%
1000-grain weight	33	6.25%
Percentage of oil	96	18.18%
Yield (kg/ha)	213	40.34%

Table 6 SSR Primers revealed polymorphism across sesame genotypes

SSR locus	Approximate product size amplified (bp)	Annealing temperature	Total number of alleles	Total number of polymorphic loci	PIC value
SSR-ES-12	200-248	55	2	2	0.36
SSR-ES-15	200-236	55	2	2	0.28
CUSSR1	152-198	55	2	2	0.15
CUSSR13	160-180	55	2	2	0.34
SSR 46	250-286	57	3	3	0.23

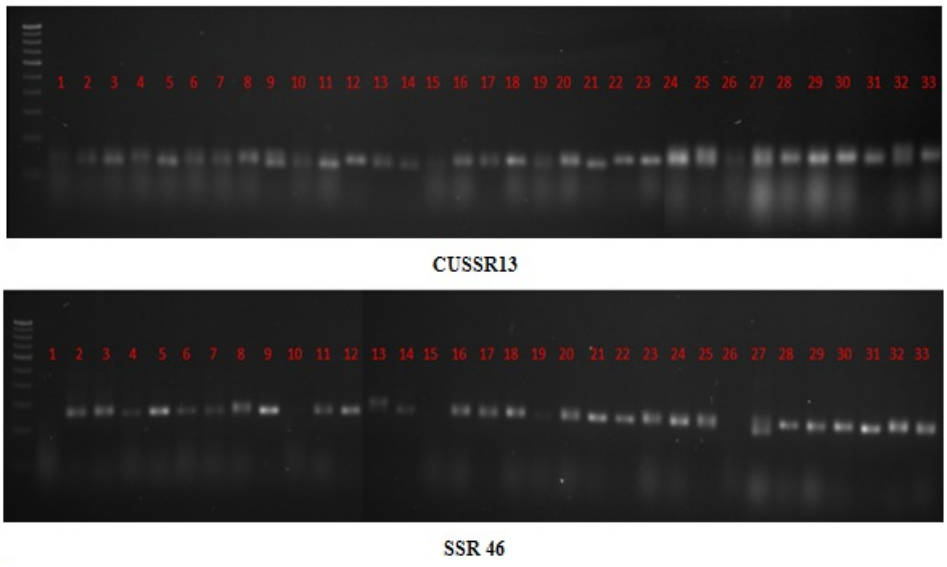

Fig.3. PCR amplification using SSR primers CUSSR 13 and SSR 46
Legends- 1 to 33 genotypes mention in Table 1

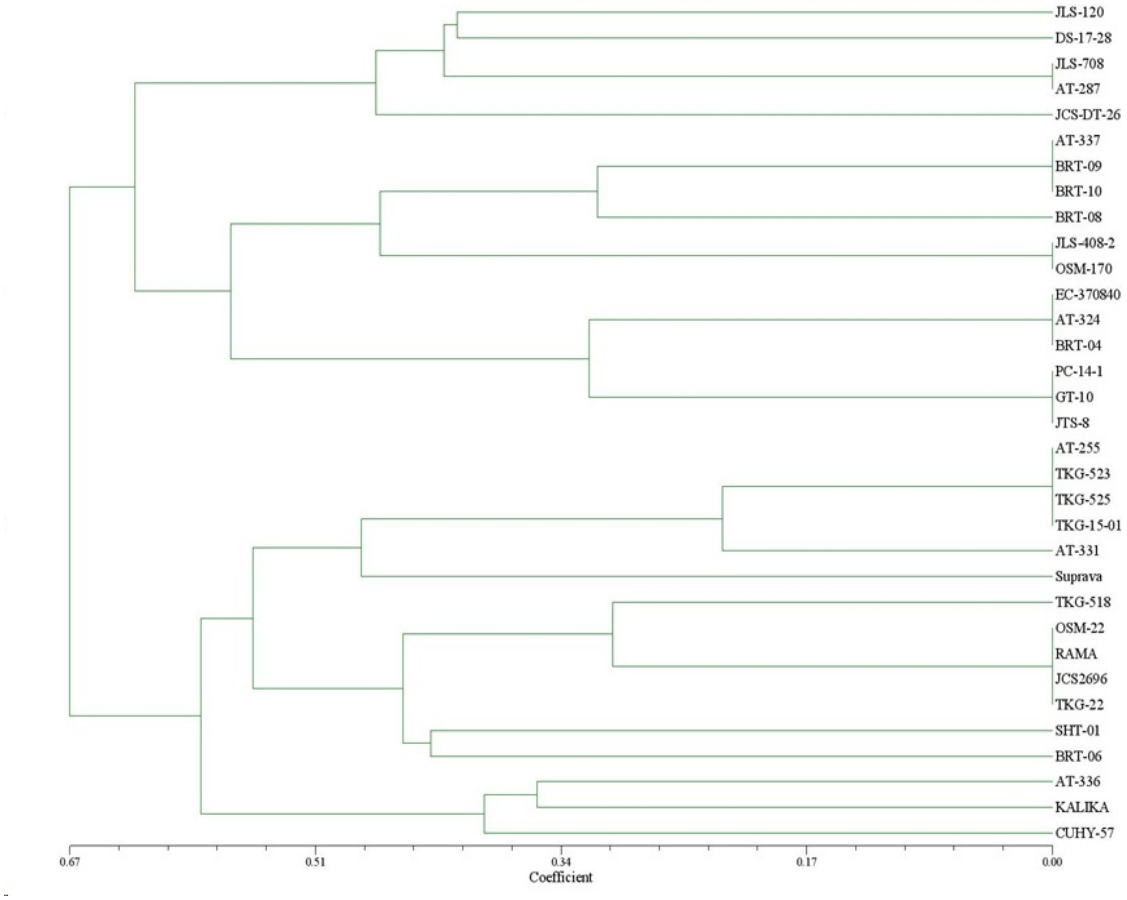

Fig. 4. Dendrogram of thirty-three sesame genotypes based on SSR marker analysis

Table 7. Cluster based on SSR marker for thirty three genotype of sesame

Cluster	No. of Genotype	Name of Genotype
I	5	JLS-120, DS-17-28, JLS-708, AT-287, JCS-DT-26
II	6	PC-14-1, BRT-08, BRT-09, BRT-10, JLS-408-2, OSM-170
III	6	EC-370840, AT-324, BRT-04, PC-14-1, GT-10, JTS-8
IV	6	AT-255, TKG-523, TKG-525, TKG-15-01, AT-331, Suprava
V	7	TKG-518, OSM-22, RAMA, JCS-2696, TKG-22, SHT-01, BRT-06
VI	3	AT-336, KALIKA, CUHY-57

The present diversity study on the sesame genotypes reveals that BRT-08 and BRT-09 of cluster I, PC-14-1, TKG-15-01, JTS-08 and TKG-22 from cluster II, OSM-170 and Suprava from cluster IV, DS-17-28 from cluster VII, TKG-518 from cluster VIII and BRT-04 from cluster IX are diverse and superior for yield and most of the attributing characters based on morphological genetic diversity. These genotypes can therefore be used in future sesame breeding programmes. Whereas, BRT-04 was more diverged genotypes followed by Suprava, TKG-15-01 and PC-14-1 in the molecular diversity analysis. At the end, BRT-04, TKG-15-01, PC-14-1 and Suprava was found common in the diversity study using morphological and molecular markers.

ACKNOWLEDGEMENT

Authors are thankful to Bihar Agricultural University, Sabour, Bhagalpur for providing financial support. We would like to also thank Dr Rajani Bisen, PC Unnit (Sesame & Niger), JNKVV, Jabalpur (MP) for providing seeds for research.

REFERENCES

Abate M and Mekib F 2015. Assessment of genetic variability and character association in Ethopian low-altitude sesame (*Sesamum indicum* L.) genotypes. *Journal of Advanced Studies in Agricultural, Biological and Environmental Science*, **2**(3): 55-66.

Badri J, Yepuri V, Ghanta A, Siva S and Siddiq E A 2014. Development of microsatellite markers in sesame (*Sesamum indicum* L.). *Turkish Journal of Agriculture and Forestry,* **38**(5): 603-614.

Bamrotiya M M, Patel J B, Ribadiya K H and Chetariya C P 2016. Genetic divergence analysis in sesame (*Sesamum indicum* L.). *AGRES-An International e-Journal*, **5**(3): 228-234.

Begum S, Islam M A, Husna A, Hafiz T B and Ratna M 2011. Genetic diversity analysis in sesame (*S. indicum* L.). *SAARC Journal of Agriculture,* **9**(2): 65-71.

Bhat KV, Babrekar P P and Lakhanpaul S 1999. Study of genetic diversity in Indian and exotic sesame (*Sesamum indicum* L.) germplasm using random amplified polymorphic DNA (RAPD) markers. *Euphytica*, **110**(1): 21-33.

Bhattacharjee M, Prakash S H, Roy S, Begum T and Dasgupta T 2018. DNA fingerprinting of CUMS 17 (Suprava): a newly developed variety of sesame. *International Journal of Pure and Applied Bioscience*, **6**(5): 161-166.

Bhattacharyya U, Pandey SK, Dasgupta T 2014. Identification of EST-SSRs and FDM in sesame (*Sesamum indicum* L.) through data mining. *Scholarly Journal of Agricultural Science*, **4**: 60-69.

Botstein D, White R L, Skolnick M and Davis R W 1980. Construction of a genetic linkage map in man using restriction fragment length polymorphisms. *American Journal of Human Genetics*, **32**: 314-331.

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

Ercan A G, Taskin M and Turgut K 2004. Analysis of genetic diversity in Turkish sesame (*Sesamum indicum* L.) populations using RAPD markers. *Genetic Resources and Crop Evolution*, **51**(6): 599-607.

Gogoi L R, Singh S K and Sarma R N 2018. Assessment of genetic diversity in indigenous sesame genotypes. *International Journal of Current Microbiology and Applied Sciences*, **7**(6): 1509-1520.

Iqbal A, Patil P K, Akhtar R, Begum T and Dasgupta T 2018. Diversity in sesame accessions. *International Journal of Agriculture, Environment and Biotechnology*, **11**(5): 725-731.

Jadhav R S and Mohrir M N 2013. Genetic divergence analysis in sesame (*Sesamum indicum* L.). *Electronic Journal of Plant Breeding*, **4**(1): 1090-1092.

Kim D H, Zur G, Danin-Poleg Y, Lee S W, Shim K B, Kang C W and Kashi Y 2002. Genetic relationships of sesame germplasm collection as revealed by intersimple sequence repeats. *Plant Breeding*, **121**(3): 259-262.

Kumar H, Kaur G and Banga S 2012. Molecular characterization and assessment of genetic diversity in sesame (*Sesamum indicum* L.) germplasm collection using ISSR markers. *Journal of Crop Improvement*, **26**(4): 540-557.

Kumhar S R and Rajani B 2021. Genetic analysis and diversity studies in sesame (*Sesamum indicum* L.). *Journal of Oilseeds Research*, **38**(4): 329-336.

Kumhar S R and Solanki Z S 2009. Genetic diversity and variability in sesame (*Sesamum indicum* L.). *Journal of Oilseeds Research*, **26**: 162-164.

Kumhar S R, Choudhary B R and Paroha S 2013. Genetic diversity analysis for seed yield and quality characters in sesame (*Sesamum indicum* L.). *Journal of Oilseeds Research*, **30**(2): 171-173.

Kumar V, Sinha S, Satyendra, Sinha S, Singh R S and Singh S N 2022. Assessment of genetic variability, correlation, path analysis in sesame (*Sesamum indicum* L.). *Electronic Journal of Plant Breeding*, **13**(1): 208-215.

Laurentin H E and Karlovsky P 2006. Genetic relationship and diversity in a sesame (*Sesamum indicum* L.) germplasm collection using amplified fragment length polymorphism (AFLP). *BMC Genetics*, **7**: 10.

Laurentin H and Karlovsky P 2007. AFLP fingerprinting of sesame (*Sesamum indicum* L.) cultivars: identification, genetic relationship and comparison of AFLP informativeness parameters. *Genetic Resources and Crop Evolution*, **54**(7): 1437-1446.

Narayan R and Murugan S 2013. Studies on variability in sesame (*Sesamum indicum* L.). *International Journal of Agricultural Research*, **2**(11): 52-55.

Pandey S K, Das A, Rai P and Dasgupta T 2015. Morphological and genetic diversity assessment of sesame *Sesamum indicum* L. accessions differing in origin. *Physiology and Molecular Biology of Plants*, **21**: 519-529.

Parameshwarappa S G, Palakshappa M G and Shinde G G 2012. Studies on genetic divergence for yield and yield attributing traits in sesame (*Sesamum indicum* L.) germplasm. *International Journal of Agricultural Sciences*, **8**(2): 441-444.

Rajitha D, Srikanth T, Padmaja D and Kiran Babu T 2021. Genetic variability and heritability studies among genotypes of sesame (*Sesamum indicum* L.). *Journal of Oilseeds Research*, **38**(1): 43-48.

Rao C R 1952. *Advanced statistical methods in biometrical research.* John Wiley and Sons Inc., New York. pp. 390.

Rohlf F J 1998. *NTSYS-pc Numerical Taxonomy and Multivariate Analysis System Version 2.0 User Guide.* Applied Biostatistics Inc., Setauket, New York, pp. 37.

Salazar B, Laurentin H, Davila M, Castillo M A 2006. Reliability of the RAPD technique for germplasm analysis of sesame (*Sesamum indicum* L.) from Venezuela. *Interciencia*, **31**(6): 456-460.

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

Soundharya B, Hemalatha V, Shobha rani T, Edukondalu B 2017. Genetic divergence studies in sesame (*Sesamum indicum* L.) genotypes. *International Journal of Current Microbiology and Applied Sciences*, **6**(9): 2615-2619.

Spandana B, Prathap RV, John PG, Anuradha G, Sivaramakrishnan S (2012) Development and characterization of microsatellite markers (SSR) in sesame (*Sesamum indicum* L.) species. *Applied Biotechemistry Biotechnology*, **168**: 1594-1607.

Swathy V, Premnath A, Viswanathan P L, Raveendran M and Manonmani S. 2018. Determination of genetic divergence based on morphological traits in sesame (*Sesamum indicum* L.). *Electronic Journal of Plant Breeding*, **9**(2): 747-752.

Tripathi A, Bisen R, Ahirwal R P, Paroha S, Sahu R, Ranganatha A R G 2014. Study on genetic divergence in sesame (*Sesamum indicum* L.) germplasm based on morphological and quality traits. *Bioscan*, **8**(4): 1387-1391.

Zhang Y X, Sun J A, Zhang X R, Wang L H and Che Z 2011. Analysis on genetic diversity and genetic basis of the main sesame cultivars released in China. *Agricultural Sciences in China*, **10**(4): 509-518.

Zhang Y X, Zhang X R, Che Z, Wang L H, Wei W L and Li D H 2012. Genetic diversity assessment of sesame core collection in China by phenotype and molecular markers and extraction of a mini-core collection. *BMC Genetics*, **13**: 102.

Unravelling the G × E interactions using AMMI biplot for phenology and agro-morphological traits in linseed (*Linum usitatissimum* L.)

MITHLESH KUMAR[1*], MANUBHAI PATEL, RAVINDRASINGH CHAUHAN, CHANDRESH TANK AND SATYANARAYAN SOLANKI

C P College of Agriculture, S D Agricultural University, Sardarkrushinagar-385 506, Gujarat

(Received: May 30, 2022; Revised: June 22, 2022; Accepted: June 24, 2022)

ABSTRACT

In the present study, additive main effects and multiplicative interactions (AMMI) biplot analysis was used to identify stable genotypes for days to flowering, maturity, plant height and number of branches per plant to dissect GEI in linseed. Trials were conducted in randomized complete block design with two replications over three consecutive years (2016-17, 2017-18 and 2018-19). ANOVA analysis revealed genotype and G×E interaction effects contributed significant sum of square for days to flower (97.31% and 0.56%); days to maturity (89.27% and 8.90%); plant height (98.29% and 0.70%) and number of branches per plant (86.40% and 2.41%) respectively. The dissection of GE interaction for all the traits was mostly explained by the first and second principal component axis (IPCA1 and IPCA2). The SSI statistic fully sync with the results of the AMMI1 biplot analysis for all the traits of top ranked genotypes across the environments. Results of genotypes stability in AMMI1 and AMMI2 biplot analyses were shown differential response with some exceptions that indicates the different sets of genes were responsible for the cumulative expression of traits under study. In the present study environments imposed variable effects with few exceptions towards the genotype stability in both AMMI1 and AMMI2 analysis models for all the traits studied. Hence, the desirable genotypes identified in linseed for phenology and agro-morphological traits could be utilized in hybridization program and varietal recommendation under semi-arid conditions.

Keywords: Additive main effects and multiplicative interactions, Genotype x Environment interaction, Linseed, Simultaneous stability index

Linseed (*Linum usitatissimum* L. 2n=30, x=15), an important oilseed crop belonging to the family Linaceae and the tribe Lineae, which includes around 230 species, is the only species of this family with commercial relevance (Kumar *et al.*, 2020a; Kumar *et al.*, 2021). It is a multipurpose crop cultivated for production of stem fiber and seed oil (Kumar *et al.*, 2021). Linseed oil is a good drying oil that is used in the production of paints, inks, varnishes, and other wood treatments, waterproof fabrics, oil cloth, soap, linoleum, putty, and pharmaceuticals, among other things (Juita *et al.*, 2012; Dwivedi *et al.*, 2021). Crop is grown for fibre, oil, or both seed and oil, but it has recently gained new interest in the emerging functional food market due to higher content of digestible proteins and lignans in seeds and high content of alpha linolenic acid (ALA), an essential Omega-3 fatty acid in its oil, which accounts for up to 61 percent of total fatty acid content (Reddy *et al.,* 2013; Kumar *et al.,* 2020a; Kumar *et al.,* 2021). In terms of area, India is second after Canada, and third in terms of production.

Linseed is mostly produced as an oilseed crop in India, covering approximately 3.2 lakh ha and producing 1.74 lakh metric tonnes. The average yield is quite low when compared to the global average yield (FAOSTAT, 2018). Low productivity could be attributed to a narrow genetic base and the lack of high-yielding varieties, cultivation in marginal lands, and vulnerability to biotic and abiotic stressors (Chauhan *et al.,* 2021). As a result of rising demand, there is an urgent need for cultivars with desired characteristics. Before designing a suitable breeding strategy for genetic improvement, the development of high yielding varieties necessitates the study of genotypes throughout time for phenology and yield component attributes.

Stability is an important criterion in breeding techniques, and it can be handled by phenotypic manifestation of features in the relevant environment (Rad *et al.,* 2013). Several statistical approaches for analysing plant stability have been presented, with the goal of dissecting GEI and stable trait expression across environments. AMMI is one such promising technique for analysing MET data and interpreting complex GEI interactions. It may show the interaction pattern graphically and indicate the contexts for evaluating the various genotypes (Kumar *et al.,* 2020a; 2020b). In the present investigation, 50 genotypes of linseed were evaluated by the AMMI analysis and the SSI statistics for selection of genotypes in terms of days to flowering, maturity, plant height and number of branches per plant. The objectives of this study were to dissect GEI for phonological and yield component traits in 50 linseed genotypes using AMMI analysis and to detect stable and superior genotypes across the environments (years) for future use in breeding programs.

Present Address: [2]AICRN on Potential Crops, ARS Mandor, Agriculture University, Jodhpur-342 304, Rajasthan; *Corresponding author's E-mail: mithleshgenetix@gmail.com

MATERIALS AND METHODS

Experimental materials and location: Fifty linseed genotypes were sown during winter season for three consecutive years 2016-17, 2017-18 and 2018-19 at Department of Genetics and Plant Breeding, C.P. College of Agriculture, S.D. Agricultural University, S.K. Nagar, Gujarat. Genotypes with their pedigree/parentage, source/origin and characteristics features are given in Table 1. Experimental site is located at 24°19'26" North latitude and 72°18'53" East longitude with an altitude of 172 meters above the mean sea level (Arabian Sea). The soil of experimental sight was loamy sand in texture with a pH of 7.5 and climatic condition falls under the category of semi-arid, characterized by less than 400 mm of annual average rainfall.

Field experiments and observations recorded: The genotypes were sown in randomized complete block design (RCBD) with 2 replications. Each genotype was represented by 2 rows of 2 m length with distance of 30 cm between rows and 10 cm between plants in a row. Thinning was performed after 21 days of germination to maintain plant geometry. From sowing till harvesting, all the recommended agronomic package of practices was followed to raise the good crops. Five plants were randomly selected and tagged for taking observations. The observations were recorded for quantitative traits such as days to flowering, maturity, plant height and number of branches per plant.

Statistical analysis: The AMMI model for the ith genotype in the jth environment is (Zobel *et al*., 1988),

$$Y_{ijr} = \mu + g_i + e_j + b_r(e_j) + \sum_{k=1}^{n} \lambda_k \alpha_{ik} \gamma_{jk} + \rho_{ij} + \varepsilon_{ij}$$

where, Y_{ijr} is yield of genotype *i* in environment *j* for replicate *r*, ? is the grand mean, gi is the deviation of genotype i from the grand mean, ej is the environment main effect as deviation from μ, λ_k is the singular value for the interaction principal component (IPC) axis *k*, α_{ik} and γ_{jk} are the genotype and environment IPC scores (i.e. the left and right singular vectors) for axis *k*, $b_r(e_j)$ is the effect of the block *r* within the environment *j*, *r* is the number of blocks, ρ_{ij} is the residual containing all multiplicative terms not included in the model, n is the number of axes or IPC that were retained in the model, and ε_{ij} is error under independent and identically distribution assumptions.

The AMMI stability index (ASI) as described by Jambhulkar (2014) was calculated as follows:

$$ASI = \sqrt{\left[PC_1^2 \times \theta_1^2\right] + \left[PC_2^2 \times \theta_2^2\right]}$$

where, PC_1 and PC_2 are the scores of 1st and 2nd IPCs respectively; and θ_1 and θ_2 are percentage sum of squares explained by 1st and 2nd principal component interaction effect respectively. The larger the IPCA score, either negative or positive, the more specifically adapted a genotype is to certain environments. Smaller ASI scores indicate a more stable genotype across environments.

Simultaneous stability index (SSI) incorporate mean and stability index in a single criteria and calculated as: SSI = rASI + rY where, rASI is the rank of ASI and rY is the rank of mean yield of genotypes across environments. This index considered the rank of AMMI stability index (ASI) and rank of genotypes based on average yield across environments (Farshadfar *et al*., 2011). The AMMI and stability indices were determined using R statistical software, version 3.4.1 (R Development Core Team, 2020).

RESULTS AND DISCUSSION

AMMI analysis of variance: The AMMI model retrieves the part of the sum of squares that determines the G×E interaction, which is called the standard portion (the genotype and environment effect), and a residual part, which corresponds to unpredictable and uninterpretable responses from the model (Cornelius *et al.,* 1996). The present AMMI analysis indicated the genotypic effect scores comparatively more scattered than the environmental effect scores, demonstrating that variability due to the genotype is moderately greater than the variability caused by environmental effects (Figs. 1a, 1b, 1c and 1d). The AMMI analysis of number of days to flower over the environments showed that 97.31% significant sum of squares was explained by the genotype and 0.56% was attributable to the G×E interaction effects respectively (Table 2). The significant sum of square of genotype and G×E interaction effects of 89.27% and 8.90% respectively reported for days to maturity. For plant height, significance of 98.29% total sum of squares was justified by genotype and 0.70% by GEI while significance sum of square of 86.40% and 2.41% contributed by genotype and GEI effects respectively for branches per plant in linseed. AMMI analysis of variance showed the large genotype and G×E interaction percentage for the sum of squares for all the traits studied. It indicates the significant differences existed among the genotypes and the environments showed differential response against the genotypes. Mean sum of squares were found significant for

the genotypes for biomass yield, harvest index, test weight and genotype x environment interaction for test weight and seed yield by Berti *et al.* (2010) in linseed. Lirie *et al.* (2013) were also observed highly significant differences exist among the genotypes and environment for seed yield and significant for genotype, environment and genotype x environment interaction for oil content and oil yield in linseed. Genotype and environment were found highly significant differences for the plant height, day to flower, seeds per boll and seed yield while genotype and environment exhibits significant differences only for plant height, day to flower and seed yield as investigated by Soto-Cerda *et al.* (2013) in linseed. Alem and Tadesse (2014) elucidated AMMI analysis and found genotype x environment and environment were shown significant differences for seeds per boll while Tadesse *et al.* (2017) found that significant differences among genotype, environment and genotype x environment interaction for the seed yield in linseed. Similarly Chobe and Ararsa (2018) studied in linseed and observed highly significant differences were exists among themselves for genotype, environment and genotype x environment interaction for seed yield. Kumar *et al.* (2020a) performed AMMI analysis using 50 diverse linseed genotypes and found highly significant differences prevails among genotype for number of bolls per plant, number of seeds per boll, seed yield per plant and oil content (%) while genotype x environment interaction for number of bolls per plant, number of seeds per boll and seed yield per plant. The partitioning of GE interaction for days to flower, maturity, plant height and number of branches per plant which was mainly explained by the first and second principal component axis (IPCA1 and IPCA2) with 86.50% and 13.50%; 92.10% and 7.90%; 86.80% and 13.20% and 84.30% and 15.70% of GEI sum of squares respectively (Table 2). The present G x E partitioning was fully agreement with the previous study of Tadesse *et al.* (2017) for seed yield and number of bolls per plant, number of seeds per boll, seed yield per plant and oil content (%) by Kumar *et al.* (2020a) in linseed.

Stability and genotypes performance: The genotypic mean, ASI, SSI and relative rankings of genotypes on the basis of yield and stability are presented in Table 3 and 4. Low value of ASI reflects the more stability of genotype and low GEI (Kumar *et al.,* 2020a; Kumar *et al.,* 2020b). Low ASI value were observed of genotypes Suyog, IC96491, Kirtika, Pusa-3, Padmini, IC96460, Janki, IC56363, IC96461; Shekhar, Suyog, Baner, IC56365, Meera and Kirtika, Sheela, IC96461, Baner, Suyog for days to flower, maturity, plant height and number of branches per plant respectively (Tables 3 and 4). Higher rY and smaller rASI ranking could be considered as desirable SSI value for rankings of suitable genotype for days to flower, maturity and plant height. Conversely, lower rY combined with lower rASI ranking was the case of identification of desirable genotype for the number of branches per plant in the linseed. SSI represents genotypic superiority in the sense of general or wide adaptation. Based on SSI and mean rank, genotypes Suyog, IC96491, IC96473, EC41528, Shival; Padmini, IC96460, IC56363, IC96461, Shival and Suyog, Sharda, Sweta, S-36, Kiran were best for days to flower, maturity and plant height respectively. Neela, Sheela, LC-54, LC-27 and Garima were desirable genotypes for number of branches per plant. SSI statistics revealed Suyog, IC96491, IC96473, EC41528, Shival; Padmini, IC96460, IC56363, IC96461, Shival and Suyog, Sharda, Sweta, S-36, Kiran were most efficient genotypes for days to flower, maturity and plant height respectively. Similarly, Neela, Sheela, LC-54, LC-27 and Garima were desirable genotypes for number of branches per plant in linseed. The similar statistics used previously by (Tadesse *et al.,* 2017) for seed yield and Kumar *et al.* (2020a) for number of bolls per plant, number of seeds per boll, seed yield per plant and oil content (%) to delineate the stable genotypes in linseed.

When we evaluated environments independently, AMMI1 (Fig. 1a, 1b, 1c and 1d) also depicted the stability of genotype for days to flower, maturity, plant height and number of branches per plant across the years. In present study, Shival, IC96491, IC96473, EC41528, Suyog, Kirtika for days to flower and Shival, Padmini, IC96460, IC56363, IC96461, IC96473, EC41528 for days to maturity were most desirable genotypes. Genotypes Suyog, Sharda, Sweta, S-36, Kiran, Shekhar for plant height and IC54970, IC56363, IC56365, IC96460, Mukta, Gaurav, Padmini, IC96461, Parvati, Rashmi, Suyog, LC-54 for number of branches per plant were most efficient genotypes in linseed (Fig. 1a, 1b, 1c and 1d). Moreover genotypes like Pratap Alsi-1, Nagarkot; Subhra; Mukta, Hira, Pratap Alsi-1 and Surabhi, EC41528 were highly unstable for days to flower, maturity, plant height and number of branches per plant respectively from biplot of AMMI1 analysis (Figs 1a, 1b, 1c and 1d). AMMI1 analysis identified genotypes Shival, IC96491, IC96473, EC41528, Suyog, Kirtika and Shival, Padmini, IC96460, IC56363, IC96461, IC96473, EC41528 were most desirable genotypes for days to flower and days to maturity respectively. Genotypes Suyog, Sharda, Sweta, S-36, Kiran, Shekhar for plant height and IC54970, IC56363, IC56365, IC96460, Mukta, Gaurav, Padmini, IC96461, Parvati, Rashmi, Suyog, LC-54 for number of branches per plant were most efficient genotypes in linseed.

The AMMI2 biplot or interaction biplot between IPCA2 versus IPCA1 showed that genotypes R-1 (J-1) and T-397 were the most desirable genotypes as it posses high stability and early flowering habit (Fig. 2a). IC96491 was the most stable genotype for days to flower. Genotypes Nagarkot and Pratap Alsi-1 were unstable for days to flower (Fig. 2a).

Table 1 List of linseed genotypes, pedigree, source/origin and their characteristic features

Genotype	Pedigree/ Parentage	Source/ Origin	Growth habit	Lodging/ Non-lodging	Flower colour	Seed coat colour
Baner	EC-21741 × LC-216	Himachal Pradesh	Semi erect	Lodging	White	Brown
Deepika	Kiran x Ayogi	IGKV, Raipur (CG)	Erect	Lodging	Blue	Brown
EC 41528	PONE-1005 / 65	Argentina	Erect	Non -lodging	Pale blue	Brown
Garima	T-126 x Neelum	CSAUAT, Kanpur (U.P.)	Erect	Non -lodging	Blue	Brown
Gaurav	Selection-3 x EC-1552	CSAUAT, Kanpur (U.P.)	Bushy	Lodging	Blue	Yellow
Hira	---	CSAUAT, Kanpur (U.P.)	Erect	Lodging	White	Brown
IC 53281	/P/619	Raigarh, M.P.	Erect	Non -lodging	Blue	Brown
IC 54970	---	India	Erect	Non -lodging	Blue	Brown
IC 56363	---	India	Erect	Non -lodging	Blue	Brown
IC 56365	---	Akola, MH	Erect	Non -lodging	Pale blue	Brown
IC 96460	---	India	Erect	Non -lodging	Blue	Brown
IC 96461	---	India	Semi-erect	Non -lodging	Blue	Brown
IC 96473	---	India	Erect	Non -lodging	Blue	Brown
IC 96491	---	India	Erect	Non -lodging	Pale blue	Brown
Janki	New River × LC-216	Himachal Pradesh	Erect	Non -lodging	Blue	Brown
JLS-9	RL-102 x R-7/J-23	Jabalpur, M.P.	Semi-erect	Non -lodging	Blue	Brown
Kartika	Kiran x LCK-88062	IGKV, Raipur (CG)	Erect	Non -lodging	Blue	Brown
Kirtika	---	India	Erect	Lodging	Blue	Brown
Kiran	Afg-8 x R-11 x Afg-8	IGKV, Raipur (CG)	Semi erect	Lodging	Blue	Brown
LC-27	---	Gurdaspur, Punjab	Bushy	Lodging	Blue	Brown
LC-185	---	Gurdaspur, Punjab	Bushy	Lodging	Blue	Yellow
LC-54	K2 x Kangra local	Gurdaspur, Punjab	Semi erect	Lodging	White	Light brown
Meera	RL-75-6-2 x RL-29-8 x LCK8528	Kota, Rajasthan	Erect	Non -lodging	Blue	Brown
Mukta	---	CSAUAT, Kanpur (U.P.)	Erect	Non -lodging	White	Brown
Nagarkot	New River × LC-216	Himachal Pradesh	Semi erect	Lodging	Blue	Brown
Neela	Local selection of WB	West Bengal	Erect	Non -lodging	Blue	Brown
Neelum	T-1 x NP (RR)-9	CSAUAT, Kanpur (U.P.)	Semi-erect	Non -lodging	Pale blue	Brown
NL-97	R-7 x RLC-4	Nagpur, Maharashtra	Erect	Non -lodging	Pale blue	Brown
Padmini	EC-41628 x EC-77959 x DPL-20 x Neelum	CSAUAT, Kanpur (U.P.)	Semi-erect	Non -lodging	Blue	Brown
Parvati	EC-41628 x EC-77959 x (DPL-20 x Neelum x EC-216 x Hira) x (BR-1 x NP-440)	CSAUAT, Kanpur (U.P.)	Semi erect	Lodging	Blue	Brown
Pratap Alsi-1	ACC.750 x RL 29-8	Kota, Rajasthan	Erect	Non -lodging	White	Brown
Pusa-2	Selection from BS-12	New Delhi	Erect	Non -lodging	White	Brown
Pusa-3	K2 x T-603	New Delhi	Erect	Lodging	White	Brown
R-1 (J-1)	---	Jabalpur, M.P.	Bushy	Lodging	Blue	Brown
Rashmi	Gaurav x Janki	CSAUAT, Kanpur (U.P.)	Erect	Non -lodging	Blue	Brown
RLC-92	Jeevan x LCK-9209	IGKV, Raipur (CG)	Erect	Non -lodging	Pale blue	Brown
Ruchi	---	CSAUAT, Kanpur (U.P.)	Semi-erect	Non -lodging	White	Brown
S-36	---	India	Semi erect	Lodging	Blue	Brown
Sharda	(Shubhra x J-1) x (J-1 x Kiran)	IGKV, Raipur (CG)	Erect	Non -lodging	White	Brown
Sheela	Gaurav x Janki	CSAUAT, Kanpur (U.P.)	Erect	Non -lodging	Pale blue	Brown
Shekhar	Laxmi-27 x EC-1387	CSAUAT, Kanpur (U.P.)	Erect	Non -lodging	Blue	Brown
Shikha	Hira x CRISTA	CSAUAT, Kanpur (U.P.)	Semi erect	Lodging	Blue	Brown
Shival	---	Nagpur, MH	Bushy	Lodging	White	Brown
Shubhra	Mukta x K-2	CSAUAT, Kanpur (U.P.)	Erect	Non -lodging	White	Brown
Subhra	---	India	Erect	Non -lodging	White	Brown
Surabhi	LC-216 × LC-185	Kangra Valley, HP	Erect	Non -lodging	Pale blue	Brown
Suyog	Kiran x KL168 x Kiran	Sagar, MP	Erect	Non -lodging	White	Brown
Sweta	Mukta x T-1206	CSAUAT, Kanpur (U.P.)	Erect	Non -lodging	Blue	Yellow
T-397	T-491 x T-1103-1	CSAUAT, Kanpur (U.P.)	Semi-erect	Non -lodging	Blue	Brown
J-7	---	Jabalpur, M.P.	Semi-erect	Non -lodging	Blue	Brown

Table 2 AMMI analysis of variance of phenology and agro-morphological traits for 50 linseed genotypes

		Days to flower						Days to maturity					
Sources of variation	Degree of freedom	Sum of squares	Mean sum of squares	F value	Pr (>F)	% explained	% accumulated	Sum of squares	Mean sum of squares	F value	Pr (>F)	% explained	% accumulated
Environment (E)	2	16	8.06	0.03	0.9747	0.04		109.20	54.61	0.50	0.65	0.45	
Rep(E)	3	850	283.33	5497.36	<2e-16***	2.07		325.20	108.40	1280.11	<2e-16***	1.33	
Genotype (G)	49	39928	814.85	15809.97	<2e-16***	97.31		21790.40	444.70	5251.38	<2e-16***	89.27	
G×E interaction	98	231	2.35	45.66	<2e-16***	0.56		6.28	0.06	1.54	<2e-16***	8.90	
IPCA1	50	199.47	3.99	77.40	0.00	86.50	86.50	2002.09	40.04	472.84	0.00	92.10	92.10
IPCA2	48	31.14	0.65	12.59	0.00	13.50	100.00	170.87	3.56	42.04	0.00	7.90	100.00
Residuals	147	8	0.05			0.02		12.40	0.08			0.05	
		Plant height								Branches per plant			
Environment (E)	2	49.10	24.53	0.47	0.66	0.23		89.64	44.82	1.65	0.33	5.61	
Rep(E)	3	156.50	52.16	916.12	<2e-16***	0.73		81.56	27.19	522.68	<2e-16***	5.10	
Genotype (G)	49	21016.60	428.91	7533.20	<2e-16***	98.29		1381.72	28.20	542.11	<2e-16***	86.40	
G×E interaction	98	150.60	1.54	27.00	<2e-16***	0.70		38.62	0.39	7.58	<2e-16***	2.41	
IPCA1	50	130.74	2.61	45.93	0.00	86.80	86.80	32.58	0.65	12.53	32.58	84.30	84.30
IPCA2	48	19.89	0.41	7.28	0.00	13.20	100.00	6.05	0.13	2.42	6.05	15.70	100.00
Residuals	147	8.40	0.06			0.04		7.65	0.05			0.48	

IPCA= Interaction Principal Component Analysis Axis; Significance codes: '***'=0.001, '**'=0.01, '*'=0.05

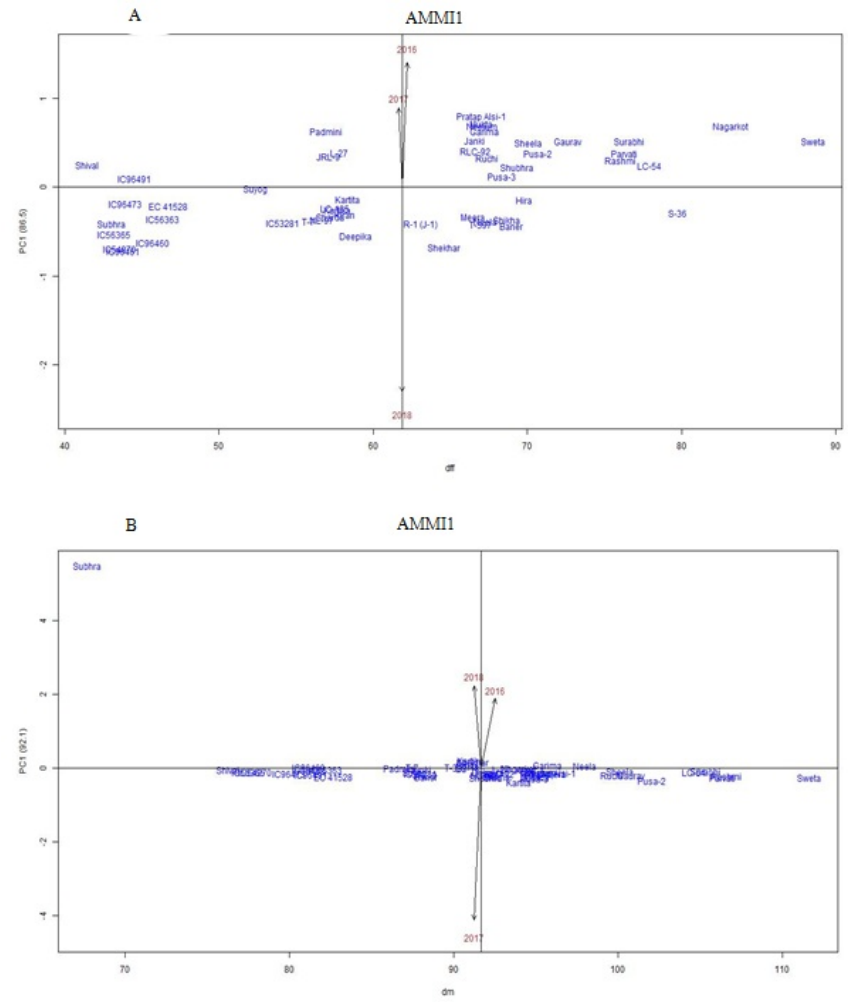

Fig. 1. AMMI biplot showing AMMI1 for a. days to flower and b. maturity of 50 linseed genotypes

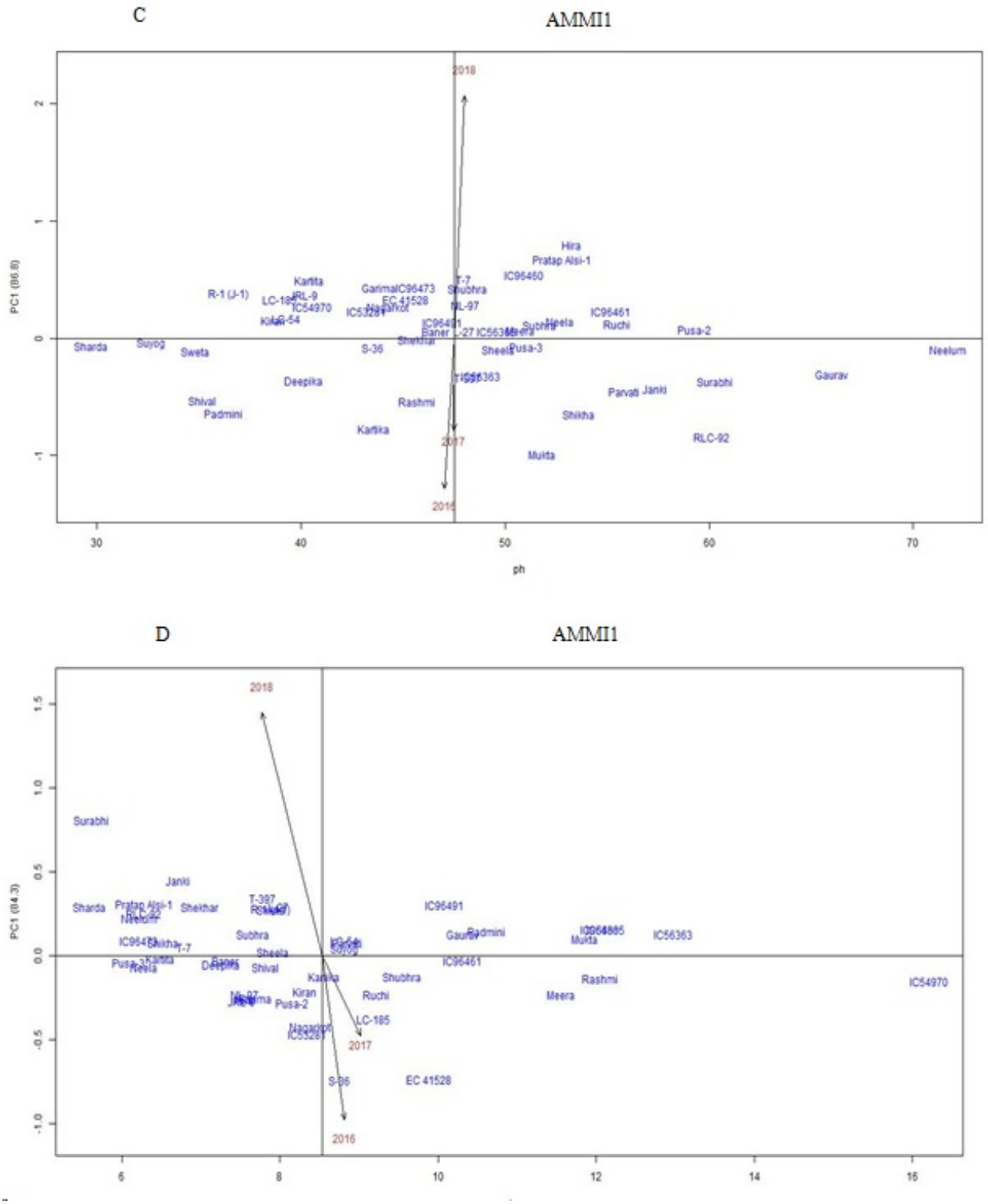

Fig. 1. AMMI biplot showing AMMI1 for c. plant height and d. number of branches per plant of 50 linseed genotypes

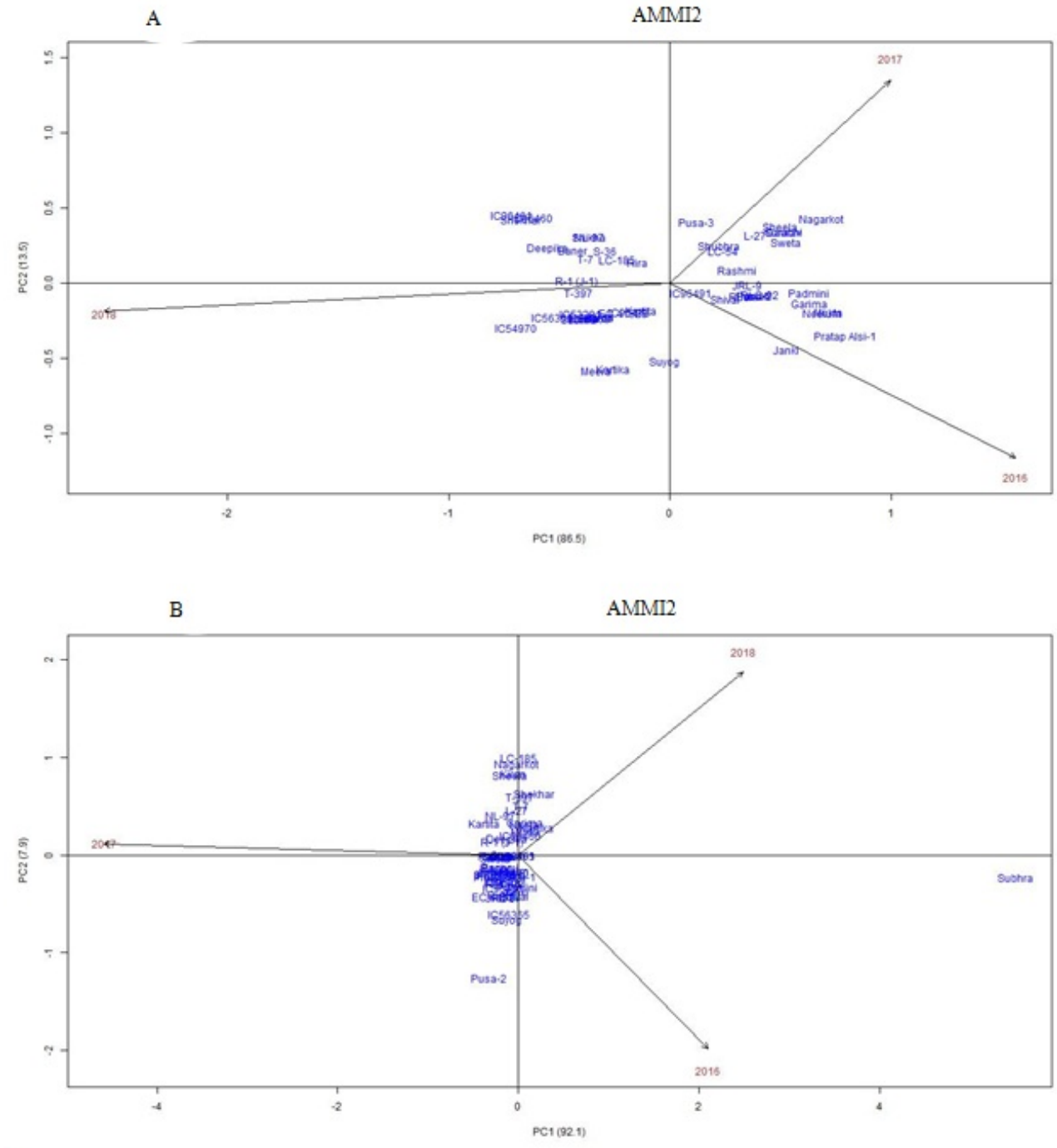

Fig. 2. AMMI biplot showing AMMI2 or interaction biplot graph for a. days to flower and b. days to maturity of 50 linseed genotypes

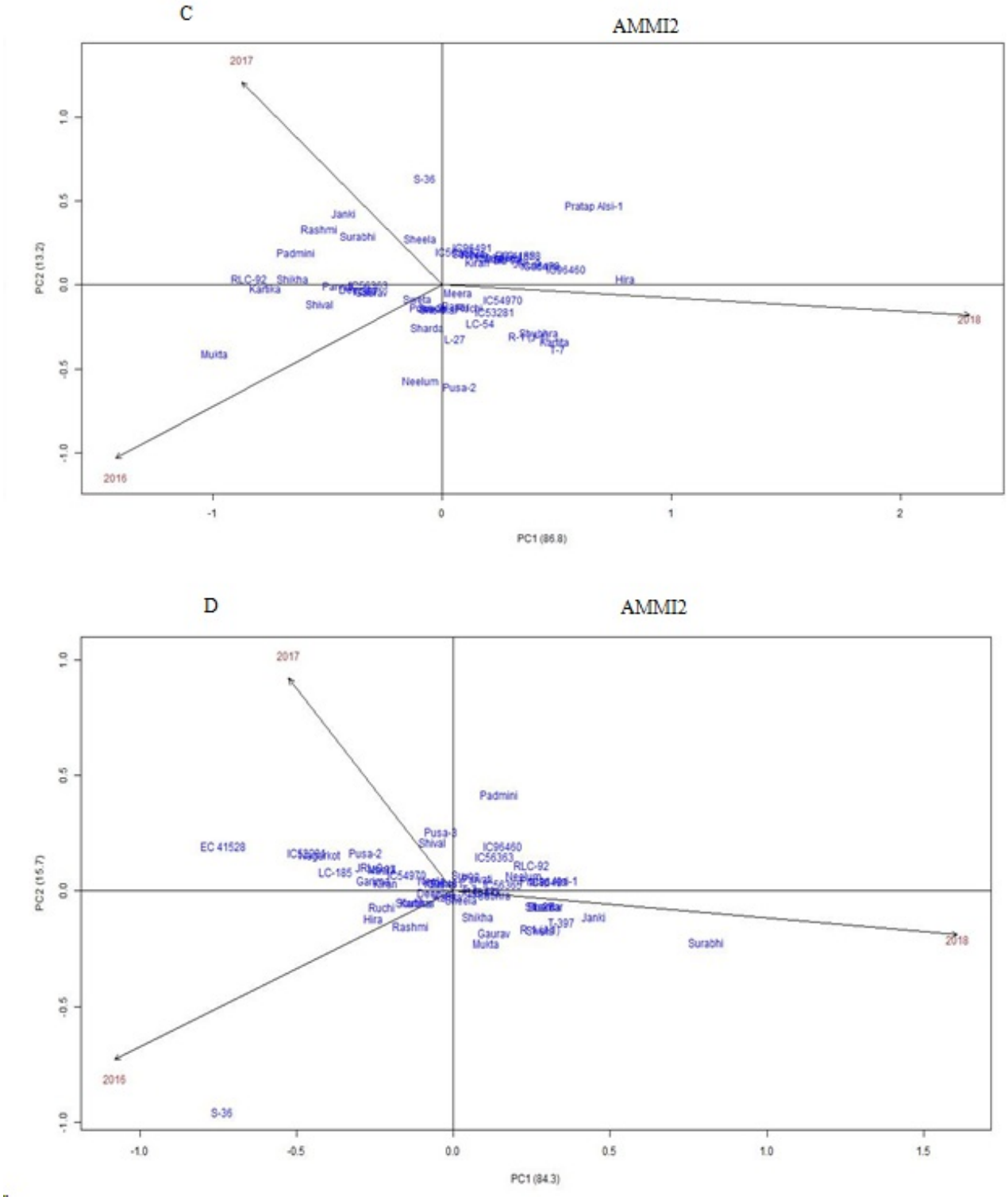

Fig. 2. AMMI biplot showing AMMI2 or interaction biplot graph for c. plant height and d. number of branches per plant of 50 linseed genotypes

Table 3 Average number of days to flower and maturity of linseed (Y) and other stability parameters: Additive Main effects and Multiplicative Interaction (AMMI) stability Index (ASI), rankings of mean performance (rY), rankings of ASI (rASI) and Simultaneous Selection Index (SSI)

	Days to flower					Days to maturity				
Genotype	Y	ASI	rY	rASI	SSI	Y	ASI	rY	rASI	SSI
Baner	68.97	0.3793	13	33	46	88.367	0.21646	34	41	75
Deepika	58.87	0.4814	28	40	68	92.100	0.12281	26	22	48
EC 41528	46.77	0.1820	41	7	48	82.700	0.21954	41	43	84
Garima	67.23	0.5481	18	43	61	95.733	0.07435	13	12	25
Gaurav	72.63	0.4494	8	35	43	100.833	0.18002	7	35	42
Hira	69.80	0.1259	11	5	16	94.833	0.18002	18	34	52
IC53281	54.17	0.3498	39	28	67	88.000	0.13211	37	26	63
IC54970	43.60	0.6026	47	47	94	77.967	0.09826	47	18	65
IC56363	46.37	0.3146	42	20	62	82.233	0.03925	42	4	46
IC56365	43.23	0.4606	48	39	87	77.533	0.10537	48	20	68
IC96460	45.73	0.5426	43	41	84	81.233	0.03046	44.5	2	46.5
IC96461	43.80	0.6224	46	49	95	81.233	0.03925	44.5	5	49.5
IC96473	43.93	0.1600	45	6	51	80.033	0.12799	46	25	71
IC96491	44.57	0.0816	44	2	46	81.333	0.15032	43	29	72
Janki	66.60	0.4605	24	38	62	88.067	0.03671	36	3	39
JLS-9	57.13	0.3028	35	19	54	88.300	0.18012	35	36	71
Kartika	57.67	0.2349	32	12	44	91.033	0.18974	30.5	38	68.5
Kirtika	58.37	0.1162	29	3	32	93.967	0.34666	20	49	69
Kiran	58.20	0.2703	30	15	45	94.400	0.08033	19	16	35
LC-27	57.80	0.3389	31	27	58	92.900	0.03929	22	6	28
LC-185	57.57	0.2056	33	9	42	91.033	0.07883	30.5	14	44.5
LC-54	77.90	0.2101	4	10	14	104.633	0.10568	5	21	26
Meera	66.47	0.2991	25	18	43	96.133	0.12799	11	24	35
Mukta	67.03	0.6198	20	48	68	90.833	0.06986	32	11	43
Nagarkot	83.18	0.5940	2	45	47	93.933	0.07516	21	13	34
Neela	67.30	0.3367	17	26	43	98.000	0.06695	10	10	20
Neelum	67.07	0.5977	19	46	65	95.300	0.09083	14	17	31
NL-97	56.67	0.3192	37	22	59	91.767	0.18599	28	37	65
Padmini	56.93	0.5430	36	42	78	86.733	0.02706	40	1	41
Parvati	76.30	0.3300	6	25	31	106.367	0.23344	3	44	47
Pratap Alsi-1	67.00	0.6886	21	50	71	95.967	0.13952	12	28	40
Pusa-2	70.70	0.3300	9	24	33	102.067	0.31990	6	48	54
Pusa-3	68.33	0.1182	15	4	19	94.933	0.24580	17	47	64
R-1 (J-1)	63.07	0.3634	27	32	59	95.100	0.16358	15	30	45
Rashmi	76.03	0.2624	7	14	21	106.600	0.18980	2	39	41
RLC-92	66.67	0.3522	23	29	52	92.800	0.13543	23	27	50
Ruchi	67.37	0.2858	16	16	32	99.633	0.17267	9	32	41
S-36	79.73	0.2554	3	13	16	92.233	0.18002	25	33	58
Sharda	57.23	0.2925	34	17	51	94.967	0.21779	16	42	58
Sheela	70.10	0.4364	10	34	44	100.133	0.10242	8	19	27
Shekhar	64.60	0.5865	26	44	70	91.167	0.17100	29	31	60
Shikha	68.67	0.3192	14	21	35	92.600	0.20673	24	40	64
Shival	41.47	0.2195	50	11	61	76.300	0.04908	49	8	57
Shubhra	69.37	0.1974	12	8	20	91.967	0.23845	27	45	72
Subhra	43.03	0.3589	49	31	80	67.700	5.06843	50	50	100
Surabhi	76.63	0.4494	5	36	41	105.333	0.07931	4	15	19
Suyog	52.37	0.0738	40	1	41	87.633	0.12728	38	23	61
Sweta	88.53	0.4534	1	37	38	111.633	0.24069	1	46	47
T-397	66.97	0.3586	22	30	52	90.133	0.04980	33	9	42
J-7	55.80	0.3296	38	23	61	87.500	0.04794	39	7	46

Table 4 Average of plant height and number of branches per plant (Y) and other stability parameters: Additive Main effects and Multiplicative Interaction (AMMI) stability Index (ASI), rankings of mean performance (rY), rankings of ASI (rASI) and Simultaneous Selection Index (SSI)

Genotype	Plant height					Branches per plant				
	Y	ASI	rY	rASI	SSI	Y	ASI	rY	rASI	SSI
Baner	46.63	0.0547	28	3	31	7.32	0.024	36	4	40
Deepika	40.13	0.3180	41	30	71	7.25	0.047	37	7	44
EC 41528	45.17	0.2898	32	27	59	9.88	0.618	12	48	60
Garima	43.83	0.3726	34	35	69	7.68	0.215	31	32	63
Gaurav	66.00	0.2687	2	25	27	10.32	0.113	9.5	19	28.5
Hira	53.27	0.6932	11	48	59	7.55	0.216	33.5	33	66.5
IC53281	43.23	0.2016	37	21	58	8.35	0.394	22	47	69
IC54970	40.57	0.2314	38	23	61	16.22	0.125	1	22	23
IC56363	48.83	0.2780	21	26	47	12.98	0.114	2	20	22
IC56365	49.60	0.0577	20	4	24	12.12	0.133	3	23	26
IC96460	50.97	0.4712	17	43	60	12.05	0.137	4	24	28
IC96461	55.20	0.2006	9	20	29	10.32	0.024	9.5	3	12.5
IC96473	45.63	0.3726	31	36	67	6.22	0.077	46.5	14	60.5
IC96491	46.93	0.1197	27	16	43	10.08	0.257	11	42	53
Janki	57.37	0.3762	6	37	43	6.72	0.380	40	46	86
JLS-9	40.17	0.3233	40	32	72	7.52	0.226	35	34	69
Kartika	43.57	0.6696	35	47	82	8.55	0.103	20	16	36
Kirtika	40.40	0.4285	39	39	78	6.48	0.013	42	1	43
Kiran	38.67	0.1360	44	18	62	8.32	0.181	23	26	49
L-27	48.00	0.0655	25	7	32	7.98	0.245	25	38	63
LC-185	38.97	0.2898	43	28	71	9.18	0.316	15	44	59
LC-54	39.27	0.1482	42	19	61	8.82	0.077	17.5	13	30.5
Meera	50.73	0.0585	18	5	23	11.55	0.192	7	28	35
Mukta	51.80	0.8643	14	50	64	11.85	0.094	6	15	21
Nagarkot	44.23	0.2251	33	22	55	8.38	0.361	21	45	66
Neela	52.70	0.1276	13	17	30	6.28	0.058	44	9	53
Neelum	71.70	0.1111	1	15	16	6.22	0.190	46.5	27	73.5
NL-97	48.07	0.2496	24	24	48	7.55	0.192	33.5	29	62.5
Padmini	36.20	0.5537	46	44	90	10.62	0.140	8	25	33
Parvati	55.84	0.3930	7	38	45	8.85	0.067	16	11	27
Pratap Alsi-1	52.77	0.5780	12	46	58	6.28	0.257	44	41	85
Pusa-2	59.30	0.1040	5	13	18	8.15	0.238	24	37	61
Pusa-3	51.03	0.0641	16	6	22	6.08	0.053	48	8	56
R-1 (J-1)	36.47	0.3300	45	33	78	7.88	0.235	27.5	35	62.5
Rashmi	45.70	0.4693	29.5	42	71.5	12.05	0.117	5	21	26
RLC-92	60.13	0.7284	4	49	53	6.28	0.213	44	31	75
Ruchi	55.50	0.1032	8	11	19	9.22	0.193	14	30	44
S-36	43.50	0.1073	36	14	50	8.75	0.640	19	49	68
Sharda	29.70	0.0672	50	8	58	5.58	0.245	50	40	90
Sheela	49.67	0.0893	19	9	28	7.92	0.022	26	2	28
Shekhar	45.70	0.0228	29.5	1	30.5	6.98	0.245	38	39	77
Shikha	53.60	0.5649	10	45	55	6.52	0.067	41	12	53
Shival	35.20	0.4629	47	41	88	7.82	0.066	29	10	39
Shubhra	48.17	0.3693	22.5	34	56.5	9.55	0.103	13	17	30
Subhra	51.67	0.1037	15	12	27	7.65	0.111	32	18	50
Surabhi	60.30	0.3214	3	31	34	5.62	0.683	49	50	99
Suyog	32.67	0.0413	49	2	51	8.82	0.034	17.5	5	22.5
Sweta	34.83	0.0964	48	10	58	7.88	0.235	27.5	36	63.5
T-397	48.17	0.2933	22.5	29	51.5	7.78	0.290	30	43	73
J-7	47.97	0.4384	26	40	66	6.78	0.043	39	6	45

AMMI2 analysis model for days to maturity showed that, Subhra was the most efficient genotype (Fig. 2b). R-1 (J-1) and Deepika were most stable genotypes identified for the maturity duration (Fig. 2b). Genotypes LC-185, Nagarkot, Pusa-2, Kiran and Sheela were unstable for days to maturity (Fig. 2b). Meera was the most stable genotype identified for plant height. RLC-92, Kartika, Shikha, Parvati, Shival, IC56363, Deepika, Gaurav and Padmini were the most desirable genotypes as it posses shorter plant height and stability over the years (Fig. 2c). The genotypes Mukta, S-36, Pratap Alsi-1, Neelum and Pusa-2 were unstable for plant height in linseed (Fig. 2c). The genotypes Deepika, Sheela and Neela were most stable for number of branches per plant (Fig. 2d). Pratap Alsi-1, Neelum, RLC-92, IC56365 and Parvati were most desirable as it posses higher number of branches with more stability while S-36 and Padmini were unstable for number of branches per plant in linseed (Fig. 2d). Similarly, AMMI2 interaction biplot showed that R-1 (J-1) and T-397 for early flowering while Subhra for days to maturity were the most efficient genotypes. RLC-92, Kartika, Shikha, Parvati, Shival, IC56363, Deepika, Gaurav and Padmini were the most desirable genotypes for dwarf plant height. Desirable genotypes like Pratap Alsi-1, Neelum, RLC-92, IC56365 and Parvati were identified for number of branches per plant in linseed. Results of AMMI1 and AMMI2 biplot analyses were differs for most of the genotypes for days to flower, maturity, plant height and number of branches per plant with some exceptions that indicates the different sets of genes and effect of environment on the cumulative expression of traits under study. The contribution of AMMI2 or interaction biplot to GEI sum of squares was in conformity with the previous studies of Lirie *et al.* (2013) for seed yield, oil content and oil yield, Alem and Tadesse (2014) for seeds per boll, Tadesse *et al.* (2017) for seed yield, Chobe and Ararsa (2018) for seed yield and Kumar *et al.* (2020a) for number of bolls per plant, number of seeds per boll, seed yield per plant and oil content (%) in linseed.

Environments with IPCA1 scores nearly or equal to zero have small contribution to the interactions and accordingly have large contribution to the stability of genotypes (Oliveira *et al.,* 2009; Akter *et al.,* 2014). The AMMI1 biplot graph of days to flower, plant height and number of branches per plant showed that environments 2017 (more), 2016 (moderate) and 2018 (low) contributed for stability of genotypes in linseed (Fig. 1a, 1c and 1d respectively). Environments 2016 and 2018 were more and 2017 as moderate contributor of stability for days to maturity in AMMI1 biplot analysis (Fig. 1b). The AMMI2 biplot or interaction biplot graphs showed environments 2016, 2017 and 2018 were contributed more towards the GxE interaction hence less towards the stability of genotypes for all the characters studies (Figs 2a, 2b, 2c and 2d respectively). AMMI2 or interaction biplot may be more accurate to extract GEI variation as it contains information of two IPCAs and greater pattern proportion compared to the AMMI1. This model is simple and elucidates the stability, genotypic performance, genetic variance between genotypes, and the environments that optimize varietal performance (Miranda *et al.,* 2009). AMMI1 and AMMI2 biplot analysis revealed environments have different response for genotype stability for days to flower, maturity, plant height and number of branches per plant. This showed that differential response of environments play significant role in stability of genotypes towards the phenotypic trait expression in linseed (Alem and Tadesse 2014; Tadesse *et al.,* 2017; Chobe and Ararsa, 2018; Kumar *et al.,* 2020a).

AMMI model is effective as it contribute to a large portion of the GEI sum of squares and separate the main and interaction effects. The results showed that the AMMI1 and AMMI2 biplot models had differential response for days to flower, maturity, plant height and number of branches per plant in sight of genotype performance across the environments. This indicated that trait is governed by different sets of genes on the cumulative expression of phenotypic traits variation. Variable results were obtained for environmental contribution towards the genotype performance in both AMMI1 and AMMI2 analysis indicated differential response of environment for all the traits studied. The results of SSI statistic agreed with the results of the AMMI1 biplot models for days to flower, maturity, plant height and number of branches per plant of top ranked genotypes in all environments. Conclusively, genotype Suyog was most desirable genotype for multiple traits like days to flower, plant height and number of branches per plant; Kirtika for days to flower and number of branches per plant; Shival for days to flower and maturity; IC96461 for days to maturity and number of branches per plant while, Baner for plant height and number of branches per plant respectively.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Dr P K Singh, PC Unit (Linseed), Kanpur, Uttar Pradesh and Director, NBPGR, New Delhi for providing the linseed genotypes to carry out the present research work. The pedigree information of linseed provided by Dr Karam Husain, Professor, CSAUAT, Kanpur, Uttar Pradesh has been greatly acknowledged.

REFERENCES

Akter A, Jamil Hassan M, Umma Kulsum M, Islam M R and Hossain K 2014. AMMI biplot analysis for stability of grain yield in hybrid rice (*Oryza sativa*). *Journal of Rice Research*, **2**(2): 126-129.

Alem C and Tadesse D 2014. Study on genotype x environment interaction of seed yield, oil content, fatty acid profile and stability analysis of related trait in linseed (*Linum usitatissimum* L.) in north western Ethiopia. *International Journal of Plant Breeding and Genetics*, **8**(2), 66-73.

Berti M, Fischer S, Wilckens R, Hevia F and Johnson B 2010. Adaptation and genotype × environment interaction of flaxseed (*Linum usitatissimum* L.) genotypes in South Central Chile. *Chilean Journal of Agricultural Research*, **70**: 345-356.

Chauhan J S, Choudhury P R and Singh K H 2021. Production, varietal improvement programme and seed availability of annual oilseeds in India: Current scenario and future prospects. *Journal of Oilseeds Research*, **38**(1): 1-18.

Chobe A C and Ararsa A D 2018. AMMI and GGE biplot analysis of linseed (*Linum usitatissimum* L.) genotypes in central and south-eastern highlands of Ethiopia. *Journal of Plant Breeding and Genetics*, **6**(3): 117-127.

Cornelius P L, Crossa J and Seyedsadr M S 1996. Statistical tests and estimators of multiplicative models for genotype - by - environment interaction. pp. 199-234. In: Kang M S, Gauch H G (eds). *Genotype-by-Environment Interaction.* CRC Press, Boca Raton, FL, USA.

Dwivedi S K, Satyaraj G R K and Panda S 2021. Foliar application of plant growth regulators on growth, yield and economics of linseed (*Linum usitatissimum* L.). *Journal of Oilseeds Research*, **38**(2): 195-198.

FAOSTAT 2018. FAO statistical data. http://faostat.fao.org.

Farshadfar E, Mahmodi N and Yaghotipoor A 2011. AMMI stability value and simultaneous estimation of yield and yield stability in bread wheat (*Triticum aestivum* L.). *Australian Journal of Crop Science*, **5**: 1837-1844.

Jambhulkar N N, Bose L K and Singh O N 2014. AMMI stability index for stability analysis, in CRRI Newsletter, January-March 2014, T. Mohapatra (ed.), Cuttack, Orissa: Central Rice Research Institute, 15.

Juita, Dlugogorski B Z, Kennedy E M and Mackie J C 2012. Low temperature oxidation of linseed oil: a review. *Fire Science Reviews,* 1: 3.

Lirie E, Habtamu Z and Adugna W 2013. AMMI analysis of yields and oil content in some linseed (*Linum usitatissimum* L.) genotypes in south and central Ethiopia. *Ethiopian Journal of Agricultural Sciences*, **24**: 79-98.

Miranda G V, Souza L V, Guimarães M, Lauro J M, Namorato H, Oliveira L R and Marcelo O S 2009. Multivariate analyses of genotype × environment interaction of popcorn. *Pesquisa Agropecuaria Brasileira*, **44**(1): 45-50.

Kumar M, Patel M, Chauhan R, Tank C and Solanki S 2020a. Deciphering genotype x environment interactions by AMMI method for yield and component traits in linseed (*Linum usitatissimum* L.). *Journal of Oilseeds Research*, **37**(2): 120-133.

Kumar M, Patel M, Chauhan R, Tank C and Solanki S 2021. Delineating multivariate divergence, heritability, trait association and identification of superior omega-3-fatty acid specific genotypes in linseed (*Linum usitatissimum* L.). *Genetika*, **53**(2): 825-849.

Kumar M, Patel M P, Chauhan R M, Tank C J, Solanki S D, Gami R A, Soni N V, Patel P C, Patel P T, Bhadauria H S, Patel N B, Patel R M and Rani K 2020b. Delineating G × E interactions by AMMI method for root attributes in ashwagandha [*Withania somnifera* (L.) Dunal]. *Indian Journal of Genetics and Plant Breeding*, **80**(4): 441-449.

Oliveira E J, de Freitas J P X and de Jesus O N 2009. AMMI analysis of the adaptability and yield stability of yellow passion fruit varieties. *Scientia Agricola*, **71**(2): 139-145.

Rad M N, Kadir M A, Rafii M Y, Jaafar H Z, Naghavi M R and Ahmadi F 2013. Genotype environment interaction by AMMI and GGE biplot analysis in three consecutive generations of wheat (*Triticum aestivum*) under normal and drought stress conditions. *Australian Journal of Crop Science*, **7**(7): 956-961.

R Development Core Team 2020. R: A language and environment for statistical computing. *R Foundation for Statistical Computing,* Vienna, Austria. URL https://www.R-project.org.

Reddy M P, Reddy B N, Arsul B T and Maheshwari J J 2013. Genetic variability, heritability and genetic advance of growth and yield components of linseed (*Linum usitatissimum* L.). *International Journal of Current Microbiology and Applied Sciences*, **2**: 231-237.

Soto-Cerda B J, Westermeyer F, In˜iguez-Luy F, Gasto´n Mun˜oz, Montenegro A and Cloutier S 2013. Assessing the agronomic potential of linseed genotypes by multivariate analyses and association mapping of agronomic traits. *Euphytica*, DOI10.1007/s10681-013-1012-1.

Tadesse T, Tekalign A, Sefera G and Muligeta B 2017. AMMI model for yield stability analysis of linseed genotypes for the highlands of Bale, Ethiopia. *Plant*, **5**(6): 93-98.

Zobel R W, Wright M J and Gauch H G 1988. Statistical analysis of a yield trials. *Agronomy Journal*, **80**: 388-393.

Investigation of genetic variability in castor (*Ricinus communis* L.) accessions through principal component analysis

YAMANURA*, R MOHAN KUMAR, C LAVANYA[1], PRASHANTH A SANGANNAVAR[2] AND B BORAIAH

AICRP on Castor, ZARS, University of Agricultural Sciences, GKVK, Bengaluru-560 065, Karnataka

(Received: October 8, 2021; Revised: December 11, 2021; Accepted: April 6, 2022)

ABSTRACT

In this study 100 castor germplasm accessions along with 4 checks (DCS-9, DCS-107, DCH-177 and DCH-519) were examined for genetic variability and agro-morphological traits at All India Co-ordinated Research Project on Castor, Zonal Agricultural Research Station, GKVK, Bengaluru during *kharif* 2019. The analysis of variance revealed that, castor accessions differed significantly for all the targeted traits except number of effective spikes per plant, which indicates considerable variability exists among the germplasm accession studied. The outcome of Principal Component Analysis (PCA) indicated that, four principal components (PCs) having eigen values more than one with 79.36% of the total variation among the 104 genotypes. Further, the PC 1 accounts 38.94% variation followed by PC 2 with17.88%, PC 3 with 13.98% and PC 4 with 8.55% variation. The germplasm studied were grouped into eleven main clusters. Cluster-I consist of 29 genotypes which was found to be a largest cluster, whereas, cluster VIII, IX, X and XI consists of single genotype in each cluster and they had solitary entries *viz.,* HCG-21, HCG-116, BCG-23 and HCG-80 respectively. Based on values of inter cluster distance, it was found that the highest divergence occurred between cluster X and XI (18772790.00). The cluster X involved BCG-23 which is high yielding (223.40g/plant), bold seeded (40.99g/100 seed weight) and better than checks and cluster XI had HCG-80, these could be utilized in heterosis breeding to get superior recombinants.

Keywords: Castor, Cluster distance, Germplasm, Genetic diversity, Multivariate analysis

Castor (*Ricinus communis* L.) is a non-edible oilseed crop extensively cultivated for bio-based raw material for wide industrial applications. The oil is a combination of saturated and unsaturated fatty acid esters connected to a glycerol. The existence of hydroxyl group, a double bond, carboxylic group and a long chain hydrocarbon in ricinoleic acid, deals numerous opportunities of transforming it into diversity of industrial materials. The oil is thus a prospective substitute to petroleum-based starting chemicals for the production of materials with multiplicity of properties. Presently, it is being cultivated in 30 countries on commercial scale of which India, China, Brazil, Russia, Thailand, Ethiopia and Philippines are major castor seed growing countries accounting for nearly 88% of the world's production.

The global castor oil and derivatives market demand was estimated at 813.2 kilotons in 2018 and is expected to grow at a compound annual growth rate (CAGR) of 4.1% from 2019 to 2025. India being the global leader in castor production and export with more than 85% of global production, the crop being cultivated in an area of 8.11 lakh ha, with the productivity potential of 2228 kg per hectare, India is producing about 17.95 lakh tones (Anonymous, 2022; Poornima *et al.*, 2022). Despite vast area under cultivation, there is a huge disparity in its productivity over geographical area in India. The reason could be many, however, lack of elite genotype with wide adoptability being the major one (Patel *et al.,* 2021). It is an established fact that, genetically diverse parents result in desirable gene combinations and produce higher heterosis, therefore efforts have to be made to identify the best parents with wide genetic divergence from germplasm pool for the characters of economic importance, so as to utilize them in hybridization programme. Handling huge numbers of heterogeneous experimental material is often confusing and tedious task in synthesising truthful and valid inferences. In such situation selection of appropriate statistical tool plays a major role. The principal component analysis (PCA) is a simple non-parametric method for extracting relevant information from confusing data sets. With minimum efforts, this provides a roadmap for how to reduce the complex data to a lower dimension to sometimes hidden, simplified structures that often underlines it. The PCA converts a set of correlated variables into a set of values of linearly uncorrelated variables called principal component. In general, plant breeder is interested in keeping only those principal components whose values are greater than 1. It is necessary to decide on the number of components which have any practical significance. According to Bartlett (1950) a simpler but arbitrary rule of thumb, which has proved to be useful in practice and is to consider only those components which have eigenvalues of 1.00 or greater as having any practical significance. Components with an eigen values of less than 1 account for less variance. In this view, 100 castor

[1]ICAR-Indian Institute of Oilseeds Research, Hyderabad-500 030, Telangana; [2]Central Silk Board, Ministry of Textiles, Govt. of India, Bengaluru-560 068, Karnataka; *Corresponding author's E-mail: yaman3181aug8@gmail.com

germplasms accession along with 4 checks (DCS-9, DCS-107, DCH-177 and DCH-519) were studied for investigation of genetic variability in castor accessions through Principal Component Analysis.

MATERIALS AND METHODS

The present investigation was carried out at the experiment blocks of All India Co-ordinated Research Project on Castor, Zonal Agricultural Research Station, GKVK, Bengaluru during *kharif* 2019. The experimental material used in this study comprised of 100 castor germplasm accessions randomly chosen along with 4 checks (DCS-9, DCS-107, DCH-177 and DCH-519) obtained from ICAR-Indian Institute of Oilseeds Research, Hyderabad-Telangana State (India) and Reginal Agricultural and Horticultural Research Station, Hiriyuru, Karnataka (India) and also local collections. Detailed list of materials studied were given in Table 1.

The experiment was laid out in augmented design had five blocks where in 20 genotypes and four check entries were randomised in each block. The complete set of 104 entries was sown in a single row of 6.0 m length was assigned to each genotype with 10 dibbles having 60 cm intra and 90 cm inter row spacing. All recommended package of practices i.e.,40:40:20 kg N: P_2O_5:K_2O/ha and as a means of plant protection measures a prophylactic spray of thiodicarb 75wp @ 1 g/l and propiconazole 25 EC @ 0.5 ml/l for the control of capsule borer and gray mold disease respectively was undertaken. The observations were recorded on five randomly selected plants for traits of interest *viz.,* Days to maturity of primary spike (DMPS), Number of nodes up to primary spike (NN), Effective Length of primary spike (ELPS), Number of capsules on primary spike (NC), Number of effective spikes per plant (NES/P), Seed yield per plant (SY), 100 seed weight (HSW) and 100 Volume weight (HVW).

Multivariate analysis was done as per Mahalanobis D^2 statistics described by Rao (1952) and the grouping of genotypes into different clusters was done according to Tochers method using statistic package Windostat Version 9.3 from Indostat services, Hyderabad (India). The data were subjected to principal component analysis (PCA). PCs with Eigen values >1.0 were selected, as proposed by Jeffers (1967).

RESULTS AND DISCUSSION

Agro-morphological analysis: The 100 castor germplasms accessions subjected to analysis of variance to study the eight various traits exhibited statistically significant variations. The data presented in the Table 2 indicated that, the important traits of interest such as days to maturity of primary spike (DMPS), number of nodes up to primary spike (NN), effective length of primary spike (ELPS), number of capsules on primary spike (NC), seed yield per plant (SY), 100 seed weight (HSW) and 100 Volume weight (HVW) has exhibited high degree of variation among the germplasm accessions studied. It is obvious that genetic relationships among studied germplasm accessions did not have force tendency to associate with their geographic origins and further, Goodarzi *et al.* (2012) opined that genetic drift and selection in different environments can cause greater diversity among the accession than geographic distance. It confirms the study conducted by Lal and Lavanya (2019). However, there were no significant variation were observed for one of the important yield attributing trait number of effective spikes per plant (NES/P) among the germplasm accession studied. It could be due to selective cultivation, domestication and long-term propagation of one or a few castor bean cultivars, which are nonetheless morphologically divergent (Allan *et al.,* 2008). A wide range of variation for agronomic parameters in castor was reported by Anjani (2000), Anjani (2012), Gabriela *et al.* (2019) and Lal and Lavanya (2019).

Principal component analysis: Principal component analysis has been widely used in studying genetic variability in germplasm collections of many species Veasey et al. (2001); Naghavi and Jahansouz (2005); Bhargava *et al.* (2007) and Nooryazdan *et al.* (2010). The PCA is a simple non-parametric method for extracting relevant information from confusing data sets. It converts a set of correlated variables into a set of values of linearly uncorrelated variables called principal component. In the present investigation, PCA was performed for 8 quantitative traits which yielded five PCs among them only four PCs exhibited more than 1.0 eigen values and showed 79.36% variability. Therefore, these four PCs were given due importance for further explanation. Of the first four PCs having eigen values greater than one with 79.36% of the total variation among the 104 test accessions, the PC 1 explained total variation 38.94% followed by PC 2 with 17.88%, PC 3 with 13.98% and PC 4 with 8.55%. PC 1 and PC 2 showed maximum contribution to the total variation are presented in the Table 3 and Figure 1. In the Figure 1, line diagram explains the percentage of variation associated with each principal component obtained by drawing a graph between eigen value and principal component number. The objective of the principal component analysis is to identify the minimum number of components, which explains maximum variability out of the total variability Jeffers (1967). PC1 is the most important component, explained 38.94% of the total variation and the characters which contributed highest on the component were number of effective spikes per plant (0.27040), 100 volume weight (0.27073), seed yield per plant (0.14010) and hundred seed weight (0.04814)

contributed more towards total variation. Days to maturity showed maximum negative values (-0.34000) which showed that early maturing primary spikes contributed more towards total variation. The plant traits that separate genotypes along PC1 were major yield contributing characters presented in Table 4 and Figure 1.

PC2, which is the second important component, explained 17.88% of total variability and the characters which contribute high on the components were seed yield per plant, volume weight, 100 seed weight, Number of capsules on primary spike, number of effective spikes per plant and maturity. The third component (PC3), explained 13.98% of total variability and the characters viz., Seed yield per plant, 100 seed weight, Number of nodes to primary spike and Days to maturity of primary spike were contributed more for the component these findings are in line with Anjani (2012) that low node number is an indicator of early flowering in castor. Further, PC4 registered 8.55% to total variability and the characters which contributed immensely on traits like number of effective spikes per plant, seed yield per plant, number of nodes up to primary spike, total and effective length of primary spike. These finding are in confirmation with the earlier findings of Bhand and Patel (1999), Shaheen (2002), Sunil *et al.* (2005), Amar *et al.* (2010), Sreelakshmi (2015) and Lal *et al.* (2019) stated the first three principal component accredited 95.48% of variation towards total divergence.

Table 1 List of castor accessions utilised for evaluation during *kharif* 2019

Details of accessions	No. of accessions	Source of supply/ collection
BCG-3, BCG-4, BCG-5, BCG-6, BCG-10, BCG-10-1, BCG-11, BCG-11-1, BCG-12, BCG-12-1, BCG-13, BCG-13-1, BCG-14, BCG-14-1, BCG-15, BCG-15-1, BCG-16, BCG-17, BCG-18, BCG-19, BCG-20, BCG-21, BCG-22, BCG-23, BCG-24, BCG-25, BCG-26, BCG-26-1, BCG-27, BCG-28, BCG-29, BCG-30, BCG-32, BCG-33, BCG-34 and BCG-35	36	These are the local collections made during the course of survey and documented as Bangalore castor germplasm (BCG)
HCG-2, HCG-4, HCG-6, HCG-8, HCG-10, HCG-11, HCG-12, HCG-13, HCG-14, HCG-15, HCG-16, HCG-20, HCG-21, HCG-24, HCG-25, HCG-26, HCG-28, HCG-30, HCG-31, HCG-32, HCG-35, HCG-37, HCG-38, HCG-39, HCG-40, HCG-43, HCG-45, HCG-47, HCG-48, HCG-50, HCG-52, HCG-56, HCG-80, HCG-81, HCG-85, HCG-91, HCG-104, HCG-107 and HCG-116	39	These are the accessions obtained from Reginal Agricultural and Horticultural Research Station, Hiriyuru- Karnataka (India)
RG-22, RG-43, RG-3798, RG-3100, RG-3477, RG-3160, RG-2661, RG-2818, RG-1624, RG-1771, RG-2787, RG-2819, RG-2822, RG-72, RG-18, RG-2722, RG-392, RG-109, RG-1608, RG-3798-1, RG-3160-1, RG-2661-1, RG-1771-1, RG-1771-2 and RG-1608-1	25	These are the trait specific accessions obtained from ICAR-Indian Institute of Oilseeds Research, Hyderabad-Telangana State (India)
DCS-9, DCS-107, DCH-177 and DCH-519	04	These are the released notified varieties and hybrids used as checks obtained from ICAR-IIOR, Hyderabad.
Total number of entries evaluated	104	

Table 2 Analysis of variance (mean squares) for yield and its components

Source of Variation	Degree of freedom	Days to maturity of primary spike	Number of nodes up to primary spike	Effective Length of primary spike (cm)	Number of capsules on primary spike	Number of effective spikes per plant	100 seed weight (g)	100 Volume Weight (g)	Seed yield per plant (g)
Block (ignoring Treatments)	4	291.01**	15.91**	791.59**	464.928**	2.44	3840.16**	127103.60**	295.43**
Treatment (eliminating Blocks)	103	304.52**	12.54**	167.31*	147.284 *	2.22	1473.98**	48764.80**	39.53**
Checks	3	1114.82**	15.50**	427.61**	193.559 *	1.585	901.48**	12.58**	16.64**
Checks+Var vs. Var.	100	280.21**	12.50**	159.49*	145.896 *	2.241	1491.15**	153227.30**	40.21**
Error	12	7.109	1.013	51.396	54.13	0.96	90.096	0.88	1.09
Entries (ignoring Blocks)	103	315.74**	13.01**	196.72**	157.928 *	2.28*	1613.45**	153700.80**	50.97**
Checks	3	1114.81**	15.45**	427.61**	193.559 *	1.585	901.48**	12.58**	16.64**
Varieties	99	257.09**	10.79**	190.45**	158.429 *	2.31*	1453.70**	159593.50**	44.40**
Checks vs. Varieties	1	3725.04**	224.69**	125.447	1.43	2.074	19564.86**	31387.17**	805.27**

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

Table 3 Eigen value and percentage of total variance of various principal components

Component	Eigen vector	Variance explained	Cumulative percentage
PC1	4.673	38.94	38.94
PC2	2.146	17.88	56.82
PC3	1.678	13.98	70.81
PC4	1.026	8.55	79.36
PC5	0.781	6.51	85.87

Table 4 Component matrix showing latent vectors associated with the five principal components

Characters	Components				
	PC1	PC2	PC3	PC4	PC5
Days to maturity of primary spike	-0.34000	0.08772	0.40979	0.00054	-0.21535
Number of nodes up to primary spike	-0.37979	0.08359	0.13551	0.10375	0.13552
Effective Length of primary spike (cm)	-0.33047	0.16061	-0.46366	0.04815	0.01139
Number of capsules on primary spike	-0.22739	0.28512	-0.29626	-0.15750	-0.49015
Number of effective spikes per plant	0.27040	0.21912	-0.20597	0.21879	0.38451
100 seed weight (g)	0.04814	0.08962	0.02598	-0.91838	0.35962
100 Volume weight (g)	0.27073	0.25707	-0.09021	-0.21518	-0.49698
Seed yield per plant (g)	0.14010	0.59210	0.19313	0.11502	0.15384

Clustering analysis: Cluster analysis is a technique to group similar observations into a number of clusters based on the observed values of several variables for each individual (Sinharay, 2010). In this study, the genetic diversity within the castor genotypes was done by Toucher Method for eight quantitative trait susing statistic package Windostat Version 9.3. Based on the cluster analysis, 104 genotypes were grouped into different clusters and sub clusters which is presented in Table 5 and Figure 3. The whole set of germplasms divided into eleven main clusters. Cluster I consist of 29 genotype which was found to be a largest cluster had sub clusters from A to T followed by Cluster II had 21 genotypes which divided into twelve sub clusters, Cluster III had 18 genotypes which divided into fifteen sub clusters, cluster VI 13, cluster V 8, cluster IV 6 and cluster VII 5 genotypes. Whereas, cluster VIII, IX, X and XI consists of one genotype in each cluster and they had solitary entries *viz.,* HCG-21, HCG-116, BCG-23 and HCG-80 respectively. Based on values of inter cluster distance (Table 6a and 6b), it was found that the highest divergence occurred between cluster X and XI (18772790.00) followed by cluster IX and XI (16875710.00), cluster VIII and XI (16648660.00) and cluster IV and XI (16626010.00) indicating the wider genetic diversity between genotypes of these groups. The highest cluster means (185.30) for seed yield was observed in tenth cluster followed by Fourth cluster (101.52) (Table 6b). The cluster X involved BCG-23 which is high yielding (223.40g/plant) and bold seeded (40.99g/100 seed weight) cluster XI had HCG-80 (Table 7). Hence, selection of parents from these clusters for hybridization programme would help in achieving novel recombinants. On the other hand, the lowest divergence was noticed between clusters I and VIII (25904.19) indicating close relationship and similarity for most of the traits of the genotypes in this cluster. The inter cluster distance was higher than the intra cluster distance these results are in Ramesh *et al.* (2012), Lal *et al.* (2019) which point out the actuality of substantial diversity among the genotypes.

To sum up, studied castor germplasm accessions showed high degree of variation for days to maturity of primary spike (DMPS), number of nodes up to primary spike (NN), effective length of primary spike (ELPS), number of capsules on primary spike (NC), seed yield per plant (SY), 100 seed weight (HSW) and 100 Volume weight (HVW). The accessions based on studied traits were classified in five groups. In this study germplasms studied were divided into eleven main clusters. Cluster-I consist of 29 genotype which was found to be a largest cluster, whereas, cluster VIII, IX, X and XI consists of one genotype in each cluster and they had solitary entries *viz.,* HCG-21, HCG-116, BCG-23 and HCG-80respectively.Based on values of inter cluster distance, it was found that the highest divergence occurred between cluster X and XI (18772790.00). The cluster X involved BCG-23 which is high yielding (223.40g/plant) and bold seeded (40.99g/100 seed weight) and cluster XI had HCG-80, these could be utilized in heterosis breeding to get superior recombinants. Germplasms were evaluated alongwith ruling varieties and hybrids to check better performing genetic resources for future breeding purpose.

Table 5 Cluster composition of castor germplasm based on quantitative characters

Clusters	Sub clusters	No. of genotypes	Name of Genotypes
I	A	2	HCG-13, HCG-39
	B	1	BCG-16
	C	1	HCG-28
	D	2	HCG-20, HCG-30
	E	1	HCG-10
	F	1	HCG-14
	G	3	HCG-4, BCG-20, HCG-37
	H	3	HCG-40, BCG-5, HCG-48
	I	1	HCG-32
	J	1	BCG-6
	J	1	HCG-12
	K	1	BCG-22
	L	1	BCG-4
	M	1	HCG-38
	N	1	HCG-26
	O	1	HCG-31
	P	2	RG-72, BCG-26
	Q	1	HCG-11
	R	1	RG-1608-1
	S	2	BCG-32, HCG-6
	T	1	BCG-24
TOTAL		29	
II	A	2	HCG-50, HCG-56
	B	1	BCG-12
	C	7	BCG-14, RG-2818, BCG-14-1, HCG-16, HCG-45, BCG-18
	D	1	BCG-29
	E	1	BCG-30
	F	2	BCG-13, BCG-13-1
	G	1	BCG-11
	H	1	BCG-15
	I	1	RG-3100
	J	1	BCG-3
	K	1	BCG-19
	L	1	HCG-85
	M	1	HCG-25
TOTAL		21	
III	A	3	RG-2661-1, RG-1771-1, RG-3160
	B	1	RG-18
	C	1	RG-2722
	D	1	BCG-25
	E	1	BCG-13
	F	1	RG-2661
	G	1	HCG-35
	H	1	RG-2822
	I	1	DCS-9
	J	2	BCG-21, BCG-12-1
	K	1	RG-109
	L	1	BCG-35
	M	1	RG-3798
	N	1	HCG-8
	O	1	HCG-52
TOTAL		18	
IV	A	2	RG-3477, RG-392
	B	1	RG-2787
	C	1	RG-3160-1
	D	1	HCG-91
	E	1	BCG-28
TOTAL		6	
V	A	2	RG-1624, RG-1771-2
	B	1	HCG-24
	C	1	HCG-15
	D	1	HCG-47
	E	1	HCG-43
	F	1	BCG-26-1
	G	1	RG-43
TOTAL		8	
VI	A	2	RG-1608, DCS-107
	B	1	RG-1771
	C	1	DCH-177©
	D	1	RG-2819
	E	1	DCH-519
	F	1	RG-3798-1
	G	1	BCG-17
	H	1	BCG-33
	I	1	BCG-11-1
	J	1	BCG-34
	K	1	HCG-2
	L	1	BCG-10-1
TOTAL		13	
VII	A	2	HCG-104, HCG-81
	B	1	BCG-27
	C	1	BCG-15-1
	D	1	RG-22
TOTAL		5	
VIII	A	1	HCG-21
IX	A	1	HCG-116
X	A	1	BCG-23
XI	A	1	HCG-80
GRAND TOTAL		104	

Table 6a Average intra and inter cluster distance of castor accessions

Clusters	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8	Cluster 9	Cluster 10	Cluster 11
Cluster 1	10222.72	41272.80	470179.10	2401914.00	174787.70	911487.80	1498520.00	25904.19	42282.27	5925359.00	16550180.00
Cluster 2		9499.17	261290.50	1884140.00	63670.80	606163.80	1096059.00	75163.52	138551.30	5092295.00	16247830.00
Cluster 3			17031.88	772383.70	91767.16	92840.82	308990.70	562769.30	742784.60	3101621.00	15956730.00
Cluster 4				20422.02	1325047.00	380193.20	119559.80	2591520.00	2984061.00	810549.00	16626010.00
Cluster 5					18979.53	316902.50	683321.80	238808.50	348392.30	4140176.00	16117670.00
Cluster 6						24792.42	91681.86	1028778.00	1283426.00	2229613.00	15968950.00
Cluster 7							11905.10	1648442.00	1966426.00	1485730.00	16133070.00
Cluster 8								0.00	57421.78	6196813.00	16648660.00
Cluster 9									0.00	6831488.00	16875710.00
Cluster 10										65284.15	18772790.00
Cluster 11											0.00

Table 6b Cluster Means for eight different agronomic traits in 100 castor accessions

Traits/Clusters	DMPS	NN	ELPS	NC	NES/P	SY	HSW	HVW
Cluster 1	108.90	15.63	39.39	25.20	3.31	11.67	30.48	52.62
Cluster 2	115.10	17.92	37.30	25.73	3.10	24.54	38.80	54.80
Cluster 3	108.39	15.52	37.72	27.35	4.24	54.04	35.82	58.05
Cluster 4	106.50	14.11	30.83	25.33	4.33	101.52	31.00	61.99
Cluster 5	104.50	14.04	36.38	26.54	4.33	36.86	30.23	54.71
Cluster 6	114.85	16.49	36.08	25.72	3.69	78.34	38.63	59.35
Cluster 7	101.40	15.13	36.13	30.13	5.47	90.68	40.34	60.25
Cluster 8	125.00	18.33	77.00	40.33	4.33	6.80	28.26	57.13
Cluster 9	82.00	11.33	25.00	18.33	3.67	0.00	28.44	51.41
Cluster 10	114.00	16.67	36.84	38.17	5.17	185.30	36.74	56.57
Cluster 11	119.00	17.33	45.33	40.67	2.33	50.10	40.28	58.80

Fig.1. Component matrix showing latent vectors associated with the five principal components

DMPS: Days to maturity of primary spike, NN: Number of nodes up to primary spike, ELPS: Effective Length of primary spike (cm), NC: Number of capsules on primary spike, NES/P: Number of effective spikes per plant, HSW: 100 seed weight (g), HVW: 100 Volume weight (g), SY: Seed yield per plant (g).

Table 7 *Per se* performance for important yield attributing traits among castor accessions

S. No	Traits / Accessions	DMPS	NN	ELPS	NC	NES/P	SY	HSW	HVW
1	BCG-10	123	14.33	18.00	13.33	5.33	169.25	64.56	52.96
2	HCG-2	125	23.33	35.00	29.00	3.33	66.44	38.24	50.80
3	HCG-4	101	20.67	39.67	20.00	2.67	8.50	28.30	46.18
4	BCG-11	120	15.67	26.67	19.00	3.67	80.50	67.48	55.64
5	BCG-12	121	17.00	45.00	19.67	4.67	53.67	43.59	47.80
6	HCG-8	118	17.67	34.33	10.33	5.33	45.00	34.14	50.18
7	HCG-11	86	12.67	26.00	7.67	4.67	12.33	33.70	59.13
8	HCG-12	84	12.33	48.67	12.00	3.67	11.88	26.87	59.08
9	HCG-13	97	14.00	33.33	21.33	3.67	8.33	28.30	46.18
10	HCG-14	95	14.33	36.67	21.33	1.67	11.63	28.26	57.13
11	HCG-15	112	14.67	37.00	19.33	2.67	35.22	22.89	47.60
12	HCG-16	127	15.67	38.33	15.00	4.33	21.11	26.19	57.70
13	BCG-13	125	13.33	16.00	9.67	2.33	51.11	68.25	58.80
14	BCG-14	127	22.00	30.00	24.00	2.00	22.63	37.50	45.08
15	BCG-15	125	15.33	16.67	11.00	4.00	92.38	74.32	58.30
16	HCG-20	95	16.33	52.67	26.67	7.67	12.83	34.09	60.10
17	HCG-21	125	18.33	77.00	40.33	4.33	6.80	28.26	57.13
18	BCG-16	113	18.33	43.00	20.67	3.00	9.75	28.35	47.10
19	BCG-17	133	24.00	52.00	17.67	2.33	65.00	29.74	52.14
20	HCG-24	103	12.33	24.67	16.00	4.00	39.13	24.86	53.30
21	HCG-25	125	18.67	81.00	51.67	2.00	18.50	26.41	50.10
22	HCG-26	84	13.33	40.00	26.67	3.67	13.00	32.28	51.43
23	HCG-28	105	16.67	46.67	28.67	3.00	6.40	17.70	36.70
24	HCG-30	87	16.67	59.33	27.33	3.67	7.22	28.45	51.13
25	HCG-31	127	18.00	38.33	26.00	2.67	13.00	30.50	44.50
26	HCG-32	126	15.00	36.00	17.00	2.33	11.00	26.19	57.70
27	BCG-18	103	17.33	48.67	23.00	2.67	19.30	28.32	62.80
28	HCG-35	125	16.00	46.00	27.00	4.00	44.30	27.28	36.81
29	BCG-19	97	15.33	49.33	13.00	4.00	27.00	29.61	54.83
30	HCG-37	107	18.33	32.33	24.33	2.33	7.38	22.52	47.70
31	HCG-38	123	16.00	34.33	30.67	3.33	4.10	32.40	57.80
32	HCG-39	109	15.67	34.67	18.67	6.33	9.38	35.90	52.14
33	HCG-40	117	18.67	38.33	33.67	3.33	10.30	23.07	44.10
34	BCG-20	130	18.33	56.33	34.33	1.00	11.00	34.59	44.86
35	HCG-43	115	16.67	58.00	39.67	4.00	45.71	19.05	36.10
36	HCG-45	110	16.33	40.67	28.00	3.33	21.89	38.27	56.94
37	HCG-47	130	16.33	51.67	31.67	3.67	28.00	43.40	57.09
38	HCG-48	132	19.00	51.33	24.00	2.33	8.70	34.70	52.60
39	HCG-50	97	20.67	37.67	16.67	6.00	18.56	34.59	57.70
40	HCG-52	118	17.33	63.33	38.67	5.67	74.86	38.08	61.13
41	BCG-21	96	15.67	50.33	21.00	4.33	71.71	30.46	50.30
42	HCG-56	95	15.33	32.67	25.67	3.00	16.40	25.66	54.10
43	BCG-22	118	17.67	48.67	48.67	1.00	11.78	28.44	40.13
44	HCG-85	131	23.00	35.00	15.00	1.33	29.75	30.16	50.21
45	BCG-23	97	16.00	35.00	35.67	5.67	223.50	40.99	54.60
46	HCG-104	98	16.33	44.67	44.67	8.67	87.33	27.62	60.10
47	BCG-24	97	16.00	46.00	27.00	4.00	38.25	25.66	55.12
48	HCG-116	82	11.33	25.00	18.33	3.67	15.00	28.44	51.41
49	BCG-25	129	19.33	44.33	24.33	3.33	48.33	44.52	52.30
50	BCG-26	127	18.00	53.67	51.00	1.33	34.70	37.57	56.71
51	BCG-3	105	12.33	34.00	35.00	5.67	45.40	16.60	60.10

52	BCG-4	119	14.33	29.00	10.67	1.67	11.30	30.75	55.26
53	BCG-5	120	16.67	35.67	24.33	2.67	11.56	30.10	56.02
54	BCG-6	97	15.00	42.00	13.67	3.33	13.00	33.14	59.21
55	HCG-6	112	13.33	42.00	26.00	2.33	14.30	25.97	57.17
56	HCG-10	135	15.00	35.00	35.00	5.00	7.44	35.90	56.80
57	HCG-80	119	17.33	45.33	40.67	2.33	50.10	40.28	58.80
58	HCG-81	107	14.33	43.67	30.00	4.67	75.20	31.16	60.50
59	HCG-91	112	14.67	43.00	26.67	5.00	98.00	32.16	58.81
60	HCG-107	131	17.33	38.67	40.67	4.67	147.10	32.49	58.54
61	RG-22	76	9.00	12.33	13.33	8.33	122.50	39.48	63.16
62	RG-43	78	9.67	15.00	8.33	7.67	48.25	26.30	64.78
63	RG-3798	129	23.33	80.00	73.33	4.00	49.33	47.56	63.10
64	RG-3100	86	14.67	30.00	6.67	3.67	23.67	31.63	59.52
65	RG-3477	99	14.00	19.00	16.67	4.00	103.67	34.71	65.08
66	RG-3160	95	12.33	26.33	16.67	5.33	46.78	34.46	63.40
67	RG-2661	115	16.00	33.33	55.33	3.33	52.22	31.40	61.80
68	RG-2818	123	17.00	25.67	20.00	2.67	18.90	35.94	54.32
69	RG-1624	80	13.33	19.33	20.00	5.33	32.75	38.24	58.81
70	RG-1771	80	13.33	21.00	32.33	3.67	57.30	27.65	64.80
71	RG-2787	113	15.00	43.33	48.33	3.00	98.78	37.35	64.12
72	RG-2819	131	17.67	31.00	20.00	3.33	65.33	36.57	59.20
73	RG-2822	97	15.00	26.00	21.67	4.33	48.80	33.59	61.50
74	RG-72	91	12.00	23.33	49.33	3.00	11.78	31.40	57.24
75	RG-18	105	13.00	32.00	35.67	3.67	53.25	25.38	64.89
76	RG-2722	118	16.00	28.33	21.67	3.67	46.22	36.10	58.29
77	RG-392	108	15.33	18.33	12.67	4.33	103.44	25.29	60.80
78	RG-109	105	15.00	36.67	20.00	4.00	51.10	32.01	66.70
79	RG-1608	106	14.00	18.33	10.00	5.33	77.14	35.38	64.27
80	RG-3798-1	125	18.00	47.00	51.67	3.00	60.20	39.39	58.19
81	RG-3160-1	80	9.67	23.67	13.33	6.67	95.56	26.19	65.70
82	RG-2661-1	84	9.00	21.67	20.00	4.33	48.44	29.05	64.84
83	RG-1771-1	86	11.00	30.00	28.33	5.67	43.20	31.30	62.35
84	RG-1771-2	91	11.33	31.67	26.33	6.00	31.11	29.51	63.26
85	RG-1608-1	97	11.00	29.33	33.33	5.33	14.78	31.71	59.02
86	BCG-26-1	131	9.67	25.33	23.33	3.33	11.78	37.57	56.71
87	BCG-27	101	20.67	63.33	51.67	1.67	76.00	29.14	59.18
88	BCG-28	127	16.00	37.67	34.33	3.00	109.67	30.30	57.40
89	BCG-29	128	19.67	58.33	50.00	3.33	20.00	34.65	52.18
90	BCG-30	107	15.67	48.67	40.00	3.67	34.00	24.77	61.90
91	BCG-32	123	18.33	38.33	18.33	3.33	15.78	47.02	57.80
92	BCG-33	131	18.33	41.67	30.00	4.00	64.10	36.30	59.30
93	BCG-34	117	17.00	39.33	45.00	2.33	68.10	32.28	63.33
94	BCG-35	107	23.33	46.33	30.00	4.33	86.50	28.56	59.80
95	BCG-10-1	123	18.00	22.00	24.33	2.67	20.56	64.56	52.96
96	BCG-11-1	120	19.00	20.00	25.00	2.67	33.17	67.48	55.64
97	BCG-12-1	121	21.67	43.67	40.00	3.33	29.67	43.59	47.80
98	BCG-13-1	125	18.33	17.00	28.33	1.67	19.00	68.25	58.80
99	BCG-14-1	127	23.33	33.67	16.67	1.67	27.57	37.50	45.08
100	BCG-15-1	125	14.33	19.67	16.67	2.33	23.75	74.32	58.30
C1	DCS-9	78.00	9.00	19.00	19.00	4.00	57.87	29.00	60.87
C2	DCS-107	108.00	13.67	44.33	19.33	4.33	86.76	31.65	61.67
C3	DCH-177	84.00	12.00	45.67	23.00	3.67	68.34	32.98	63.33
C4	DCH-519	110.00	13.00	49.00	24.00	3.67	89.98	29.98	65.98

DMPS: Days to maturity of primary spike, NN: Number of nodes up to primary spike, ELPS: Effective Length of primary spike (cm), NC: Number of capsules on primary spike, NES/P: Number of effective spikes per plant, HSW: 100 seed weight (g), HVW: 100 Volume weight (g), SY: Seed yield per plant (g)

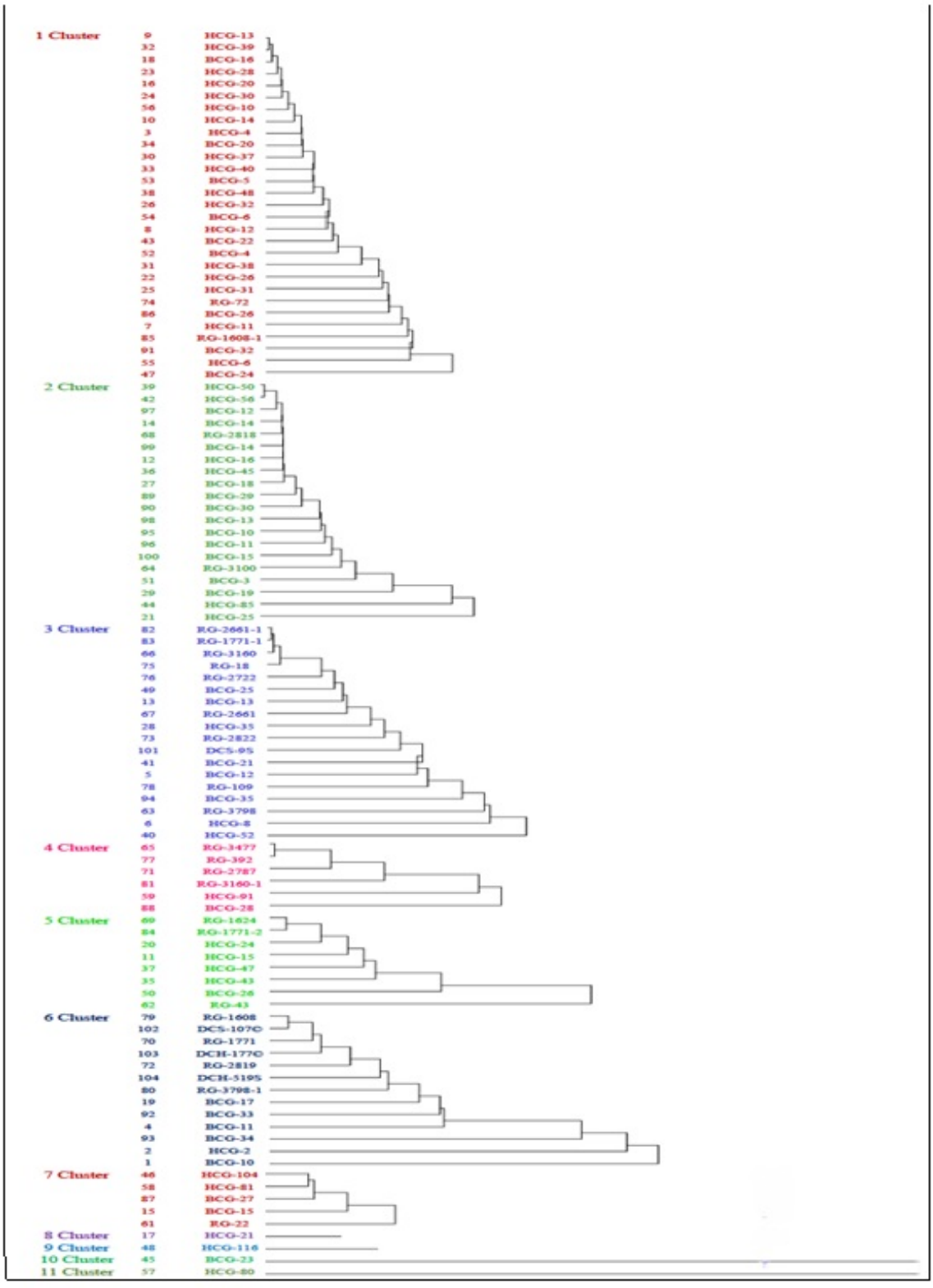

Fig. 2. Clustering by Toucher Method for eleven quantitative characters of castor

REFERENCES

Allan G, Williams A, Rabinowicz P D, Chan A P, Ravel J, Keim P 2008. Worldwide genotyping of castor bean germplasm (*Ricinus communis* L.) using AFLPs and SSRs. *Genetic Resource and Crop Evolution*, **55**: 365-378.

Amar A, Sakure, Dhaduk H L , Mehta D R , Kavani R H and Madariya R B 2010. Genetic diversity analysis among castor (*Ricinus communis* L.) genotypes using morphological markers. *Crop Improvement*, **37** (2): 99-104.

Anjani K 2000. *Catalogue of castor,* Volume 1, Directorate of Oilseeds Research, Hyderabad, India.

Anjani K 2012. Castor genetic resources: A primary gene pool for exploitation. *Industrial Crops and Products*, **35**: 1-14.

Bartlett M S 1950. Tests of significance in factor analysis. *The British Journal of Psychiatry* (Statistics Section), **3**: 77-85.

Bhand D J and Patel D R 1999. Inheritance of some morphological characters in castor (*Ricinus communis* L.). *Gujarat Agriculture University Research Journal*, **25**(1): 103-105.

Bhargava A, Shukla S, Rajan S and Ohri D 2007. Genetic diversity for morphological and quality traits in quinoa (*Chenopodium quinoa* Willd.) germplasm. *Genetic Resource and Crop Evolution*, **54**: 167-173.

Gabriela N da Piedade, Lucas V, Amanda R P dos Santos, Deoclecio J, Amorim, Maurício D. Zanotto and Maria M P Sartori 2019. Principal component analysis for identification of superior castor bean hybrids. *Journal of Agricultural Science*, **11**: No. 9

Goodarzi F, Darvishzadeh R, Hassani A and Hassanzaeh A 2012. Study on genetic variation in Iranian castor bean (*Ricinus communis* L.) accessions using multivariate statistical techniques. *Journal of Medicinal Plants Research*, **6**(7): 1160-1167.

https://seaofindia.com/ State-wise Area, Production and Yield of Castor Seeds in India -2019-20 to 2021-22.

Jeffers J N R 1967.Two case studies in the application of principal component analysis. *Applied Statistics*, **16**: 225-236.

Lal J J and Lavanya C 2019. Pattern of genotypic diversity in indigenous castor (*Ricinus communis* L.) genotypes. *International Journal of Current Microbiology and Applied Science*, **8**(1): 2465-2471.

Naghavi M R and Jahansouz M R 2005. Variation in the agronomic and morphological traits of Iranian chickpea accessions. *Journal of Integral Plant Biology*, **47**(3): 375-379.

Nooryazdan H, Serieys H, Bacilieri R, David J, Berville A 2010. Structure of wild annual sunflower (*Helianthus annuus* L.) accessions based on agro-morphological traits. *Genetic Resource and Crop Evolution*, **57**: 27-39.

Patel D K, Patel D A, Patel J R and Patel K V 2021. Generation mean analysis for seed yield and its component traits in five crosses of castor (*Ricinus communis* L.). *Journal of Oilseeds Research*, **38**(1): 25-36.

Poornima K, Giribabu P, Mohanrao M D and Senthilvel S 2022. Genomic regions linked to reniform nematode (*Rotylenchulus reniformis*) resistance in castor. *Journal of Oilseeds Research*, **39**(1): 1-6.

Ramesh M, Lavanya C and Brahmeshwar Rao M V 2012. Genetic divergence in some indigenous and exotic germplasm lines of castor (*Ricinus communis* L.) under rainfed conditions. *Indian Journal of Dryland Agricultural Research and Development*, **27** (2): 79-83.

Rao C R 1952. *Advanced Statistical Methods in Biometrical Research.* John Wileyand Sons, New York.

Shaheen A M 2002. Morphological variation within *Ricinus communis* L. in Egypt: Fruit, Leaf, Seed and Pollen. *Pakistan Journal of Biological Sciences*, **5**(11): 1202-06.

Sinharay, S, 2010. An Overview of Statistics in Education. *International Encyclopedia of Education,* Third Edition, pp. 1-11.

Sreelakshmi C A S D 2015. Germplasm evaluation in pigeonpea (*Cajanus cajan* Millisp.) using mahalanobis D^2 statistics. *Journal of Global Bioscience*, **4**(7): 2282-2832.

Sunil N K, Ashok Reddy A, Ashokavardhan P and Varaprasad K S 2005. Collection of diversity in castor (*Ricinus communis* l.) germplasm from parts of Andhra Pradesh. *Indian Journal of Plant Genetic Resources*, **18**(3): 136-139.

Veasey E A, Schammass E A, Vencovsky R, Martins P S, Bandel G 2001. Germplasm characterization of Sesbania accessions based on multivariate analyses. *Genetic Resource and Crop Evolution*, **48**(1): 79-90.

Effect of integrated phosphorus management on productivity, nutrient uptake, nutrient content and soil properties of summer sesame (*Sesamum indicum* L.)

L PEACE RAISING AND RAYAPATI KARTHIK[1*]

B A College of Agriculture, Anand Agricultural University, Anand-388 110, Gujarat

(Received: February 26, 2022; Revised: May 17, 2022; Accepted: May 20, 2022)

ABSTRACT

A study was carried out to know the impact of integrated phosphorus management on nutrient uptake, content and soil properties of summer sesame during summer, 2018 in Gujarat under irrigated condition with 10 treatments i.e. 25 kg P_2O_5/ha (100 % RDF), FYM @ 5 t/ha, VC @ 2 t/ha, 12.5 kg P_2O_5/ha (50 % RDF) + PSB @ 5 ml/kg (seed treatment), FYM @ 2.5 t/ha + PSB @ 5 ml/kg (seed treatment), VC @ 1 t/ha + PSB @ 5 ml/kg (seed treatment), 12.5 kg P_2O_5/ha (50% RDF) + FYM @ 2.5 t/ha, 12.5 kg P_2O_5/ha (50 % RDF) + VC @ 1 t/ha, FYM @ 2.5 t/ha + VC @ 1 t/ha and FYM @ 2.5 t/ha + VC @ 1 t/ha + PSB @ 5 ml/kg (seed treatment) and 4 replications in a RBD. It is found that among ten treatments, application of 12.5 kg P_2O_5/ha + VC @ 1 t/ha significantly increased the nutrient uptake and nutrient content of summer sesame compared to other treatments which has shown a positive impact on crop productivity and application of 12.5 kg P_2O_5/ha + PSB @ 5 ml/kg has resulted in significantly higher available phosphorus and 12.5 kg P_2O_5/ha + FYM @ 2.5 t/ha has lead to highest organic carbon in the soil.

Keywords: Gujarat, Phosphorus, Sesame, Vermicompost, Yield

Sesame (*Sesamum indicum* L.) is commonly known as 'til' and has been known to be one of the earliest domesticated edible oilseed used by the mankind. The cultivated type, Sesamum indicum originated in India. It has an important advantage as it can be grown under fairly high temperature, low water supply and low levels of other inputs (Vora *et al.,* 2018). It is known as "the sovereign of oil seeds" since it is valued for its nutritive incentive as well as for the quality and amount of its oil which is plentiful in nutrient E and has a lot of linoleic corrosive that can control blood cholesterol levels (Salame *et al.,* 2020; Angel and Poonguzhalan, 2022). The oil content and protein content in sesame generally varies from 46-52% and between 18-20%, respectively.

Phosphorus plays a key role in growth and development and improves the quality of sesame. It enhances root growth as well as development and quickly establishes the seedlings which is why it shall be applied at the time of sowing with a proper source. P management is very crucial as recovery of added phosphorus hardly exceeds 20%. As the concentration of available P in the soil solution is normally insufficient to support the plant growth, continual replacement of soluble P from inorganic and organic sources is necessary to meet the P requirements of crop (Tisdale *et al.,* 2010). The major constraint, limiting the growth and development of this crop is the poor fertility status of Indian soils (Nagaveni *et al.,* 2021). Moreover, most of the soils of Gujarat are low in organic carbon. The organic matter content in the soil has to be built up with the help of bulky organic manures (i.e. FYM and compost etc.) as the use of organic manures held a prestigious position among the farmers. It is well documented that addition of organic manures has shown considerable increase in the crop yield and has exerted a significant influence on physical, chemical and biological properties of the soil. Phosphate solubilizing bacteria (PSB) are a group of beneficial bacteria capable of hydrolyzing organic and inorganic phosphorus from insoluble compounds and make it available to the plant, which may increases the yield of crops by 10-30%. Therefore, this study was aimed to achieve higher efficiency of applied phosphatic fertilizers and to study the effect of organic and inorganic sources with and without PSB inoculation.

[1]Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad-500 030, Telangana; Corresponding author's E-mail: karthikrayapati48@gmail.com

MATERIALS AND METHODS

The present experiment was carried out during summer, 2018 on loamy sand soil of Anand, Gujarat under irrigated condition with 10 treatments and 4 replications in a randomized block design. The soil of the experimental area was loamy sand in texture, 0.34 organic carbon, low in available nitrogen (183.40 kg N/ha), medium in both available phosphorus (28.06 kg P_2O_5/ha) and available potash (281.63 kg K_2O/ha) with soil EC 0.55 and pH 7.49. The treatments were 25 kg P_2O_5/ha (100 % RDF) (T_1), FYM @ 5 t/ha (T_2), Vermicompost @ 2 t/ha (T_3), 12.5 kg P_2O_5/ha (50 % RDF) + PSB @ 5 ml/kg (seed treatment) (T_4), FYM @ 2.5 t/ha + PSB @ 5 ml/kg (seed treatment) (T_5), vermicompost @ 1 t/ha + PSB @ 5 ml/kg (seed treatment) (T_6), 12.5 kg P_2O_5/ha (50% RDF) + FYM @ 2.5 t/ha (T_7), 12.5 kg P_2O_5/ha (50 % RDF) + Vermicompost @ 1 t/ha (T_8), FYM @ 2.5 t/ha + vermicompost @ 1 t/ha (T_9) and FYM @ 2.5 t/ha + Vermicompost @ 1 t/ha + PSB @ 5 ml/kg (seed treatment) (T_{10}). Application of 50 kg N/ha i.e. 25 kg N/ha at sowing and 25 kg N/ha at 30 DAS was done as common

dose, while SSP (16% P_2O_5 and 12% sulphur), FYM, vermicompost and PSB were applied as per treatments. Sesame variety Gujarat Til 3 was sown in 4.5 m x 5.0 m plot having spacing of 45 cm between the rows.

Chemical analysis of soil sample: Representative soil sample from 0-15 cm soil depth was drawn from the experimental field before sowing of the crop. The collected samples were air dried and passed through 2.0 mm sieve and were used for analysis by adopting wet oxidation method (Walkey and Black, 1934) for organic carbon estimation and Olsen's method (Olsen *et al.,* 1954) for available P_2O_5 estimation.

Chemical analysis of N and P content (%) in seed sample: Representative soil sample from 0-15 cm soil depth was drawn from the experimental field before sowing of the crop. Representative sample from seed were taken separately for the estimation of N and P content from each treatment from all the four replications. The sample were sun dried for a week and then oven dried at 700C temperature for 24 hours and grounded into powder by mechanical grinder. The N and P content were determined by using Modified Kjeldahl's method Wet digestion (Diacid), Vanadomolybdic yellow colour method, respectively (Jackson, 1973).

Nutrient uptake by seed (kg/ha): The uptake values of nitrogen (N) and phosphorus (P) for seed were worked out by following formula:

$$\text{Nutrient uptake by seed (kg/ha} = \frac{\text{Nutrient content in seed (\%) x Seed yield (kg/ha)}}{100}$$

Statistical analysis: The statistical analysis of the various growth, yield and quality characters studied during the course of investigation was carried out by using statistical methods appropriate to Randomized Block Design at the Computer Centre, Department of Agricultural Statistics, B A College of Agriculture, AAU, Anand as per the procedure described by Cochran and Cox (1957). The variance of different sources of variation in ANOVA was tested by "F? test and compared with the value of F-table at 5% level of significance.

RESULTS AND DISCUSSION

Productivity: The difference in seed yield was significant due to the different treatments. T_8 has recorded significantly higher seed yield (881 kg/ha) than other treatments, but was at par with treatments T_7 and T_{10}. However, the sole application of inorganic fertilizer (T_1) and organic manure (T_3) and their combination effect with biofertilizer (T_4, T_5 and T_6) produce lower seed yield comparatively. The lowest (632 kg/ha) seed yield was recorded in treatment T_2. The increment in seed yield under treatments T_8 and T_7 was due to increase in growth characters. Treatments T_7 and T_8 which include chemical source of phosphorus along with FYM and vermicompost not only supply phosphorus, but also other macro and micro nutrients. Besides, it improves the physical, chemical and biological properties of the soil which eventually increases the uptake of nutrients by the plant and thereby, the seed yield of the crop was increased. These treatments were also at par with T_9 and T_{10}, which might be also due to similar reasons. The increase in the seed yield may also be due to the increase in P availability through solubilization of phosphate rich compound. The phosphate solubilizing organisms secrete a number of organic acids, which may form chelates, resulting in effective solubilization of phosphate. Similar result were also reported by Parewa *et al*. (2018) and Nouri *et al*. (2019)

Significantly higher stalk yield (2377 kg/ha) was observed under treatment T_8 but was remained at par with treatment T_7 and significantly the lowest stalk yield of 1623 kg/ha was obtained under treatment T_2 and was at par with treatments T_3 and T_6. The respective values of stalk yield under treatments T_1, T_4, T_5, T_9 and T_{10} were 1883, 1857, 1647, 2075 and 2113 kg/ha. The data pertaining to harvest index (%) as influenced by different treatments did not show any significant differences among the treatments. However, treatment T_1 has recorded the highest harvest index (28.56). The lowest harvest index (26.53) was observed in treatment T9.

Nitrogen and phosphorus content in seeds: There is a significant difference observed in nitrogen and phosphorus content of the seeds because of different inorganic phosphatic fertilizer, organic manures and PSB treatments (Table 2). T_8 has recorded the highest nitrogen content in the seeds (4.02%), which was remained at par with treatments T_7, T_{10}, T_9 and T1 while the lowest nitrogen content (3.63%) was recorded in the treatment T_2. Treatment T_8 has recorded the highest phosphorus content in the seeds (0.81%) followed by treatment T_7 while the lowest (0.61%) was observed in treatment T_2.

Integration of inorganic and organic sources of plant nutrients results in more uptake of nitrogen and phosphorus as compared to sole use of inorganic or organic source alone. This may be due to the fact that balanced and combined use of various plant nutrient sources results in proper absorption, translocation and assimilation of this nutrient, ultimately increasing the dry matter accumulation and nutrient contents in the seed. Increased nitrogen and phosphorus content with increasing level of phosphate fertilization was also observed by Pathak and Pal (2016) and Lal *et al.* (2017).

Table 1 Productivity of summer sesame as influenced by integrated phosphorus management

S. No.	Treatments	Seed yield (kg/ha)	Stalk yield (kg/ha)	Harvest index (%)
T_1	25 kg P_2O_5/ha (100% RDP)	753	1883	28.56
T_2	FYM @ 5 t/ha	632	1623	28.03
T_3	Vermicompost @ 2 t/ha	656	1748	27.29
T_4	12.5 kg P_2O_5/ha (50% RDP) + PSB @ 5ml/kg (seed treatment)	714	1857	27.82
T_5	FYM @ 2.5 t/ha + PSB @ 5ml/kg (seed treatment)	643	1647	28.08
T_6	Vermicompost @ 1 t/ha + PSB @ 5 ml/kg (seed treatment)	653	1718	27.58
T_7	12.5 kg P_2O_5/ha (50% RDP) + FYM @ 2.5 t/ha	794	2192	26.60
T_8	12.5 kg P_2O_5/ha (50% RDP) + Vermicompost @ 1 t/ha	881	2377	27.09
T_9	FYM @ 2.5 t/ha + Vermicompost @ 1 t/ha	754	2075	26.53
T_{10}	FYM @ 2.5 t/ha+ Vermicompost @ 1 t/ha + PSB @ 5ml/kg (seed treatment)	778	2113	27.03
	S.Em. ±	39	78	1.21
	CD at 5 %	112	228	NS

Table 2 Nitrogen and phosphorus content in the sesame seeds as influenced by integrated phosphorus management

S. No.	Treatments	Nitrogen content (%)	Phosphorus content (%)
T_1	25 kg P_2O_5/ha (100% RDP)	3.83	0.70
T_2	FYM @ 5 t/ha	3.63	0.61
T_3	Vermicompost @ 2 t/ha	3.75	0.65
T_4	12.5 kg P_2O_5/ha (50% RDP) + PSB @ 5ml/kg (seed treatment)	3.79	0.67
T_5	FYM @ 2.5 t/ha + PSB @ 5ml/kg (seed treatment)	3.68	0.62
T_6	Vermicompost @ 1 t/ha + PSB @ 5ml/kg (seed treatment)	3.72	0.65
T_7	12.5 kg P_2O_5/ha (50% RDP) + FYM @ 2.5 t/ha	3.95	0.76
T_8	12.5 kg P_2O_5/ha (50% RDP) + Vermicompost @ 1t/ha	4.02	0.81
T_9	FYM @ 2.5 t/ha + Vermicompost @ 1 t/ha	3.89	0.72
T_{10}	FYM @ 2.5 t/ha + Vermicompost @ 1 t/ha + PSB @ 5ml/kg (seed treatment)	3.92	0.75
	SEm. ±	0.06	0.01
	CD at 5%	0.19	0.04

Table 3 Nitrogen and phosphorus uptake by the sesame seeds as influenced integrated phosphorus management

S. No.	Treatments	Nitrogen uptake (kg/ha)	Phosphorus uptake (kg/ha)
T_1	25 kg P_2O_5/ha (100% RDP)	28.88	5.23
T_2	FYM @ 5 t/ha	22.89	3.83
T_3	Vermicompost @ 2 t/ha	24.57	4.27
T_4	12.5 kg P_2O_5/ha (50% RDP) + PSB @ 5 ml/kg (seed treatment)	27.11	4.75
T_5	FYM @ 2.5 t/ha + PSB @ 5ml/kg (seed treatment)	23.71	3.99
T_6	Vermicompost @ 1 t/ha + PSB @ 5ml/kg (seed treatment)	24.30	4.22
T_7	12.5 kg P_2O_5/ha (50% RDP) + FYM @ 2.5 t/ha	31.37	6.01
T_8	12.5 kg P_2O_5/ha (50% RDP) + Vermicompost @ 1t/ha	35.34	7.18
T_9	FYM @ 2.5 t/ha + Vermicompost @ 1 t/ha	29.28	5.41
T_{10}	FYM @ 2.5 t/ha + Vermicompost @ 1 t/ha + PSB @ 5 ml/kg (seed treatment)	30.50	5.80
	S Em. ±	1.54	0.33
	CD at 5 %	4.40	0.93

Table 4 Organic carbon and available phosphorus in the soil after harvest of sesame as influenced by integrated phosphorus management

S.No.	Treatments	Organic Carbon (%)	Available P_2O_5 (kg/ha)
T_1	25 kg P_2O_5/ha (100% RDP)	0.36	32.95
T_2	FYM @ 5 t/ha	0.41	31.03
T_3	Vermicompost @ 2 t/ha	0.39	31.85
T_4	12.5 kg P_2O_5/ha (50% RDP) + PSB @ 5 ml/kg (seed treatment)	0.37	36.57
T_5	FYM @ 2.5 t/ha + PSB @ 5ml/kg (seed treatment)	0.38	32.10
T_6	Vermicompost @ 1 t/ha + PSB @ 5 ml/ kg (seed treatment)	0.37	32.68
T_7	12.5 kg P_2O_5/ha (50% RDP) + FYM @ 2.5 t/ha	0.38	35.51
T_8	12.5 kg P_2O_5/ha (50% RDP) + Vermicompost @ 1 t/ha	0.38	36.25
T_9	FYM @ 2.5 t/ha+ Vermicompost @ 1 t/ha	0.39	31.32
T_{10}	FYM @ 2.5 t/ ha + Vermicompost @ 1 t/ ha0 + PSB @ 5ml/kg (seed treatment)	0.40	34.53
	Initial	0.34	28.06
	SEm. ±	0.02	1.08
	CD at 5 %	NS	3.15

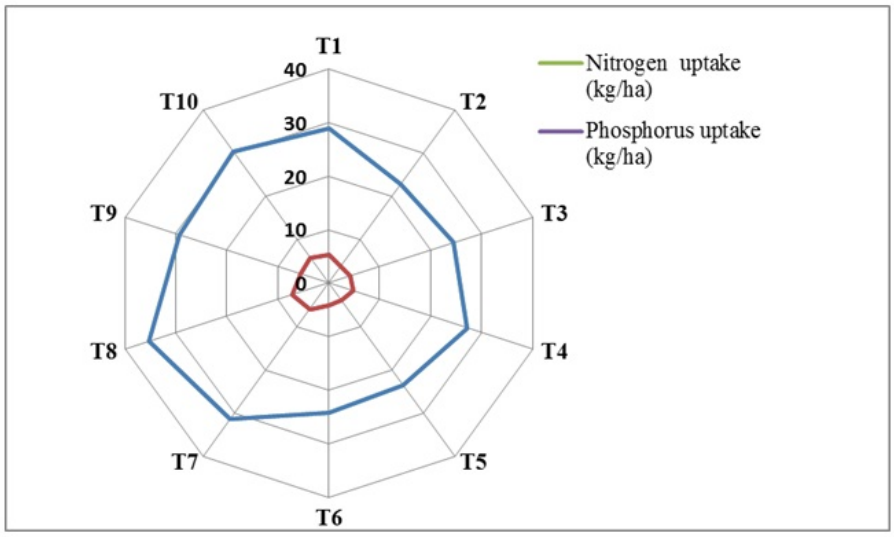

Fig. 1. Nitrogen and phosphorus uptake by the sesame seeds as influenced by different treatments

Input composition of inputs

	N	P	K
FYM	0.50%	0.25%	0.50%
Vermicompost	3.0%	1.0%	2.0%

Nitrogen and phosphorus uptake by seeds: The difference in nitrogen uptake by the seeds was significant due to different inorganic phosphatic fertilizer, organic manures and PSB treatments (Table 3). T_8 has recorded significantly higher nitrogen uptake by the seeds (35.34 kg/ha) than the other treatments, but was remained statistically similar with treatments T_7, while the lowest was recorded in the treatment T_2. Significantly higher phosphorus uptake (7.18 kg/ha) was recorded under treatment T_8 followed by treatment T_7 while treatment T_2 has recorded the lowest phosphorus uptake (3.83 kg/ha) by the seeds. Application of phosphorus through different sources improves the phosphorus availability, which enhance various phyto-hormones like phosphatase in the soil and increases the uptake. Apart from the phosphorus fertilizer, organic manures also supply N, P and K and other traces elements and thus, enhancing the availability of nutrients for plant uptake, which ultimately increased the nitrogen and phosphorus uptake by the seeds. The results were in conformity with those of Pathak and Pal (2016) and Lal *et al.* (2017).

Organic carbon: There is no significant effect of treatments on the organic carbon (Table 4). Treatment T_2 has recorded the highest organic carbon (0.41%) followed by treatment T_{10} (0.40%). The lowest organic carbon was recorded with T_1 (0.36%). The increase in the organic carbon in T_2 is due to addition of organic matter through organic manures where as sole application of fertilizer recorded least organic carbon. Similar findings were also observed by Ghosh *et al.* (2013). Available phosphorus: Significantly higher available phosphorus in the soil after harvest of the crop (36.57 kg/ha) was observed under treatment T_4 than the other treatments, but was remained at par with treatments T_8, T_7 and T_{10} and recorded available phosphorus were 36.25, 35.51 and 34.53 kg/ha, respectively (Table 4). The lowest available phosphorus in the soil after harvest of the crop was found with treatment T_2 (31.03 kg/ha). Treatment T_4 increases available phosphorus by 30.32% in the soil after harvest of the crop than its initial. This might be due to the combined application of graded doses of phosphorus in conjugation with inoculation of phosphorus solubilizing bacteria, may showed higher response than the application of phosphorus alone. The increase in available phosphorus with PSB inoculation may be due to the increase in P availability through solubilization of phosphate rich compounds throughout the crop period and finally increased available phosphorus in the soil after harvest of crop (Nayek *et al.,* 2014).

Sesame is gaining attention now-a-days among the farmers as its economic potential is unrealized till now. To attain maximum yield as well as income for any crop, proper nutrient management is vital which is the main objective of this study. Inclusion of organics would only benefit the crop and enhances the soil fertility as well as productivity in long term. Application of 12.5 kg P_2O_5/ha + VC @ 1 t/ha to sesame crop grown during summer improved the nutrient uptake and content, increased the soil nutrient status and also give higher net realization of sesame followed by application of 12.5 kg P_2O_5/ha + FYM @ 2.5 t/ha which could be recommended to farmers of Gujarat.

REFERENCES

Angel I and Poonguzhalan R 2022. Yield and nutrient uptake of sesame (*Sesamum indicum* L.) as influenced by plant growth regulators. *Journal of Oilseeds Research*, **39**(1): 55-57.

Cochran W G and Cox G M, 1957. *Experimental designs,* John Willey and Sons. Inc., New York, pp. 546-568.

Ghosh A K, Duary B and Ghosh D C 2013. Nutrient management in summer sesame and its residual effect on succeeding *kharif* black gram. *International Journal of Bio-resource and Stress Management*, **4**(4): 541-546.

Jackson M L 1973. *Soil Chemical Analysis*. Prentice Hall of Indian Pvt. Ltd., New Delhi, pp. 183-192.

Lal B, Yadav L R, Choudhary K M, Bera M, Jat L and Bijarnia A 2017. Nutrient uptake, quality and economics of sesame as influenced by vermicompost and moisture conservation practice. *International Journal of Chemical Studies*, **5**(4): 1546-1548.

Nagaveni M, Kumar G D S and Chandana B 2021. Identification of potential districts for technology transfer in sesame (*Sesamum indicum* L.). *Journal of Oilseeds Research*, **38**(4): 362-368.

Nayek S S, Koushik B and Chowdhury M D R 2014. Integrated approach in nutrient management of sesame with special reference to its yield, quality and nutrient uptake. *The Bioscan,* **9**(1): 101-105.

Nouri M, Maman G, Gonda A and Charles S W 2019. Sesame sole crop and intercrop response to fertilizer in Semi-arid Niger. *Agronomy Journal*, **111**(4): 1-4.

Olsen S R, Cole V C, Watandable F S and Dean L A 1954. Estimation of available phosphorus in soil by extraction with sodium hydrogen carbonate, USDA, Circ. No. 939, 19.

Parewa H P, Moola R, Kumar J L and Chaudhary A 2018. Residual effect of organic nutrient management practices on growth and yield of sesame (*Sesamum indicum* L.). *International Journal of Chemical Studies*, **6**(4): 2340-2342.

Pathak J and Pal R L 2016. Effect of integrated plant nutrient management on content and uptake of phosphorus by Indian mustard. *Progressive Agriculture*, **16**(1): 61-66.

Salame R., Mishra U S, Mohbe S, Subhash, Dotaniya C K, Pahade V, Doutaniya RK and Wagadre D, 2020. Influence of growth and yield attributes of sesame (*Sesamum indicum* L.) by sulphur and phosphorus different combination fertilizer levels under the rainfed condition. *Indian Journal of Pure & Applied Biosciences*, **8**(4): 115-124.

Tisdale S L, Nelson W L, Beaton, J D and Havlin J L 2010. Soil fertility and fertilizer: *An introduction to nutrient management.* PHI Learning Pvt. Ltd., New Delhi, 184 pp.

Vora V D, Hirpara D S, Vekaria P D, Sutaria G S and Vala F G 2018. Effect of phosphorus management on yield, nutrient uptake by sesame and post-harvest soil fertility under rainfed condition. *Journal of Pharmacognosy and Phytochemistry*, **7**(5): 65-69.

Walkley A and Black I A 1934. An examination of methods for determining organic carbon and nitrogen in soils. *Journal of Agricultural Science*, **25**: 589-609.

Influence of irrigation scheduling and fertility levels on growth, yield and economics of linseed (*Linum usitatissimum* L.) in Kymore Plateau and Satpura Hills region

ANAMIKA JAIN BADKUL[1], P B SHARMA[1], ARCHIT KUMAR NAYAK[2], SHRITAMA BHUNIA[1] AND NAMRATA JAIN[1]

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

(Received: May 26, 2022; Revised: June 21, 2022; Accepted: June 23, 2022)

ABSTRACT

A field experiment was conducted to assess the growth, yield and economics of linseed crop under the influence of various irrigation schedule and fertility levels on sandy loam soil of Kymore plateau and Satpura hills region during the *rabi* season of 2020-21 at Research farm, College of Agriculture, JNKVV, Jabalpur. A split plot design with three irrigation levels that comprised of no irrigation, 0.6 IW/CPE ratio and 0.8 IW/CPE ratio and four fertility levels of NPKS i.e. 30:20:10:00, 30:20:10:20, 60:40:20:00 and 60:40:20:20 with three replications was adopted. Results revealed that irrigation scheduling as per 0.8 IW/CPE ratio recorded maximum seed yield (1327.71 kg/ha). However, in case of fertility levels, the seed yield registered was high (1324 kg/ha) under 60:40:20:20 kg NPKS/ha dose of fertilizer. Irrigation at 0.8 IW/CPE ratio accrued highest B:C ratio of 2.45 followed by 0.6 IW/CPE ratio (2.37). Among the different nutrient levels, application of 60:40:20:20 kg NPKS/ha fetched highest B:C ratio of 2.43 followed by 60:40:20:00 kg NPKS/ha (2.13).

Keywords: Fertility levels, Growth, Irrigation schedule, Linseed, Yield

Oilseeds crops are among the major determinants of Indian agricultural economy, next to cereals. Among the oilseeds crops, linseed is considered as one of the most important *rabi* crop. Linseed is rich in oil (41%), protein (20%), dietary fiber (28%), ashes (3.3%) and contains 7.7% moisture (Morris, 2005). The industrial or non-edible portion of oil is an important ingredient used in the manufacture of paints, varnishes and linoleum. The edible linseed oil is used for human consumption and contains α-linolenic acid (ALA) a polyunsaturated fatty acid that is known to have nutritional and health benefits. In India, linseed is predominantly grown under rainfed condition (63%), *utera* (25%) and irrigated condition (12%) with low input (Dash *et al.,* 2017; Dwivedi *et al.,* 2021). Linseed cultivation is primarily limited to marginal and sub-marginal areas, with limited supply of irrigation and fertilisers, as well as poor management conditions (Singh *et al.,* 2013). Irrigation to this crop is mostly based on physiological growth stages and the latest approach of scheduling irrigation through IW/CPE ratio has not been thoroughly tested. The ideal scheduling of irrigation depends upon the soil, climate and plant characteristics and one scientific approach is IW/CPE ratio approach for scheduling of irrigation. Additionally, there has been a continuous decline in linseed area in the country during the last four decades and the growth in the domestic production of oilseeds has not been able to keep pace with the growth in the demand in the country (Sharma, 2014).The inadequate use of fertilizer is understood to be one of the important causes for low production of linseed in India. Dordas (2010) found that fertilization is known to affect seed yield the most. Among the agro-techniques that can increase its productivity, one is judicious application of nutrients, especially nitrogen, phosphorus and potash (Pali and Tripathi, 2000). Sulphur also plays an important role in improving the quality and quantity of oilseed. It gives rise to bold seeds in oilseed crops. The sulphur requirement of oilseed crops is more than that of many other crops for proper growth and yield (Patel *et al.,* 2019). The studies on nutritional requirement of linseed has been restricted mainly under rainfed condition but it has been well documented that the crop responds well to applied fertilizers under irrigated conditions (Kushwaha *et al.,* 2006). In this context, the present study attempts to access the response of irrigation scheduling and nutrients levels on growth, yield and economics of linseed crop.

MATERIALS AND METHODS

The field experiment was conducted at Instructional Research Farm, Krishi Nagar, Adhartal, Department of Agronomy, JNKVV, Jabalpur (Madhya Pradesh) during rabi 2020-21. Jabalpur is situated at 23° 09' North latitude and 79° 58' East longitudes at an altitude of 411.78 meters above the mean sea level. The field selected for experimentation was having uniform topography with a gentle slope of nearly 0.5%. The experimental plots comprised of 3 irrigation scheduling i.e. no irrigation, 0.6 IW/CPE Ratio and 0.8

[2]Anand Agriculture University, Anand, Gujarat; Corresponding author's E-mail: anamika.badkul@rediffmail.com

IW/CPE ratio with four different fertility levels (kg/ha) N:P:K:S i.e. 30:20:10:00 (N_1), 30:20:10:20 (N_2), 60:40:20:00 (N_3) and 60:40:20:20 (N_4) replicated thrice laid out in a split plot design. The nutrients were supplied through urea, DAP, MOP (60 kg K_2O/ha) and elemental sulphur (90% w/w). A basal application of N, P, K and S were applied at the time of sowing and half dose of N was top dressing at the time of 1st irrigation. Linseed cv. JLS-66 was sown manually in line with maintaining optimum row spacing 30 cm. However, all the other intercultural operations were done for weed management and as per crop requirement. Irrigation scheduling was done on the basis of IW/CPE ratio, for obtaining the desired IW/CPE ratio. The CPE was calculated separately for I1 (0.6 IW/CPE ratio) and I2 (0.8 IW/CPE ratio), for an irrigation water depth of 5 cm. For irrigation scheduling with 0.6 IW/CPE ratio, the CPE calculated was 62.5 mm and for irrigation scheduling with 0.8 IW/CPE ratio, the CPE calculated was 83.3 mm. Accordingly, as and when the above value of cumulative evaporation was attained, the irrigation was applied in the treatments. The irrigation under different treatment was given at 5 cm depth of irrigation. The irrigation water was measured by coordinate method. The crop was harvested when the stem turned yellow and capsules began to dry. After complete sun drying, threshing was done and stover yield was calculated by subtracting seed yield from bundle weight. In order to assess the effects of various treatments, periodically observations were taken. Seed yield was calculated on plot basis and converted into kg/ha.

RESULTS AND DISCUSSION

Effect of varying IW/CPE ratio: To obtain maximum possible yield, it is essential for crop to utilize equitably and efficiently all the resources such as water, nutrients, light, CO2 and space which can be achieved by optimum plant population. At harvest, different treatments did not differ significantly. Among irrigation schedules, treatment of 0.8 IW/CPE (I_2) ratio significantly recorded the tallest plants (46.51 cm). The increase in the plant height under the treatment I_2 might be due to optimum supply of soil moisture in the root zone that desirably improved the nutrient uptake and translocation and ultimately favoured plant height. Significantly, shortest plants (42.75 cm at harvest) were observed under treatment I_0 (No irrigation).These results are in accordance with Dohat *et al.* (2017) and Tiwari *et al.* (1988) in linseed crop. Number of branches/plant of linseed was significantly influenced due to different irrigation schedules. Irrigation at 0.8 IW/CPE ratio recorded significantly the highest number of branches/plant (6.67) which could be attributed to sufficient available soil moisture in the root zone during vegetative growth. Significantly lower number of branches/plant was observed under treatment I_0 (5.28) due to deficiency of moisture as compared to other treatments. Significant increase in drymatter accumulation was recorded under treatment of irrigation scheduling at 0.8 IW/CPE ratio in which the first irrigation was applied at 30 DAS. Less accumulation of dry matter under I_1 and I_0 (no irrigation) can be attributed to moisture stress during growth period. It is known that reduced water supply to crop plants causes closure of stomata, which raises the plant temperatures, consequently increase in respiration leading to higher breakdown of assimilates and ultimately reduced growth and poor dry matter accumulation (Jatin and Agarwal, 1998).Varying irrigation schedules exerted a significant influence on number of capsules per plant. Treatment I_2 i.e. irrigation scheduling as per 0.8 IW/CPE ratio recorded the maximum no. of capsules/plant (53.85). The increase in number of capsules/plant under higher IW/CPE ratio can be ascribed partly to better branching due to adequate soil moisture supply. The required availability of soil moisture at flowering at higher IW/CPE ratio might have also increased the number of capsules/plant. Less number of capsules/plant (38.82) was recorded under treatment I_0 i.e. under no irrigation than other irrigation treatments. The lower number of capsules can be attributed to limited water supply, which inhibited ability under low moisture conditions. These results were in accordance with Reddaih *et al.* (1993) in linseed crop.

Varying irrigation schedules also posed a significant response on seed yield of linseed. The results showed that irrigation at IW/CPE ratio of 0.6 (treatment I_1) and 0.8 (treatment I_2) recorded significantly higher seed yield over treatment I_0 i.e. under no irrigation than other irrigation treatments. Maximum seed yield (1344 kg/ha) was obtained under treatment I_2 i.e. irrigation scheduling as per 0.8 IW/CPE ratio. The increase in yield was to the extent of 3.62 and 78.94 per cent over treatment I_1 and treatment I_0 respectively. The increase in seed yield can be attributed to increase in frequency of irrigations at shorter intervals and total consumptive use of water under higher IW/CPE ratio. Under this situation, moisture stress was avoided which provided favourable conditions for availability moisture and nutrients to the plant and eventually resulted in higher yield attributes and seed yield. The significantly lowest yield (742 kg/ha) was obtained under treatment I_0 i.e. under no irrigation which can be attributed to moisture stress. Significant increase in stover yield was obtained with irrigation at IW/CPE ratio of 0.6 (treatment I_1) and 0.8 (treatment I_2) over treatment I_0. This increased stover yield might be the result of increased vegetative growth of the plants. The increase in dry matter by each plant component and increase in morphological components such as plant height and branching could be ascribed as possible reasons for increased stover yield under irrigated environment. These results were in close conformity to Dohat *et al.* (2017). The data indicated that irrigation scheduling brought out significant response on water use efficiency of linseed.

Table 1 Effect of irrigation scheduling and fertility levels on growth, yield and economics attributes of linseed

Treatments	Plant population	Plant height (cm)	Branches/ plant	Dry-matter accumulation /plant (g)	Capsules/ plant	Seeds/ capsule	1000-seed weight (g)	Seed yield (kg/ ha)	Straw yield (kg/ ha)	Water use efficiency	B:C Ratio
IW/CPE ratio											
No Irrigation	51.92	42.75	5.28	4.18	38.82	7.18	6.01	742	1586	14.84	1.52
0. 6 IW/CPE ratio	56.91	46.90	6.03	5.72	48.43	7.87	8.34	1281	2550	8.54	2.37
0.8 IW/CPE ratio	58.93	46.51	6.67	5.43	53.85	7.28	8.65	1344	2674	6.72	2.45
SEm±	1.29	0.96	0.18	0.27	0.66	0.31	0.39	42	35	0.34	
CD (P=0.05)	5.21	3.88	0.71	1.08	2.65	NS	1.59	169	141	1.36	
Fertility levels (N:P:K:S kg/ha)											
30:20:10:10	53.97	41.49	5.27	4.00	40.45	7.51	7.26	966	2032	8.95	1.93
30:20:10:20	54.73	44.40	5.51	4.22	43.16	7.44	7.71	1045	2141	9.54	1.96
60:40:20:0	57.32	46.69	6.58	5.86	50.73	7.20	7.63	1156	2337	10.12	2.13
60:40:20:20	57.64	48.97	6.62	6.35	53.79	7.62	8.07	1324	2570	11.53	2.43
SEm±	1.23	0.87	0.14	0.29	1.08	0.25	0.31	47	74	0.38	
CD (P=0.05)	NS	2.60	0.42	0.88	3.24	NS	NS	140	223	1.14	

Effect of varying fertility levels: Plant population of linseed under various levels of nutrients was found non-significant. At the time of harvest, the maximum plant height of 48.97 cm was observed under treatment N_4 i.e. the application of Nitrogen, Phosphorus, Potassium and Sulphur @ 60:40:20:20 kg/ha while the lowest plant height at all growth stages was observed under treatment N_1 i.e. application of N, P and K @ 30:20:10 kg/ha. It significantly improved various morphological and physiological components of growth of linseed over preceding levels, thereby capacitating the plant to increase in height. This may be attributed to the fact that optimum supply of nitrogen has favoured better nutritional environment in the root zone as well as in the plant system. The number of branches per plant were noted to be significantly higher (6.62) under application of NPKS @ 60:40:20:20 kg/ha at 90 DAS followed (6.58) by NPK @ 60:40:20 kg/ha and the lowest (5.27) number of branches per plant were observed under application of NPK @ 30:20:10 kg/ha at 90 DAS. When nutrients applied in soil, their availability increases to plant and start luxury consumption especially in case of K. The N, P and S are utilized for dry matter production, hence, their increase in concentration are less as compared to K in straw and grain. Similar finding was noticed by Meena *et al.* (2012). It is possible that at higher levels of NPKS application, the vigorous plant growth might have produced more photosynthesis. Efficient partitioning of accumulated photosynthesis enhanced yield attributes which ultimately increased the seed yield. The application of sulphur yielded better performance than the treatments which were not applied with sulphur. Treatment N_2 (application of NPKS @30:20:10:20 kg/ha) and treatment N_4 (application of NPKS @ 60:40:20:20 kg/ha) recorded significant increase in plant height, number of branches at 90 DAS as well as dry matter accumulation over treatment N_1 (application of NPK @30:20:10 kg/ha) and treatment N_3 (application of NPK @ 60:40:20 kg/ha) at successive stages of growth of linseed. Application of NPKS might exert flower initiation and seeds/capsules by increasing the rate of photosynthesis and transport from source to sink sites. Therefore, supply of NPKS must be adequate at reproductive phase in order to obtain maximum yield. These results corroborate the findings of Singh *et al.* (2000). The higher stover yield was recorded at higher rates of NPKS application. This could be attributed to the increased plant height, branching and dry matter accumulation with increasing levels of NPKS application. This indicates that both seed and stover utilized the applied NPKS at almost the same level of efficiency.Varying levels of nutrients also had pronounced effect on seed yield of linseed. The significantly highest seed yield of 1324 kg/ha was obtained with the application of NPKS @ 60:40:20:20 kg/ha. It was higher at an extent of 16.77, 26.69, 37.05 per cent than treatment N_3, N_2 and N_1 respectively. The lowest seed yield of 966 kg/ha was obtained under the treatment of NPK @ 30:20:10 kg/ha which was found to be at par with those under NPKS @ 30:20:10:20 kg/ha (1045 kg/ha). This showed that at lower level of NPK the response of sulphur was not prominent. However, at the higher level of NPK i.e. @ 60:40:20 kg/ha, the seed yield (1134 kg/ha) was increased

significantly with the addition of 20 kg Sulphur i.e. as in case of N_4. Varying levels of nutrients also had a significant effect on the water use efficiency of linseed. The significantly higher water use efficiency was noted under treatment N_4 (application of NPKS @60:40:20:20 kg/ha) which gave an efficiency of 11.42 kg/ha/mm. The lowest water use efficiency of 8.95 kg/ha/mm was seen under treatment N_1 (application of NPK @ 30:20:10 kg/ha).

Economics: Irrigation level I_2 (0.8 IW/CPE ratio) accrued maximum net realization of ₹ 39,209, with a highest B:C ratio of 2.45 closely followed by irrigation level I_1 (0.6 IW/CPE ratio) whereas the lowest net return of ₹ 12,922 with lowest B:C ratio of 1.52 was recorded under irrigation level I_0 i.e. under no irrigation. Similar results were obtained by Dohat *et al.* (2017) and Sharma *et al.* (2012). Among the different nutrient level N_4 i.e. application of 60:40:20:20 kg NPKS/ha fetched maximum net realization of ₹ 39,156 with highest B:C ratio of 2.43 closely followed by nutrient level N_3 whereas the lowest net return of ₹ 23,634 with B:C ratio 1.93 was obtained under nutrient level N_1 i.e. application of 30:20:10 kg NPK/ha.

Irrigation scheduling at IW/CPE ratio of 0.8 and 0.6 resulted in significant increase in yield attributes and seed yield of linseed over no irrigation. Application of 60:40:20:20 kg of NPKS per hectare resulted in maximum seed yield of linseed. Irrigation scheduling at 0.8 IW/CPE ratio with application of 60:40:20:20 kg NPKS per hectare was found to be the best treatment combination with respect to growth and yield of linseed. The treatment combination of I_1N_4 i.e. irrigation scheduling at 0.6 IW/CPE ratio along with application of 60:40:20:20 kg NPKS per hectare was found to be the most economically viable followed by I_2N_4 i.e. irrigation scheduling at 0.8 IW/CPE ratio along with application of 60:40:20:20 kg NPKS per hectare.

REFERENCES

Dohat M P, Patel R A, Patel V Y and Patel H K 2017. Effect of irrigation and nitrogen on growth and yield of linseed (*Linum usitatissimum* L.). *Journal of Pure and Applied Microbiology,* **11**(2), 949-951.

Dordas C A 2010. Variation of physiological determinants of yield in linseed in response to nitrogen fertilization. *Industrial Crops and Products*, **31**: 455-465.

Dwivedi S K, Satyaraj G R K and Panda S 2021. Foliar application of plant growth regulators on growth, yield and economics of linseed (*Linum usitatissimum* L.). *Journal of Oilseeds Research*, **38**(2): 195-198.

Jatin N K and Agarwal K K 1998. Effect of irrigation levels, (based on IW/CPE ratio) fertility and weed control methods in linseed (*Linum usitatissimum* L.). *World and Weeds*, **5**: 41-45.

Kushwaha C L, Prasad K and Kushwaha S P 2006. Effect of row spacings and nitrogen doses on yield attributes and yield of linseed (*Linum usitatissimum* L.) varieties under irrigated conditions of Bundelkhand. *Plant Archives*, **6**(2), 741-743.

Meena Rang Lal, Singh T K, Kumar Rakesh and Kumar Pramod 2012. Nutrient uptake, yield and quality of linseed (*Linum usitatissimum* L.) as affected by fertility levels and seed rates in dryland condition of Eastern Uttar Pradesh, *Plant Resource Management*, **2**(1): 83-85.

Morris D H 2005. Flax - A health and nutrition Primer. Flax Council of Canada, Available at http://www. flaxcouncil.ca/english/ index.php?p=primer&mp=nutrition.

Pali G P and Tripathi R S 2000. Performance of linseed (*Linum usitatissimum* L.) varieties under varying sowing and fertilizer management under rainfed condition. *Indian Journal of Agronomy*, **45**(4), 771-775.

Reddaih M, Singh N P and Singh S 1993. Response of linseed (*Linum usitatissimum* L.) to irrigation and nitrogen applications. *Annals of Agricultural Research*, **14**(3): 269-275.

Sharma J C, Tomar R R and Prakash C 2012. Water requirement, water use efficiency, consumptive use, yield and quality parameters of linseed (*Linum usitatissimum* L.) varieties as influenced by fertility levels, irrigation scheduling. *Advances in Life Sciences*, **1**(2): 180-182.

Singh M K, Singh T K and Singh U N 2000. Effect of nitrogen and sulphur levels on yield and quality of linseed (*Linum usitatissimum* L.) under dryland conditions. *Journal of Oilseeds Research*, **17**(1): 162-164.

Tiwari K P, Dixit J P and Saran R N 1988. Effect of nitrogen and irrigation on linseed (*Linum usitatissimum* L.). *Indian Journal of Agronomy*, **33**(1): 44-46.

Singh D N, Bohra J S and Singh J K 2013. Influence of NPK, S and variety on growth, yield and quality of irrigated linseed (*Linum usitatissimum* L.). *Indian Journal of Agricultural Sciences*, **83**(4): 456-458.

Dash Janakinath, Naik B S and Mohapatra U B 2017. Linseed: a valuable crop plant. *International Journal of Advance Research*, **5**(3): 1428-1442.

Sharma V P 2014. Problems and Prospects of Oilseeds Production in India. Centre for Management in Agriculture (CMA), Indian Institute of Management (IIM), Ahmedabad, 38 pp.

Patel P K, Kadivala Varis A H and Patel V N 2019. Role of sulphur in oilseeds crop: A Review. *Journal of Plant Development Sciences*, **11**(3): 109-114.

Compatibility of *Trichoderma*, *Bradyrhizobium* sp. and *Bacillus subtilis* with insecticides and biopolymers

S LAKSHMI PRASANNA*, R D PRASAD AND K S V P CHANDRIKA

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

(Received: May 5, 2021; Revised: December 22, 2021; Accepted: April 4, 2022)

ABSTRACT

Compatibility of three different strains of *Trichoderma, Trichoderma harzianum* Th4d, Th, *Trichoderma asperellum* TaDOR7316, two isolates of Rhizobium (*Bradyrhizobium* sp.) isolated from root nodules of soybean, groundnut and *Bacillus subtilis* with two insecticides, (thiamethoxam and imidacloprid) and two biopolymers (chitosan and cellulose) at different concentrations was tested *in vitro.* Bradyrhizobium isolates (soybean and groundnut) and *Bacillus subtilis* were found compatible with insecticides and biopolymers. All the three *Trichoderma* strains *Trichoderma harzianum* Th4d, *Trichoderma harzianum* Th, and *Trichoderma asperellum* TaDOR7316 were compatible with biopolymers. Imidacloprid showed inhibition ranging from 3.7% to 16.2% of *Trichoderma* @1000ppm. Thiamethoxam showed 7.5 to 10% inhibition of *Trichoderma harzianum,* Th4d @1000ppm. *Trichoderma* is compatible with Bacillus subtilis and Bradyrhizobium isolates of soybean and groundnut.

Keywords: *Bacillus subtilis, Bradyrhizobium,* Imidacloprid*,* Thiamethoxam*, Trichoderma*

Seed and soil borne diseases are the major constrains in crop production. Seed treatment with microbial agents and chemicals is one of the best options to protect any crop from pests and disease and to grow healthy plant. The seed dressing is usually done with plant protection chemicals and biocontrol agents. Compatibility testing of recommended chemicals, biocontrol agents and seed polymers should be done if both the agents are to be used for seed treatment. *Trichoderma* is potential biocontrol agent against many soil (Srijana Bastakoti *et al.,* 2017) and seed borne pathogens, alleviates biotic, abiotic, and physiological stresses in germinating seeds and seedlings (Mastouri *et al.,* 2010), promotes plant growth and induce defense responses (Prasad *et al.,* 2016). Inoculation of *Rhizobia* is one of the decades old practice continued to be followed in leguminous crops (Lindstrom *et al.,* 2010) helps in promoting plant growth shows antagonistic effects against certain plant pathogenic fungi (Glick, 2012). It application significantly reduce synthetic N requirements (30%-60%) in comparison with conventional crops (Jensen *et al.,* 2012). *Bacillus subtilis* not only promotes plant growth but also enhance stress tolerance in plants, induce systemic resistance (Abeer *et al.,* 2019). Widely used seed dressing insecticides *viz.,* thiamethoxam which is compatible with natural enemies (Prabhaker *et al.,* 2011), and imidacloprid, that is environmentally safe (Pike *et al.,* 1994), both are effective against sucking pests that vector many plant viruses were selected for the studies. Seed coatings requires the polymeric binding agents which can be chosen differently, according to the purpose of application and the type of seed, chemicals and microbes. Two biopolymers, chitosan which enhances antimicrobial activity and seed quality (Chandrika *et al.,* 2019), cellulose the safe surfactant and film former (Camargo *et al.,* 2017) were selected for introducing seed coating agents. The present investigation was taken up to explore the possibility of using combination of insecticides and biocontrol in conjuncture with seed polymers for seed dressing.

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

MATERIALS AND METHODS

Microbial cultures: Fungal biocontrol agents *viz., Trichoderma harzianum* Th4d, *Trichoderma harzianum* Th and *Trichoderma asperellum* TaDOR7316 bacterial agents *viz.,* two *Bradyrhizobuim* isolates from soybean and groundnut and *Bacillus subtilis* were obtained from culture collection of Plant Pathology Laboratory, ICAR-IIOR, Hyderabad, Telangana to carry out present investigations. All fungal cultures were maintained on potato dextrose agar (PDA) plates and for bacterial cultures nutrient agar medium was used and cultures were maintained at 25±2 ºC.

Insecticides: Two insecticides thiamethoxam 30% FS and imidacloprid 17.8% SL with seven different concentrations (in ppm) 20, 50, 100, 250, 500, 750, 1000 were used in compatibility studies.

Biopolymers: Two polymers formulations chitosan and cellulose are prepared followed procedure described by Chandrika *et al.* (2019). These formulations at three different concentrations 2.5, 10, 50 ml/kg (recommended 10 ml/kg seed) were used in this study.

Compatibility of *Trichoderma* with insecticides and biopolymers: The insecticides were tested against *Trichoderma* using poisoned food technique (Dhingra and Sinclair, 1985). Insecticides thiamethoxam and imidacloprid at seven concentrations (20,50,100,250,500,750 and 1000 µg/ml) were prepared from stock solution 1000 µg/ml. Required insecticide concentration (100ml) was added to sterilize PDA medium (100 ml) are totally mixed. Three Petri plates of each concentration of the insecticide were prepared by pouring 15 ml PDA aliquot in each sterilized plate of 90 mm diameter. After solidification of medium, 5 mm discs of four days old cultures of *T. harzianum* Th4d, *T. harzianum* Th and *T. asperellum* TaDOR7316 were placed in center of the plates. The control was inoculated with the fungus without any addition of insecticide. All plates were incubated at 25±2°C till the mycelial growth of the *Trichoderma* completely covered the control PDA plates.

Three concentrations of chitosan and cellulose are prepared by adding 0.25ml, 1ml and 5ml of prepared formulation (Chandrika *et al.,* 2019) directly to sterilize PDA medium (100 ml) and mixed thoroughly. Three Petri plates of each concentration were prepared. After solidification of medium, 5 mm discs of four days old PDA cultures of *T. harzianum* Th4d, *T. harzianum* Th and *T. asperellum* TaDOR7316 were placed in center of the plates. The PDA plate without any biopolymer inoculated with *Trichoderma* serves as control.

All plates were incubated at 25±2°C till the mycelial growth of the *Trichoderma* completely covered the control PDA plates. The radial growth of the colonies on PDA with and without insecticide/biopolymer was measured in two directions at right angles to each other. The percentage of inhibition in mycelial growth of the *Trichoderma* over control was calculated using the following formula:

Mean colony inhibition (%) = (C-T/C) x100

C = Growth of pathogen in control (cm)

T = Growth of pathogen in treatment (cm)

Compatibility of bacterial bio agents with insecticides and biopolymers: Bacterial broth culture (2 day old) suspension is evenly spread onto the surface of the NA plates. After the inoculum has dried the sterile disks (6mm) dipped in recommended dose of insecticide/biopolymers (prepared as above) are placed in the center of the agar plates with flamed forceps and gently pressed down to ensure contact. Disc dipped in sterile water serves as control. Three replications for each concentration are prepared. The plates are incubated overnight. The zone diameters are measured with a ruler on the undersurface of the Petri dish. A reading of 6mm indicates no zone. The end point is taken as complete inhibition of growth. (Bauer *et al.,* 1959). The diameter of the inhibition zone was recorded until its effect was lost. The per cent inhibition was calculated as per the method of (Vincent JM. 1947).

Compatibility bacterial bio agents with fungal bio agents: *In vitro* compatibility of *Trichoderma* with Rhizobium (*Bradyrhizobium* sp) soybean and groundnut, *Bacillus subtilis* were tested by dual culture technique (Manoj *et al.,* 2014). Two days old bacterial isolates were streaked at one side of Petri dish (one cm away from the edge) containing PDA. 9mm mycelial disc from seven day old *Trichoderma* culture were placed at the opposite side of Petri dish perpendicular to the bacterial streak respectively and incubated at 27±2°C for 5-7 days. Petri dishes inoculated with fungal discs alone serves as control. Three replications were maintained for each isolate. Observations on width of inhibition zone and mycelial growth of *Trichoderma* were recorded and per cent inhibition growth was calculated by using the formula proposed by Vincent (1927).

Compatibility of *Bradyrhizobium* isolates of soybean and groundnut with *Bacillus subtilis*: Bacterial cultures were streaked on nutrient agar plates in such a way that the single bacterial culture streaked in the center of the plate, other cultures are streaked radiating from the center. The plates were incubated at 37°C for 48 h and the zone of inhibition was observed and recorded (Andhare and Subramanian, 2016).

RESULTS AND DISCUSSION

Compatibility of bacterial agents with insecticides and biopolymers: All the concentrations i.e., 2, 50, 100, 250, 500, 750, 1000 ppm of imidacloprid and thiamethoxam and biopolymers, chitosan and cellulose (0.25, 0.1, 0.5 gm/100ml) were highly compatible with. *Bradyrhizobium* isolates from soybean and groundnut and *Bacillus subtilis.* There observed no zone of inhibition around sterile disks (6mm) dipped in recommended dose of insecticide/ biopolymers.

Compatibility of *Trichoderma* with insecticides: The data presented in the Table 1 and 2 indicates that all the five concentrations i.e., 20, 50, 100, 250, 500 ppm of imidacloprid and thiamethoxam are highly compatible with *T. harzianum* Th4d, *T. harzianum* Th and *T. asperellum* TaDOR7316.

In the media containing 750ppm of imidacloprid, inhibition in radial growth of *Trichoderma harzianum* Th4d was 7.5%. The inhibition in radial growth of *Trichoderma* strains ranged between 3.5-16.5% at 1000ppm concentration. (Table 1; Fig. 1 and 2).

In plates with 750 and 1000 ppm concentration of thiamethoxam inhibition (%) in the radial growth of

Trichoderma harzianum Th4d was 7.5 and 10%, respectively. Minimal inhibition of 1.2% in radial growth of *T. asperellum* TaDOR 7316 was noticed at 1000ppm concentration of thiamethoxam (Fig. 3 and Table 2).

Compatibility studies of *Trichoderma* with polymers: There observed full growth of culture in all the Petri plates of polymers with different concentrations (2.5, 1, 5 gm/100 ml) which shows that all the *Trichoderma strains, T. harzianum* Th4d, *T. harzianum* Th and *T. asperellum* TaDOR 7316 are highly compatible with chitosan and cellulose even at a concentration of 50gm/kg more than the recommended dose (10gm/kg).

Compatibility studies of bio agents: All *Trichoderma* strains are highly compatibility with *Bacillus subtilis* (Harshita *et al.*, 2018; Ali Abeer *et al.,* 2017) and Bradyrhizobium isolates from soybean and groundnut. *Bacillus subtilis* and *Bradyrhizobium* isolates from soybean and groundnut are found compatible with each other as there observed no zone of inhibition at point of contact of two bacterial isolates (Fig. 4).

Table 1 Compatibility of *Trichoderma* strains with imidacloprid 17.8% SC

Concentration	*T. harzianum* Th4d		*T. asperellum* TaDOR7316		*T. harzianum* Th	
	% growth inhibition	% compatibility	% growth inhibition	% compatibility	% growth inhibition	% compatibility
20 ppm	0.0	100.0	0.0	100.0	0.0	100.0
50 ppm	0.0	100.0	0.0	100.0	0.0	100.0
100 ppm	0.0	100.0	0.0	100.0	0.0	100.0
250 ppm	0.0	100.0	0.0	100.0	0.0	100.0
500 ppm	0.0	100.0	0.0	100.0	0.0	100.0
750 ppm	7.5	92.5	0.0	100.0	0.0	100.0
1000 ppm	16.2	83.7	3.7	96.2	12.5	87.5
Control	0.0	100.0	0.0	100.0	0.0	100.0

Table 2 Compatibility of *Trichoderma* strains with thiamethoxam 30% FS

Concentration	*T. harzianum* Th4d		*T. asperellum* TaDOR7316		*T. harzianum* Th	
	% growth inhibition	% compatibility	% growth inhibition	% compatibility	% growth inhibition	% compatibility
20 ppm	0.0	100.0	0.0	100.0	0.0	100.0
50 ppm	0.0	100.0	0.0	100.0	0.0	100.0
100 ppm	0.0	100.0	0.0	100.0	0.0	100.0
250 ppm	0.0	100.0	0.0	100.0	0.0	100.0
500 ppm	0.0	100.0	0.0	100.0	0.0	100.0
750 ppm	7.5	92.5	0.0	100.0	0.0	100.0
1000 ppm	10.0	90.0	1.2	98.7	0.0	100.0
Control	0.0	100.0	0.0	100.0	0.0	100.0

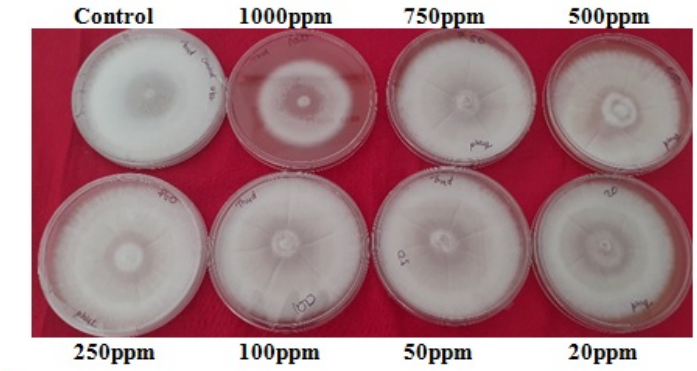

Fig. 1. Compatibility of *Trichoderma harzianum* Th4d with imidacloprid

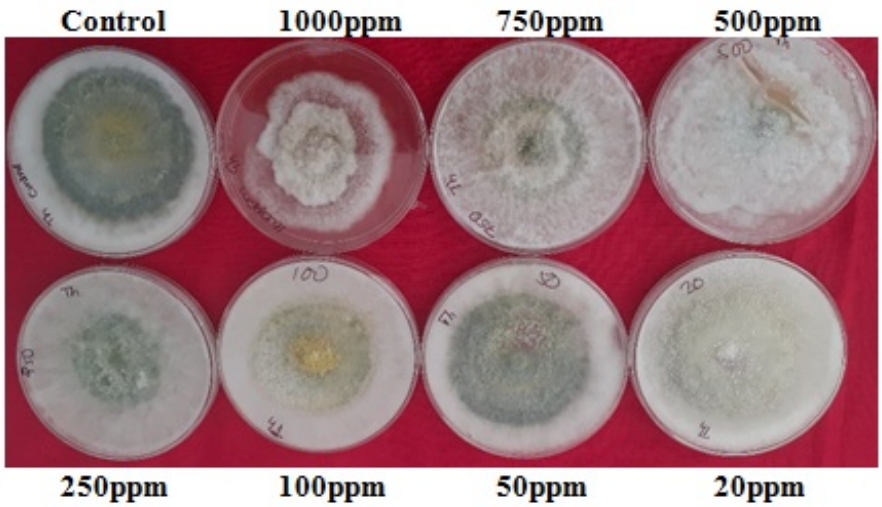

Fig. 2. Compatibility of *Trichoderma harzianum* Th with imidacloprid

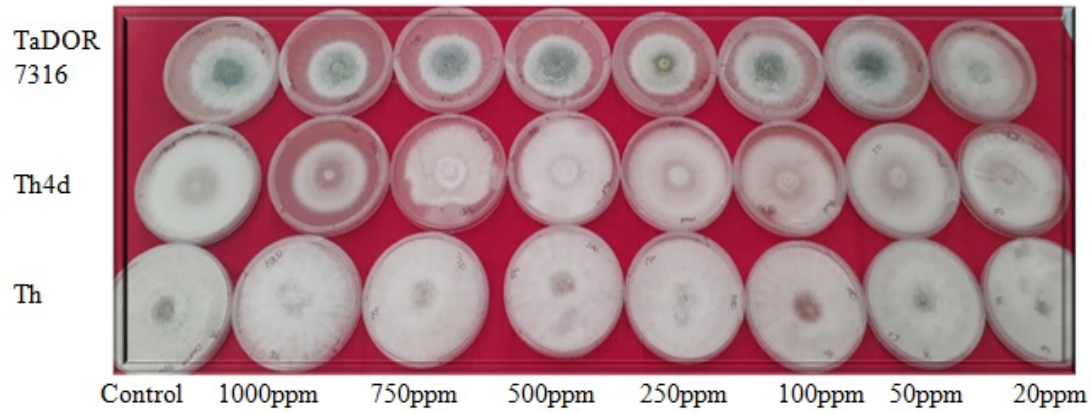

Fig. 3. Compatibility of *Trichoderma* isolates with thiamethoxam

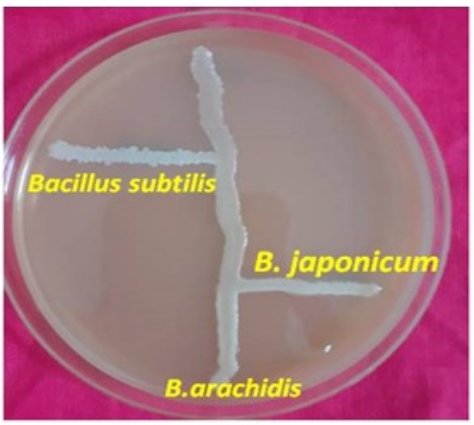

Fig. 4. Compatibility of *Bacillus subtilis* and *Bradyrhizobium* isolates
(No zone of inhibition at any contact point of two bacteria (Compatible with each other)

From the above studies we can conclude that insecticides, thiamethoxam, imidacloprid, and biopolymers, chitosan and cellulose at recommended doses are highly compatible with *Trichoderma* strains, *Bacillus subtilis* and isolates of *Bradyrhizobium* from soybean and groundnut. Hence a combination of the above insecticide, *Trichoderma* strain and bacterial isolate isolate can be mixed together for seed treatment. These combinations are to be studied in vitro for growth parameters, pest and disease incidence. Along with this best fungicides should be included for testing. Combination of insecticide, fungicide, biocontrol agents, polymer with different combinations and in different layer coatings are to be studied further. This provides a complete protection for seed growth, reducing cost inputs and prevent environmental pollution.

REFERENCES

Abeer Hashem, Baby Tabassum and Elsayed Fathi Abd-Allah 2019. *Bacillus subtilis:* A plant-growth promoting rhizobacterium that also impacts biotic stress. *Saudi Journal of Biological Sciences*, **26**(6): 1291-1297. https://doi.org/10.1016/j.sjbs.2019.05.004.

Ali Abeer A, Abd El-Kader A E S and Ghoneem K H M 2017. Two *Trichoderma* species and *Bacillus subtilis* as biocontrol agents against rhizoctonia disease and their influence on potato productivity. *Egyptian Journal of Agricultural Research*, **95**(2): 527-547.

Andhare A P and Subramanian Babu 2017. Compatibility of *Azospirillum brasilense* and *Pseudomonas fluorescens* in growth promotion of groundnut (*Arachis hypogaea* L.). *Annals of the Brazilian Academy of Sciences*, **89**(2): 1027-1040.

Bauer A W, D M Perry and W M M Kirby 1959. Single disc antibiotic sensitivity testing of Staphylococci. *AMA Archives of Internal Medicine*, **104**: 208-216.

Camargo, Fernando S, Isneider B, Patricio A, Diego R, Renato B, Nilton A, Jose T, Itamar D, Ivano C and Andre 2017. Physiological quality of soybean seeds treated with carboxymethyl cellulose and fungicide. *American Journal of Plant Sciences*, **8**: 2748-2757. 10.4236/ajps.2017.811185.

Chandrika K S V P, Prasad R D and Godbole V 2019. Development of chitosan-PEG blended films using *Trichoderma:* Enhancement of antimicrobial activity and seed quality. *International Journal of Biological Macromolecules*, **126**: 282-290.

Dhingra O D and Sinclair J B 1985. *Basics plant pathology methods.* CRC Press. Inc. Boca Raton Florida. pp. 13-44.

Glick B R 2012. Plant growth-promoting bacteria: mechanisms and applications. *Scientifica*. **1**-15. doi: 10.6064/2012/963401.

Harshita A, Sinha J B, Khan S, Trivedi A, Verma and Rao S G 2018. Compatibility of fungal and bacterial bio-agents and their antagonistic effect against *Fusarium oxysporum* f. sp. *Lycopersici*. *International Journal of Current Microbiology and Applied Sciences*, **7**(7): 2305-2316.

Jensen E S, Peoples M B, Boddey R M, Gresshoff P M, Hauggaard-Nielsen H, Alves B J R 2012. Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. A review. *Agronomy for Sustainable Development,* **32**: 329-364. doi: 10.1007/s13593-011-0056-7.

Lindstrom K, Murwira M, Willems A and Altier N 2010. The biodiversity of beneficial microbe-host mutualism: the case of rhizobia. *Research in Microbiology*, **161**: 453-463.

Manoj K M., Tomer A and Ramji S 2014. In vitro evaluation of antagonistic activity of *Pseudomonas fluorescens* against fungal pathogen. *Journal of Biopesticides*, **7**(1): 43-46.

Mastouri F, Bjorkman T and Harman G E 2010. Seed treatment with *Trichoderma harzianum* alleviates biotic, abiotic, and physiological stresses in germinating seeds and seedlings. *Phytopathology*, **100**(11): 1213-1221.

Prabhaker N, Castle S J, Naranjo S E, Toscano N C and Morse J G 2011. Compatibility of two systemic neonicotinoids, imidacloprid and thiamethoxam, with various natural enemies of agricultural pests. *Journal of Economic Entomology,* **104**(3): 773-781.

Pike K S, Reed G L, Graf G T and Allison D 1993. Compatibility of imidacloprid with fungicides as a seed-treatment control of Russian wheat aphid (Homoptera: Aphididae) and effect on germination, growth, and yield of wheat and barley. *Journal of Economic Entomology*, **86**(2): 586-593.

Prasad R D, Navaneetha, Tokala and Linga, Venkateswar 2016. Plant growth promotion and induced defense response in safflower (*Carthamus tinctorius* L.) by *Trichoderma. Journal of Biological Control*, **30**(1): 40-48. 10.18311/jbc/30/1/6458.

Srijana Bastakoti, Shiva Belbase, Shrinkhala Manandhar and Charu Arjyal 2017. *Trichoderma* species as biocontrol agent against soil borne fungal pathogens. *Nepal Journal of Biotechnology*, **5**(1): 39-45.

Effect of different fungicides against stem and root rot of sesame (*Sesamum indicum* L.) caused by *Macrophomina phaseolina* (Tassi) Goid

PRADIP KUMAR BAIRWA, DAMA RAM AND ANAND CHOUDHARY[1]

College of Agriculture, Agriculture University, Jodhpur-342 304, Rajasthan

(Received: May 24, 2022; Revised: June 13, 2022; Accepted: June 16, 2022)

ABSTRACT

Stem and root rot disease caused by *Macrophomina phaseolina* is the serious soil-borne disease in sesame. The present study was conducted at College of Agriculture, Jodhpur during *kharif* season 2020-21 to evaluate the nine different fungicides under in vitro condition and five different fungicides under in vivo against *M. phaseolina.* Result of *in vitro* study indicated that the fungicide, carbendazim (50% WP) gave complete mycelial growth inhibition (100%) at 500 and 1000 ppm concentrations, respectively. Second best of pyraclostrobin 5% + metiram 55% WG, carbendazim 12% + mancozeb 63%, then propiconazole 25% EC, thiophanate methyl (70% WP) and cymoxanil 8% + mancozeb 64% also gave 100% inhibition of mycelial growth at 1000 ppm respectively. The lowest disease per cent was recorded in combination fungicide of tebuconazole 50% + trifloxystrobin 25% WG (8.91%) followed by 9.14% with cymoxanil 8% + mancozeb 64%, pyraclostrobin 5% + metiram 55% WG (11.02%) whereas, maximum disease incidence was recorded in control plot (55.32%) when tested under in vivo condition.

Keywords: Fungicides, *In vitro, In vivo,* Management, *M. phaseolina,* Sesame

Sesame (*Sesamum indicum* L.) a diploid (2n=26) dicotyledonous, belongs to the family Pedaliaceae, is the most ancient oil crops in the world (Weiss *et al.,* 1983). It is native to Africa region but now it is grown in tropical regions around the world and cultivated for its edible seeds. In India, sesame cultivated during *kharif* 2020-21 in 15.26 lakh ha area with a production of 7.49 lakh tonne and the productivity of 491 kg/ha (Anonymous, 2020). Among all sesame growing states Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat account nearly 85% of area and 82% of the production of country (Anonymous, 2020). Sesame seeds and its oil are in high export demand as its seeds are a good source of dietary protein, with high-quality amino acids building up 20% of the seed (Pathak and Pathak, 2014). Its oil is rich source for some phyto-nutrients such as omega-6 fatty acids, flavonoid phenolic anti-oxidants, vitamins and dietary fiber with potent anti-cancer as well health promoting properties. It is stable and free from undesirable nutrition or flavor component. The oil also contains oleic (35.9-47%), linoleic (35.6-47.6%), palmitic (8.7-13.8%), stearic (2.1-6.4%), as well as arachidic acids (0.1-0.7%) (Elleuch *et al*., 2007; Borchani *et al*., 2010).

The main reason for low productivity of this crop is due to the attack of various fungal, bacterial, viral and phytoplasmal diseases (Sangeetha *et al.,* 2021). About 72 fungi, seven bacteria, one phytoplasmal and one viral disease reported from India (Vyas and Woodside., 1984). The pathogen M. phaseolina affect the fibro vascular system of the root and basal internodes of its host, impeding the transport of nutrients and water to the upper part of the plant, as a result progressive wilting, premature dropping of leaves, loss of vigor, and reduced yield are major characteristic symptoms of M. phaseolina infection (Gupta *et al.,* 2012).

Stem and root rot caused by *Macrophomina phaseolina* affects severely at all stages of the crop growth. *M. phaseolina* is a diverse, omni present soil borne pathogen which causes dry root rot on number of economically important crops i.e. vegetables, pulses, oil seeds and fruit crops (Viana and De Souza, 2002; Jayaramachandran *et al.,* 2021). Seedling mortality due to seed borne infection aggravates the disease problem by reducing the plant stand per unit area, resulting in low yield and 5-100% yield loss have been reported by Vyas *et al.* (1981). Murugesan *et al.* (1978) observed 1.8 kg yield loss per hectare at every one per cent increase in disease intensity. This disease reports up to 50 per cent incidence resulting in heavy yield losses (Chattopadhyay and Sastry, 1998). In severe conditions, the losses have been reported up to 67% (Kumar *et al.,* 2006). Keeping in view the importance of the disease, the present study was undertaken to identify the most effective fungicides in controlling the stem and root rot disease of sesame.

MATERIALS AND METHODS

***In vitro* evaluation of fungicides**: The efficacy of nine fungicides was studied against mycelia growth of *M. phaseolina* by poisoned food technique (Nene and Thapliyal, 1979) with two different concentrations (500 & 1000 ppm). The details of fungicides screened are given in Table 1 along

[1]College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner-334006, Rajasthan; Corresponding author's E-mail: anandparoda84@gmail.com

with their concentrations. The required quantity of each fungicide under study was mixed thoroughly in sterilized 100 ml PDA media filled in 250 ml flask separately under aseptic conditions. The medium was supplemented with streptomycin sulphate @ 50 ppm to prevent the bacterial contamination. The poisoned medium was then poured in sterilized petri plates (20 ml) and allowed it to solidify. The plates were then inoculated with five mm. diameter disc of seven days old culture of *M. phaseolina* by placing in the centre of the plate. Control was maintained for each set where fungal disc was placed on PDA medium without fungicide. Each treatment was replicated three times. The inoculated plates were then incubated at 27±1°C in BOD incubator. The observations on mycelial growth (mm) and per cent growth inhibition of test fungi were recorded after 8 days of incubation. The per cent growth inhibition (PGI) of the pathogen in each treatment was calculated by following formula (Asalmol *et al.,* 1990).

$$I = \frac{C - T}{C} \times 100$$

Where; I = Per cent growth reduction of test pathogen; C = Radial growth of test pathogen in control (mm); T = Radial growth of test pathogen in treatment (mm)

***In vivo* evaluation of fungicides**: The field experiment was laid out in Randomized Block Design (RBD) with five treatments and four replications during *kharif* season 2020 at the Farm, College of Agriculture, Jodhpur. The seeds of RT-351 were sown in the field with a spacing of 60 cm x 30 cm in plot measuring 2 x 1.5 to 2 m. All other cultural and pest control practices were followed as recommended in package of practices. The seeds were treated with Penflufen 240 fs (0.64%), Trifloxystrobin 500 SC (0.3%), Penflufen + Trifloxystrobin 308 fs (0.6%), Vitavax power (0.3%). The seeds without treatment were sown and served as control. The observations on seed germination, pre and post emergence mortality were recorded after 3, 5 and 10 days of sowing, respectively. For yield loss assessment, 50 healthy and 50 infected capsules were collected at the time of maturity. From the healthy and infected capsules seeds were taken and per cent loss was calculated by using the following formula.

In another experiment, foliar application with five fungicides (Table 2) i.e., Tebuconazole 50% + trifloxystrobin 25% WG (75 WG), pyraclostrobin 5% + metiram 55% WG, cymoxanil 8% + mancozeb 64%, carbendazim 12% + mancozeb 63%, azoxystrobin 11% + tebuconazole 18.3% W/W SC were applied of at the time 45 days after sowing, The seeds without any treatment were kept as control. The observations were recorded for per cent disease incidence and per cent disease control.

Statistical analysis: Per cent disease incidence (PDI) and disease control in various experiments were calculated as follows:

Per cent Disease Incidence (PDI)=

$$\frac{\text{Number of infected plants}}{\text{Total number of plants}} \times 100$$

RESULTS AND DISCUSSION

***In vitro* evaluation of fungicides**: Nine fungicides were evaluated through poisoned food techniques against stem and root rot of sesame pathogen. All the tested fungicides showed significantly higher mycelial growth inhibition over control (Table 4, Fig. 1 and Plate 1a and 2b).

Among these fungicides, carbendazim (50% WP) gave complete mycelial growth inhibition (100%) at 500 and 1000 ppm concentrations, respectively. Pyraclostrobin+ metiram WG, carbendazim + mancozeb, propiconazole EC, thiophanate methyl (70% WP), and cymoxanil + mancozeb inhibit cent per cent growth at 1000 ppm respectively. Tebuconazole + trifloxystrobin WG (75 WG) inhibited mycelial growth by 74.64 and 93.85 per cent at 500 and 1000 ppm, respectively and was found at par with azoxystrobin + tebuconazole W/W SC. Captan + hexaconazole were found least effective with inhibition of the mycelial growth by 68.29 and 87.54 per cent at 500 and 1000 ppm concentration, respectively. The data presented in Table 4 reflected that for mean mycelial growth inhibition. Carbendazim (50% WP) found superior over all the tested fungicides and it inhibit cent per cent mycelium growth at 500 and 1000 ppm, respectively. Similar results were also observed by Singh *et al.* (2003) and Choudhary *et al.* (2014) they studied the efficacy of different fungicides and found that the Carbendazim inhibited maximum mycelium growth at *in vitro* condition

***In vivo* evaluation of fungicides**: Five systemic fungicides along with control were evaluated in field conditions and the results presented in (Table 5 and Fig. 2). Among the treatments in management of stem and root rot of sesame, tebuconazole 50% + trifloxystrobin 25% WG (75 WG) (8.91%) statistically at par with the foliar spray, cymoxanil 8% + mancozeb 64% (9.14%) recorded least per cent disease incidence followed by pyraclostrobin 5% + metiram 55% WG (11.02%) whereas, 55.32% disease incidence was recorded in control. The maximum seed yield was recorded with application of tebuconazole 50% + trifloxystrobin 25% WG (75 WG) (769 kg/ha) followed by cymoxanil 8% + mancozeb 64% (737 kg/ha) and pyraclostrobin 5% + metiram 55% WG (693 kg/ha). The minimum seed yield (417 kg/ha) was observed in control.

Table 1 Fungicides evaluated against *M. phaseolina* by poison food technique (*in vitro*)

Common Name	*In vitro*	Conc. (ppm)
Carbendazim (50% WP)	500	1000
Tebuconazole 50% + Trifloxystrobin 25% WG (75 WG)	500	1000
Pyraclostrobin 5% + Metiram 55% WG	500	1000
Cymoxanil 8% + Mancozeb 64%	500	1000
Captan 70% + hexaconazole 5%	500	1000
Carbendazim 12% + Mancozeb 63%	500	1000
Thiophanate methyl (70% WP)	500	1000
Propiconazole 25% EC	500	1000
Azoxystrobin 11% + Tebuconazole 18.3% W/W SC	500	1000
Control	-	-

Table 2 Fungicides evaluated against *M. phaseolina* (*in vivo*)

Common Name	Doses (%)
Tebuconazole 50% + Trifloxystrobin 25% WG (75 WG)	0.2
Pyraclostrobin 5% + Metiram 55% WG	0.2
Cymoxanil 8% + Mancozeb 64%	0.2
Carbendazim 12% + Mancozeb 63%	0.2
Azoxystrobin 11% + Tebuconazole 18.3% W/W SC	0.2
Control	-

Table 3 Effect of different fungicides against *M. phaseolina in vitro*

Treatment	Per cent inhibition of mycelial growth*		
	Concentration (ppm)		
	500	1000	Mean
Carbendazim (50% WP)	100.0 (88.7)	100.0 (88.7)	100.0 (88.7)
Tebuconazole 50% + Trifloxystrobin 25% WG (75 WG)	74.6 (59.7)	93.8 (75.7)	84.2 (67.7)
Pyraclostrobin 5% + Metiram 55% WG	98.1 (82.3)	100.0 (88.7)	99.0 (85.5)
Cymoxanil 8% + Mancozeb 64%	85.7 (67.7)	100.0 (88.7)	92.8 (78.2)
Captan 70% + hexaconazole 5%	68.2 (55.7)	87.5 (69.3)	77.9 (62.5)
Carbendazim 12% + Mancozeb 63%	95.2 (77.4)	100.0 (88.6)	97.6 (83.0)
Thiophanate methyl (70% WP)	86.4 (68.3)	100.0 (88.7)	93.2 (78.5)
Propiconazole 25% EC	89.4 (71.0)	100.0 (88.7)	94.7 (79.8)
Azoxystrobin 11% + Tebuconazole 18.3% W/W SC	79.4 (63.0)	92.4 (73.9)	85.9 (68.5)
Control	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Factor	SEm (±)	CD (p=0.05)	
Fungicide (F)	0.366	1.050	
Concentration (C)	0.164	0.470	
Interaction F x C	0.518	1.485	

*Average of three replications; Figures in parentheses are angular transformed values

Table 4 Effect of different fungicides against *M. phaseolina in vivo*

Treatment	Dosage (g/kg or ml/lit. of seed)	PDI**	Disease control (%)	Yield (kg/ha)*	Yield increase over control (%)
Tebuconazole 50% + Trifloxystrobin 25% WG (75 WG)	0.5	8.9 (17.3)	83.8	769	84.4
Pyraclostrobin 5% + Metiram 55% WG	2	11 (19.3)	80	693	66.1
Cymoxanil 8% + Mancozeb 64%	2	9.1 (17.5)	83.4	737	76.7
Carbendazim 12% + Mancozeb 63%	2	16.9 (24.3)	69.3	640	53.4
Azoxystrobin 11% + Tebuconazole 18.3% W/W SC	2	20 (26.5)	63.7	577	38.3
Control	-	55.3	0.0	417	
SEm (±)	-	0.262		20.317	
CD (p = 0.05)	-	0.798		61.243	
CV (%)	-	2.914		6.360	

*Average of four replications; **PDI = Per cent Disease Incidence; Figures in parentheses are angular transformed values

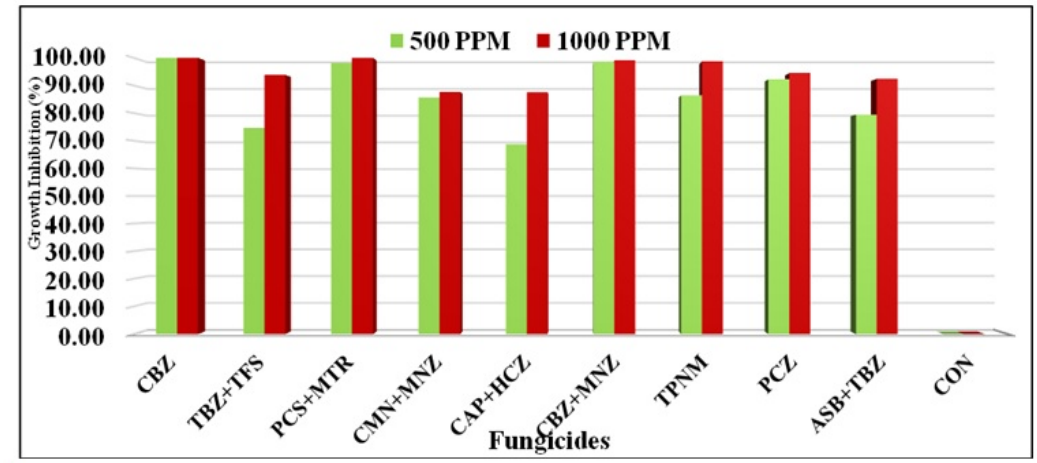

Fig.1. Efficacy of fungicides against *M. phaseolina* (*in vitro*)

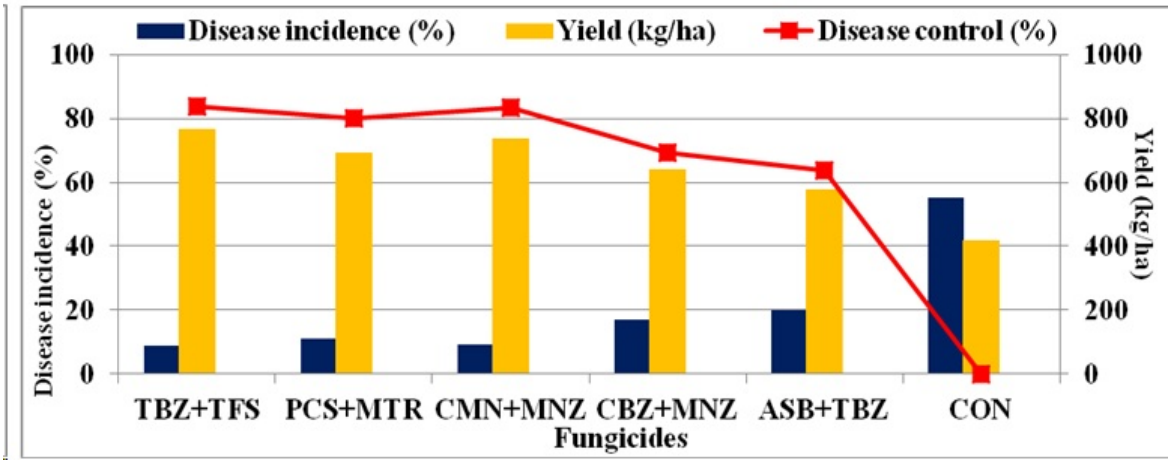

Fig. 2. Efficacy of fungicides against *M. phaseolina* (*in vivo*)

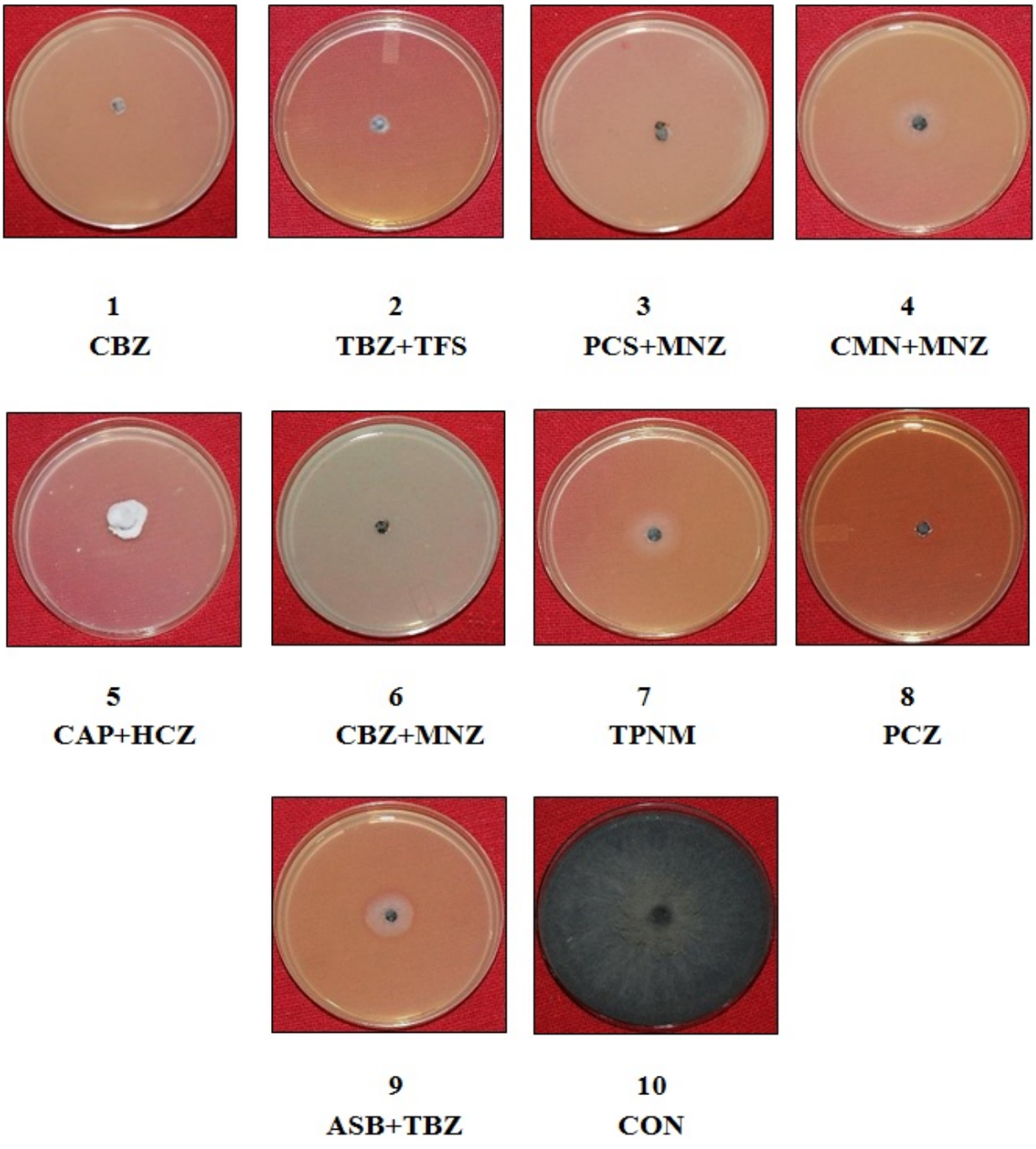

Fig. 3a. *In vitro* evaluation of fungicides on mycelial growth inhibition of *M. phaseolina* (500 ppm)

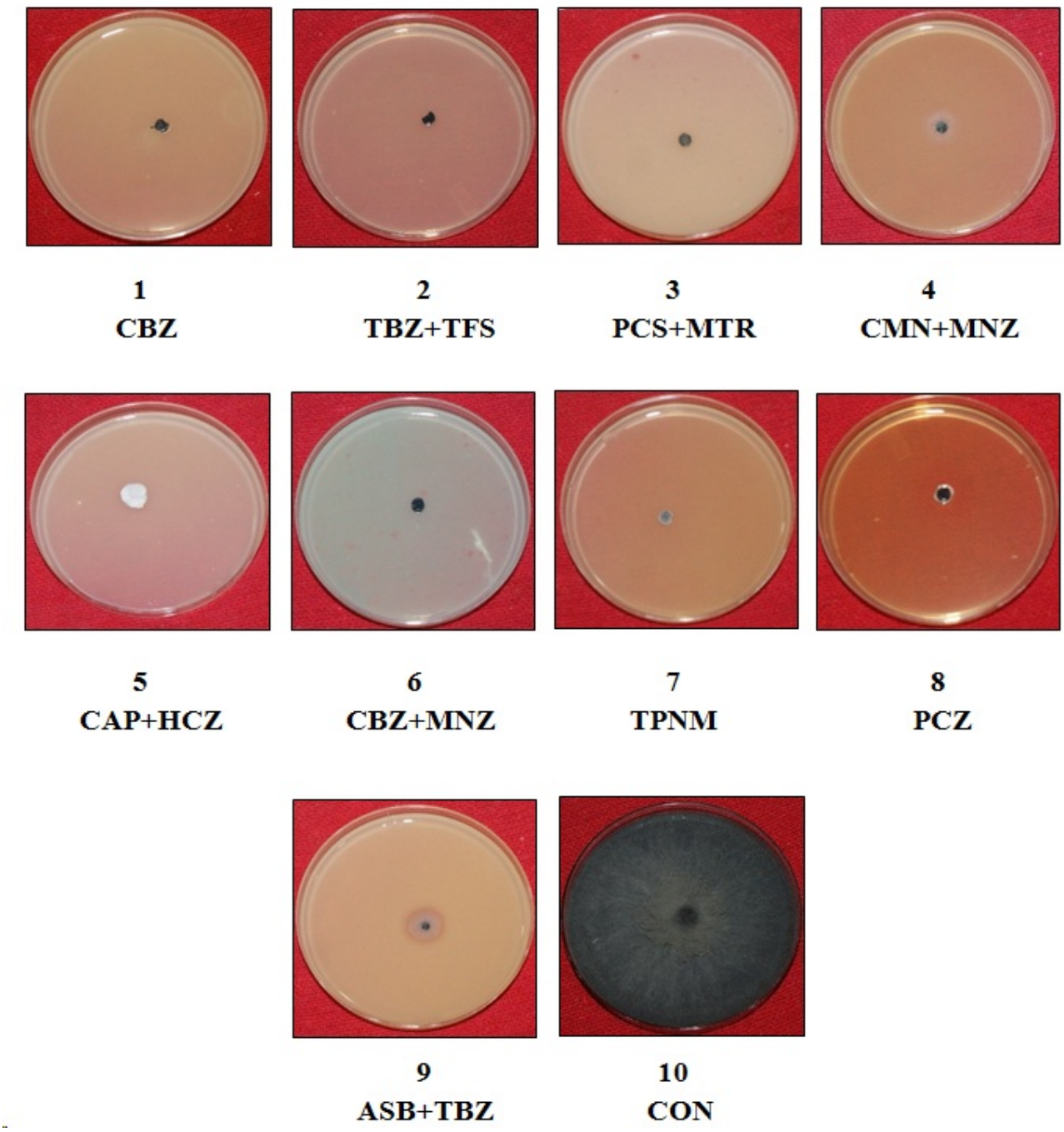

Fig. 3b. *In vitro* evaluation of fungicides on mycelial growth inhibition of *M. phaseolina* (1000 ppm)

Similar results were also observed by Rajpurohit and Bishnoi (2004) with the application of thiram + carbendazim as seed treatment and mancozeb as spray found most superior and significantly decreased the disease incidence of *M. phaseolina* in sesame and increased the seed yield. Tandel *et al.* (2010) studied seven fungicides and found that carbendazim + mancozeb was significantly superior with minimum disease incidence (8.13%) for the management of leaf spot of mung bean. Deepthi *et al.* (2014b) evaluated some fungicides under field conditions and found that the carboxin + thiram gave highest seed germination and less mortality in sesame. Ashwini *et al.* (2015), Maruti *et al.* (2017) and Choudhary *et al.* (2018) observed that the systemic fungicides were most effective for the control of root rot disease in sesame. Thombre and Kohire (2018) reported that the spray application of carbendazim + mancozeb against root rot of mung bean the controlled 67.07% disease at field conditions. Most of fungicides have site specific action like benzimidazoles (carbendazim). When soil is treated with mancozeb then population of fungi and actinomycetes are decreases due to production of toxic subtracts by mancozeb in soil (Fawole *et al.,* 2010).

Nine fungicides were tested under *in vitro* and *in vivo* conditions against stem and root rot and recorded that the maximum mycelial growth inhibition was (100%) in case of carbendazim (50% WP) at 500 and 1000 ppm and pyraclostrobin + metiram WG at 500 and 1000 ppm concentrations, respectively. Under natural conditions tebuconazole + trifloxystrobin WG (75 WG) showed minimum disease incidence (8.91%) with 83.89 per cent disease control. The maximum seed yield was recorded with application of tebuconazole + trifloxystrobin WG (75 WG) (769 kg/ha) followed by cymoxanil + mancozeb (737 kg/ha) and pyraclostrobin + metiram WG (693 kg/ha). The minimum seed yield (417 kg/ha) was observed in control.

REFERENCES

Anonymous 2020. Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India, pp. 1-98

Asalmol M N, Sen B and Awasthi J 1990. Role of temperature and pH in antagonism of *Aspergillus niger* and *Trichoderma viride* against *Fusarium solani. Proceedings of Indian Phytopathological Society*, 11-13.

Ashwini C, Giri G K and Halgekar N 2015. Efficacy of fungicides against seed borne fungi in black gram. *Environment and Ecology*, **33**: 140-142.

Borchani C, Besbes S, Blecker C H and Attia H 2010. Chemical characteristics and oxidative stability of sesame seed, sesame paste, and olive oils. *Journal of Agricultural Science Technology*, **12**: 585-596.

Chattopadhyay C and Kalpana Sastry R 1998. Important diseases of sesame and their management options. *IPM Systems in Agriculture*, 5.

Choudhary C S, Singh S N and Prasad S M 2014. In vitro effectiveness of chemicals to control *Macrophomina phaseolina* (Tassi.) Goid. causing stem and root rot of sesame. *Journal of Applied Biology*, **14**: 46-47.

Choudhary K, Meena A K, Dhakar H and Kumar M 2018. Management of charcoal rot of sesame [*Macrophomina phaseolina* (Tassi.) Goid.] by different bio-agent and fungicide. *International Journal of Chemical Studies*, **6**: 1556-1559.

Deepthi P, Shukla C S, Verma K P and Reddy S S 2014. Yield loss assessment and influence of temperature and relative humidity on charcoal rot development in sesame (*Sesamum indicum* L.). *International Journal of Life Science*, **9**: 193-195.

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.

Fawole O B, Aliko M and Olowonihi T E 2010. Effects of a carbendazim-mancozeb fungicidal mixture on soil microbial populations and some enzyme activities in soil. *Agrosearch,* **10**: 65-74.

Gupta O, Patel S and Mishra M 2012. Diversity in isolates of *Rhizoctonia bataticola* causing dry root rot in chickpea from Central India. *JNKVV Research Journal*, **46**(3): 376-381.

Kumar A S, Durai A R and Sornakumar T 2006. Wear behaviour of alumina-based ceramic cutting tools on machining steels. *Tribology International*, **39**: 191-197.

Maruti S A S, Sunkad G, Mahalinga D and Patil M G 2017. Incidence of dry root rot of pigeon pea in north eastern Karnataka, India. *International Journal of Current Microbiology and Applied Science*, **6**: 1071-1078.

Murugesan P and Moravcsik M J 1978. Variation of the nature of citation measures with journals and scientific specialties. *Journal of the American Society for Information Science*, **29**: 141-147.

Nene Y L and Thapliyal B W 1979. Fungicides in plant disease control. Oxford & IBH Publisher House, New Delhi, 425 pp.

Pathak C P and Pathak H C 2014. Compositions, methods and devices for local drug delivery. *U S Patent Application*, **14**: 209-827.

Rajpurohit T S and Bishnoi H R 2004. Integrated disease management in sesame (*Sesamum indicum* L.). *Journal of Mycology and Plant Pathology*, **34**: 994.

Jayaramachandran M, Ravichandran V and R Vaithiyalingan 2021. Assessment of genetic variability and resistance against stem and root rot caused by *Macrophomina phaseolina* in segregating generations of sesame (*Sesamum indicum* L.). *Journal of Oilseeds Research*, **38**(1): 115-120.

Sangeetha A, Subrahmaniyan K, Meena B and Gupta K. 2021. Screening of elite lines of sesame (*Sesamum indicum* L.) against major diseases. *Journal of Oilseeds Research*, **38**(3): 280-285.

Singh S, Yadav J P S, Tripathi N N and Kalita M K 2003. Comparative efficacy of fungi toxicants in controlling root rot of cotton caused by *Rhizoctonia solani* Kühn. *Annals of Agriculture and Biological Research*, **8**: 61-63

Tandel D H, Sabalpara A N, Pandya H H and Naik R M 2010. Effect of leaf blight [*Macrophomina phaseolina* (Tassi.) Goid.] on growth parameters and yield of green gram and its chemical control. *International Journal of Plant Protection*, **3**: 329.

Thombre B B and Kohire O D 2018. Integrated management of *Macrophomina* blight of mungbean (*Vigna radiata* L.) caused by *Macrophomina phaseolina* (Tassi) Goid. *Indian Phytopathology*, **71**: 423-429.

Viana F M P and De Souza N L 2002. Effect of temperature water tension interaction on germination of *Macrophomina phaseolina microsclerotia. Fitopatolagia Brasileira*, **27**: 268-272.

Vyas N and Woodside A G 1984. An inductive model of industrial supplier choice processes. *Journal of Marketing*, **48**: 30-45.

Weiss J, Tabor M and Carnevale G 1983. The Painlevé property for partial differential equations. *Journal of Mathematical Physics*, **24**: 522-526.

Population dynamics of insect pest and natural enemies of castor (*Ricinus communis* L.) under different intercrops

M SENTHIL KUMAR[1*] AND P DURAIMURUGAN[2]

Tapioca and Castor Research Station, Tamil Nadu Agricultural University, Yethapur-636 119, Tamil Nadu

(Received: May 16, 2022; Revised: June 14, 2022; Accepted: June 18, 2022)

ABSTRACT

A field experiment was conducted at Tapioca and Castor Research Station, Tamil Nadu Agricultural University, Yethapur, Tamil Nadu during *kharif* 2015 and *rabi* 2016 to study the population dynamics of insect pests and natural enemies in different castor intercrops. The defoliators population was significantly lesser in castor + red gram + pearl millet intercropped treatments than in the sole castor crop, which served as a control. The cumulative mean number of sucking pest population was found to be lesser in (castor + red gram), followed by castor + red gram + pearl millet intercrop system. Capsule borer percentage infestation is significantly lesser in castor + red gram + pearl millet intercropped treatments with increased percentage parasitization by *Micropliti macullipennis* and *Apanteles angaleti.*

Keywords: Castor, Intercropping, Insect pest, Natural enemies, Population dynamics

Castor (*Ricinus communis* L.) is an industrially important non-edible oilseed crop. Among the biological constraints in castor production, insect pests dominate the scenario. In India, several insect pests infesting castor have been recorded. The most important ones are the defoliators including semilooper (*Achaea janata* L.), tobacco caterpillar [*Spodoptera litura* (F.)], hairy caterpillars (*Euproctis* spp. and *Ergolis merione* Cramer) and shoot and capsule borer (*Conogethes punctiferalis* Guenee) (Lakshminarayana and Duraimurugan, 2014). The castor semilooper is common and regular pests in Tamil Nadu and its outbreaks occurring during August-September. The economic threshold level for the semilooper is 4 larvae/plant on 30 days old crop. The tobacco caterpillar is another major pest on castor and the pest appears more between August and October causing heavy defoliation. The hairy caterpillars like *Euproctis* sp. and *Ergolis merione* Cramer reported to cause damage to castor particularly during October-December months. The young instars feed gregariously and confined to certain portion of the field (Bharathi and Duraimurugan, 2022). The habit continues even in the mature larvae, on contact with larvae causing urticarial or nettle rash in human beings. The castor shoot and capsule borer is another major and serious pest of castor, which attacks the economic part causing direct seed yield loss upto 30 to 40% in Tamil Nadu. The seed yield loss due to semilooper and *spodoptera* is to the tune of 31.0-40.8% followed by hairy caterpillars 19.0% (Anonymous, 2006). Management of defoliators and capsule borer relies heavily on insecticides when other management strategies of pest control do not give satisfactory control under high pest infestation level. In India, Gujarat, Andhra Pradesh and Rajasthan are the major castor producing states (84% of total area) followed by Chhattisgarh (9.1%), Karnataka (2.3%), Odisha (2%) and Tamil Nadu (0.6%). The highest productivity of castor (2061 kg/ha) is from Gujarat followed by Rajasthan (1465 kg/ha), where the crop is grown under irrigation and high input management. The average productivity is low (309 kg/ha) in Tamil Nadu and other states in Southern and Central India where the crop is cultivated mostly as rainfed with low input management. The biotic stresses mostly the whiteflies and thrips were major reasons for low yields of castor cultivated during *rabi* season. Castor whitefly (*Trialeurodes ricini* Misra) its infestation is prevalent throughout the year, but its severity is high during March-June (Rai, 1976). Adults are tiny moths like with milky white coating on the body. The female whitefly lays about 80-90 eggs singly, mostly on the lower surface of the tender leaves. The yellowish nymphs are oval translucent with waxy projections all round and remain adhered to the lower surface of the leaves. Both nymphs and adults suck sap mostly from under surface of the leaves and cause yellowing of leaves and stunting of plants in case of infestation. Sooty mould is developed on the honey secreted by the pest. The yield losses to the tune of 12.4 to 15% due to whitefly were reported from Gujarat (Patel, 2002). Adoption of intercropping methods offers an opportunity to protect the crops by natural pest management. There is also a strong need to develop pest management practices that are affordable for resource-poor farmers. With these considerations in view, the present study aimed to examine how the incidence of insect pests differs in an intercropping system compared to a castor monocrop.

MATERIALS AND METHODS

To evaluate the population dynamics of insect pests and natural enemies in different castor intercrops, field

[1]Present address: Horticultural Research Station, Tamil Nadu Agricultural University, Yercaud, Salem-636 601, Tamil Nadu; [2]ICAR-Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad-500 030, Telangana; Corresponding author's E-mail: senthilkumariari@gmail.com

experiments were conducted at Tapioca and Castor Research Station, Yethapur (Tamil Nadu) during kharif 2015 and *rabi* 2016 using castor hybrid DCH-519 and sown in plots of 5.4 m x 6.0 m with the spacing of 90 cm x 90 cm. The experiment was conducted in a randomized block design with eight treatments (seven castor based intercropping systems and one castor monocrop as control) and replicated thrice with a large plot size of 500m^2 per replicate. Intercrops were sown in between rows of castor in an additive manner to keep the population of castor plants constant across the eight cropping systems. All other intercrops were sown in two rows 30 cm apart from each other and 30 cm away from castor rows on either side. Routine agronomic practices such as application of recommended doses of fertilizers to castor, intercrops, and intercultural operations were taken up at appropriate growth stages of the crops. No pest control measures were undertaken during the entire crop growth period. The data were analysed by OPSTAT (Sheoran *et al.,* 1998). Population data were square root transformed and the percentage infestation data were arcsine transformed. Based on the castor yield, cost benefit ratio was worked out.

RESULTS AND DISCUSSION

The results of the experiment carried out during *kharif* 2015 revealed that the combination of castor with intercrops confirmed significant differences in insect population with each other (Tables 1 and 2). Defoliators population was significantly lesser in castor + red gram + pearl millet intercropped treatments (T_3) than in the sole castor crop which was served as control (T_8). The cumulative mean number of sucking pest population was found to be lesser in T_1 (castor + red gram), followed by treatments, T_3 (castor + red gram + pearl millet). Capsule borer percentage infestation significantly lesser in castor + red gram + pearl millet intercropped treatments (T_3). Thus, the sole crop control T_8 had the more defoliators, sucking pest population and capsule borer damage during *kharif* 2015. It has been shown that, castor main crop, when raised with green gram as intercrop significantly increased the percentage parasitization by *Microplitis maculipennis* and *Apanteles angaleti* by 53 and 21%, respectively. During *rabi* 2016 also the same trend has been observed (Table 2). Defoliators population was significantly lesser in castor + red gram + pearl millet intercropped treatments (T_3) than in the sole castor crop which was served as control (T_8). The cumulative mean number of sucking pest population was found to be lesser in T_1 (castor + red gram), followed by treatments T_3 (castor + red gram + pearl millet). Capsule borer percentage infestation significantly lesser in castor + red gram + pearl millet intercropped treatments (T_3). Castor when intercropped with red gram and pearl millet significantly reduced the defoliators population by harbouring natural parasitization by *Microplitis maculipennis* and *Apanteles angaleti.* The maximum parasitization by *Microplitis maculipennis* (73.0 and 24.2 percentage) on semilooper larvae were observed during *kharif* 2015 and *rabi* 2016, respectively.

Table 1 Population dynamics of insect pest and natural enemies of castor under different intercrops (*kharif,* 2015)

Treatments	Defoliators (No. of larvae/plant)*			Sucking pest population*		Capsule borer* (% damage)@	Parasitoids*	
	Semilooper#	Tobacco caterpillar#	Hairy caterpillar#	Leafhopper (No./3leaves/ plant)#	Thrips (No./spike)#		*Microplitis macullipennis* % parasitization@	*Apanteles angaleti* % parasitization@
T_1 Castor + Red gram	3.6(2.14)	4.6(2.36)	3.3(2.07)	8.6(3.09)	18.3(4.38)	5.3(2.50)	71(62.73)	25(4.34)
T_2 Castor + Pearl millet	4.3(2.29)	3.3(2.07)	2.6(1.89)	9.3(3.20)	17.6(4.30)	4.6(2.36)	56(46.13)	23(3.45)
T_3 Castor + Red gram + Pearl millet	3.3(2.07)	2.3(1.81)	2.3(1.81)	10.3(3.35)	11.3(3.49)	3.3(2.07)	73(59.08)	30(4.11)
T_4 Castor + Groundnut	6.3(2.69)	15.6(4.06)	4.6(2.36)	18.3(4.38)	20.3(4.60)	6.6(2.75)	60(44.39)	24(2.64)
T_5 Castor + Green gram	4.3(2.29)	10.3(03.35	3.6(2.14)	19.6(4.52)	15.6(4.06)	5.6(2.56)	53(46.13)	21(3.86)
T_6 Castor + Groundnut + Green gram	5.6(2.56)	12.6(3.67)	4.3(2.29)	22.3(4.81)	22.3(4.81)	6.3(2.69)	57(44.97)	29(4.23)
T_7 Castor + Daincha	8.3(3.04)	8.3(3.04)	5.6(2.56)	18.6(4.41)	16.3(4.14)	7.3(2.87)	63(52.64)	31(4.57)
T_8 Castor	10.3(3.35)	11.3(3.49)	6.6(2.75)	26.3(5.21)	29.3(5.49)	9.6(3.24)	60(48.46)	25(3.15)
CD (p=0.05)	0.38	0.47	0.31	0.67	0.71	0.38	12.38	0.60
SEd (±)	0.17	0.21	0.14	0.31	0.33	0.18	5.72	0.28
CV (%)	8.39	8.93	7.87	9.26	9.16	8.35	13.85	9.02

*Mean of three replications; #Figures in parentheses are square root transformed values; @Figures in parentheses are arc sine transformed values

Table 2 Population dynamics of insect pest and natural enemies of castor under different intercrops (*rabi,* 2015)

Treatments	Defoliators (No. of larvae/plant)*			Sucking pest population*			Capsule borer* (% damage)@	Predators and Parasitoids*		
	Semilooper#	Tobacco caterpillar#	Hairy caterpillar#	Leafhopper (No./3leaves/ plant) #	Thrips (No./spike)#	Whiteflies (No./leaf) #		*N. regularis* (No./leaf)#	*C. nigrita* (No./leaf)#	*M. maculipennis* % parasitization@
T_1 Castor + Red gram	1.30(1.51)	1.4(1.54)	3.5(2.11)	2.2(1.78)	30.5(5.59)	34.2(5.91)	2.2(8.50)	2.20(1.78)	6.20(2.67)	22.2(28.03)
T_2 Castor + Pearl millet	0.60(1.26)	3.4(2.09)	1.8(1.67)	3.9(2.21)	28.5(5.41)	26.2(5.20)	1.9(7.90)	1.20(1.48)	3.40(2.09)	7.1(15.40)
T_3 Castor + Red gram + Pearl millet	0.30(1.14)	0.4(1.18)	0.5(1.22)	2.1(1.75)	21.8(4.76)	28.6(5.42)	0.6(4.42)	2.80(1.94)	6.80(2.78)	24.2(29.39)
T_4 Castor + Groundnut	5.10(2.46)	13.1(3.74)	4.5(2.34)	6.2(2.67)	30.8(5.62)	16.2(4.13)	3.9(11.35)	1.50(1.58)	2.40(1.84)	11.2(19.49)
T_5 Castor + Green gram	3.90(2.21)	9.1(3.17)	2.5(1.86)	7.1(2.84)	25.8(5.16)	26.2(5.20)	2.6(9.25)	2.60(1.89)	6.60(2.75)	4.3(11.93)
T_6 Castor + Groundnut + Greengram	5.00(2.44)	14.1(3.87)	3.1(2.02)	5.2(2.48)	33.5(5.85)	24.2(5.00)	3.1(10.11)	2.70(1.92)	6.50(2.73)	8.5(16.90)
T_7 Castor + Daincha	5.90(2.62)	8.4(3.05)	5.5(2.54)	8.3(3.04)	25.5(5.13)	29.4(5.49)	4.1(11.65)	1.40(1.54)	3.20(2.04)	14.6(22.39)
T_8 Castor	6.80(2.78)	9.2(3.18)	8.2(3.02)	10.2(3.33)	41.8(6.52)	40.2(6.40)	6.2(14.37)	1.80(1.67)	4.20(2.27)	10.8(19.12)
CD (p=0.05)	0.29	0.43	0.29	0.37	0.90	0.88	1.75	0.19	0.33	3.85
SEd (±)	0.13	0.20	0.13	0.17	0.41	0.40	0.81	0.09	0.15	1.77
CV (%)	8.15	9.09	7.99	8.46	9.30	9.32	10.25	6.39	7.92	10.71

*Mean of three replications; #Figures in parentheses are square root transformed values; @Figures in parentheses are arc sine transformed values

Table 3 Economics of castor intercrops during *kharif* and *rabi* 2015

Treatments	*Kharif* 2015		*Rabi* 2015	
	Yield (kg/ha)	B:C ratio	Yield (kg/ha)	B:C ratio
T_1 Castor + Red gram	1757	1.72	1420	1.39
T_2 Castor + Pearl millet	1720	1.69	1530	1.50
T_3 Castor + Red gram + Pearl millet	1615	1.58	1395	1.37
T_4 Castor + Groundnut	1735	1.70	1650	1.62
T_5 Castor + Green gram	1691	1.66	1590	1.56
T_6 Castor + Groundnut + Green gram	1720	1.69	1610	1.58
T_7 Castor + Daincha	1640	1.61	1360	1.33
T_8 Castor	1751	1.72	1480	1.45
CD (p=0.05)	632.2	-	499.7	-
SEd (±)	294.7	-	232.9	-
CV (%)	21.2	-	18.9	-

With reference to whiteflies population during *rabi* 2016 (Table 2), treatment T_4 had the lesser population 16.2 whiteflies/leaf as against the maximum population of 40.2 in sole castor crop. The maximum population of coccinellids *viz., Nephus regularis* (2.80) and *Chilocorus nigrita* (6.80) were recorded during *rabi* 2016 in T3 (castor + red gram + pearl millet). Rao *et al.* (2012) reported that the intercropping systems castor + pigeon pea recorded significantly lower population levels of *A. janata* (0.89) as compared to higher level population in castor monocrop (1.12 to 1.29/plant). Result of the present study was also in concurrence with the report of Midega and Khan (2003). They reported that border crops increased the abundance of natural enemies like *Cheilomenes* sp., *Chrysoperla* sp., ants, ear wigs and spiders concurrently with reducing target insect pests in main crop. Similarly the sucking pest population during *kharif* 2015 and *rabi* 2016 had the lesser population in treatments T_1, T_2, T_3 (red gram, pearl millet) as against the highest population in sole castor crop T_8. The treatment included tall crop as intercrops recorded lesser population of sucking pests than short crops in T_4, T_5, T_6 (groundnut, green gram). Alegbejo and Uvah (1986) reported that high, tall, barrier crops may act as mechanical barriers that impede insect colonization on the protected crop. Diversity in the crop field may have a profound effect on colonization by insects, and has been well-documented in the case of intercropping (Risch *et al.,* 1983). Baliddawa (1985) observed that up to 30% of pest reduction in intercropping systems could be due to the "natural enemy effect".From the above results it is concluded that castor crop intercropped with taller, pollen yielding, fast growing cereals and pulse crops like pearl millet and red gram reduce the pest

population and increase the activity of natural enemies with increased yield in castor.

REFERENCES

Alegbejo M D and Uvah I 1986. Effect of intercropping pepper with tall crops on the incidence of pepper veinal mottle virus disease on pepper. *Nigerian Journal of Entomology*, **7**: 2-87.

Anonymous 2006. *Annual Progress Report - Castor 2005-06.* Directorate of Oilseeds Research, Hyderabad.

Baliddawa C W 1985. Plant species diversity and crop pest control - an analytical review. *Insect Science and its Application*, **6**(4): 479-487.

Bharathi E and Duraimurugan P 2022. Pathogenicity of entomopathogenic fungi Beauveria bassiana and *Metarhizium* (Nomuraea) *rileyi* against castor hairy caterpillar, *Euproctis fraterna* (Lepidoptera: Lymantriidae). *Journal of Oilseeds Research*, **39**(1): 58-60.

Suganthy M 2012. Bio-efficacy of newer insecticides on castor capsule borer, *Dichocrocis punctiferalis* Guenee. *Journal of Oilseeds Research*, **29**: 65-66.

Midega C A O and Khan Z R 2003. Impact of a habitat management system on diversity and abundance of maize stem borer predators in western Kenya. *Insect Science and its Application,* **23**: 301-308.

Patel M M, Naik M M, Vyas H N and Patel A T 1986. Evaluation of certain insecticides against whitefly (*Trialeurodes ricini* Misra) and jassid (*Empoasca kerri* Pruthi) infesting castor. *Indian Journal of Plant Protection*, **14**(1): 81-82.

Lakshminarayana M and Duraimurugan P 2014. Assessment of avoidable yield losses due to insect pests in castor (*Ricinus communis* L.). *Journal of Oilseeds Research*, **31**(2): 140-144.

Rao M S, Rama Rao C A, Srinivas K, Pratibha G, Vidya Sekhar S M, Sree Vani G and Venkatswarlu B 2012. Intercropping for management of insect pests of castor, *Ricinus communis,* in the semi-arid tropics of India. *Journal of Insect Science*, **12**: 14 .

Risch S J, Andow D amd Altieri M A 1983. Agro-ecosystem diversity and pest control: data, tentative conclusions and new research directions. *Environmental Entomology*, **12**: 625-662.

Price behaviour of groundnut (*Arachis hypogaea* L.) in major markets of India

BHOOMI SUTHAR*, R S PUNDIR AND VIJAY BALDODIYA

B A College of Agriculture, Anand Agricultural University, Anand-388 110, Gujarat

(Received: June 2, 2022; Revised: June 20, 2022; Accepted: June 22, 2022)

ABSTRACT

Groundnut is the major oilseed crop in India and it is growing many states of the country. Market integration concept explain the relationship between the markets that are spatially or temporally separated. The study was based on secondary data from 2002 to 2019. Mandies were selected namely, Gondal and Rajkot (Gujarat), Bikaner and Chomu (Rajasthan), Avalurpet and Tindivanam (Tamil Nadu), Adoni and Kurnool (Andhra Pradesh), Yadgir and Laxmeshwar (Karnataka). Augmented Dickey Fuller test (ADF), Johansen' Co-integration, Vector Error Correction Model and Granger Causality test were used for analysis. The results of ADF showed that original series were non stationary and after differencing the series at order one it became stationary. It was found that nine groundnut markets were found cointegrated among ten markets. The results of vector error correction showed that the estimated short-term coefficients of the groundnut markets in Adoni, Chomu, Kurnool, and Laxmeshwar were 5.39 per cent, 16.78 per cent, 8.54 per cent, and 11.04 per cent, respectively, and they were corrected within a month by changes in their own prices, with the remainder influenced by other market forces. Prices of groundnut in Gondal market had bidirectional causality with Bikaner, Kurnool, Laxmeshwar, Rajkot and Yadgir markets.

Keywords: Augmented Dickey Fuller test, Granger Causality test, Groundnut, Vector Error Correction Model

India is the world's largest producer of oilseeds and the oilseed sector plays a significant role in the country's agrarian economy. Apart from cereals, oilseeds are one of the most important crops in our country (Kadirvel *et al.,* 2021). Oilseeds in India are grown during rainy (*kharif*) as well winter (*rabi*) seasons and comprise nine annual crops *viz.,* groundnut, soybean, rapeseed, mustard, sesame, niger, sunflower, safflower and castor (Chauhan *et al.,* 2021). Markets are more vibrant and transparent in their integration in the age of globalization. The degree of price transmission between two connected markets, either vertically or regionally, is referred to as market integration. Integrated markets can be defined as markets in which prices of the comparable goods do not behave independently. In an integrated market, price of a commodity is responsive to price changes of the same quality products in other markets (Mahesh *et al.,* 2018). The law of one price (LOOP) is the operational definition of market integration, which states that identical products are offered at the same price in all market places. Market integration occurs when prices among different location follows similar pattern over a long period of time. The concept of market integration describes the relationship between markets that are spatially or temporally separated. The study on integration can suggest products as to where, when, and how much to sell, which will have an impact on farmers' production strategies and resource allocation. Market integration occurs when prices among different locations or related goods follow similar patterns over a period of time (Nayak *et al.,* 2020). Although several studies have been done empirically using cointegration techniques which concern the market integration of agricultural commodities in India (Kar *et al.,* 2004; Jha *et al.,* 2005; Yogisha, 2005; Shenoy, 2008; Reddy *et al.,* 2012). Vector Error Correction Model (VECM) was employed to know the speed of adjustments among the markets for long run equilibrium. Granger causality test was applied in order to find out the dominating market for price formulation as well as the direction of information flow. Gujarat, Telangana, Rajasthan, Uttar Pradesh, Karnataka, Madhya Pradesh, Tamil Nadu, Andhra Pradesh are the major states for groundnut arrivals followed by Maharashtra and Chhattisgarh. Fluctuations in market arrivals contribute significantly to produce price volatility. To devise appropriate methods and means of reducing agricultural commodity price fluctuations, a thorough understanding of price behaviour over time and space is required. This type of analysis is also beneficial to farmers in determining the best time to dispose of their produce. Analyzing the price behaviour of agricultural commodities is important for maximising surpluses or returns for both farmers and consumers. Research of market integration of regulated markets in India will provide a foundation for farmers and agricultural policy makers. In this regard, critical analysis may be useful in identifying the issues and formulating an appropriate strategy for the growth of agricultural marketing.

During 2019 maximum arrivals of groundnut was in Gujarat (5.72 lakh tons), followed by Telangana (2.73 lakh tons) and Rajasthan (2.46 lakh tons). In Gujarat Gondal (2.27 lakh tons) and Rajkot (0.55 lakh tons) are the major markets of groundnut, in terms of arrivals. The growers, the oil industry, and the customers are also involved in determining the price of groundnuts and groundnut products. The price

*Corresponding author's E-mail: bhoomisuthar1@gmail.com

paid to groundnut growers is also influenced by variations in the quality of matured groundnuts, shell size, groundnut content, oil content, marketing costs, and marketing strategies for fresh groundnut output.

MATERIALS AND METHODS

Groundnut is the major oilseed crop in India and it is growing many states of the country. States were selected on the basis of their triennium average groundnut production from the year 2016-17 to 2018-19. The selected states namely Gujarat, Rajasthan, Tamil Nadu, Andhra Pradesh and Karnataka. After selection of major groundnut producing states agricultural markets (mandies) were selected. Two mandies from selected states were selected based on triennium highest arrivals from the year 2017 to 2019. Mandies were selected namely, Gondal and Rajkot (Gujarat), Bikaner and Chomu (Rajasthan), Avalurpet and Tindivanam (Tamil Nadu), Adoni and Kurnool (Andhra Pradesh), Yadgir and Laxmeshwar (Karnataka). Time series data regarding monthly wholesale prices of groundnut were collected from secondary sources like Agmark.net and Department of Agricultural Marketing.

Augmented Dickey Fuller test: Co-integration test is used to examine the study whether or not two markets are co integrated. Before performing the co-integration test, however, the data must be verified whether it is stationary or not, because the lack of stationarity makes the relationship spurious as well as meaningless. A statistical test for stationarity or unit root has been proposed by Dickey and Fuller (1979).

ADF test consist of estimating the following regression.

$$\Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \sum_{i=1}^{p} \alpha_i \Delta Y_{t-i} + \varepsilon_t \quad (1)$$

Where,
Y_t = Price of groundnut market at time t
ε_t is a pure white noise error term
$\Delta Y_{t-1}=(Y_{t-1}-Y_{t-2})$, $\Delta Y_{t-2}=(Y_{t-2}-Y_{t-3})$, (t-i-lagged prices and Δ is differenced series)
α is the drift parameter
t is the time trend effect, β_i, δ_i and b_i is coefficients p is the optimal lag value which is selected on the basis of Schwartz Basic Criteria (SBC).

The null hypothesis that, $\delta=0$; signifying unit root, states that the time series is nonstationary, while the alternative hypothesis, $\delta<0$, signifies that the time series is stationary, thereby rejecting the null hypothesis.

Johansen' Co-integration Test: Johansen and Juselius (1990) developed Co-integration test to test the long run relationship among the price series and likelihood ratio test statistics are proposed to test number of co-integrating vectors. Trace statistic and maximum Eigen values are used to test the null hypothesis of at most 'r' co-integrating vectors against 'more than r' (the alternative hypothesis co-integrating vectors.

$$J_{trace} = -T \sum_{i=r+1}^{n} \ln(1-\hat{\lambda}_i) \quad (2)$$

$$J_{max} = -T \ln(1-\lambda\square_i+1) \quad (3)$$

λ_i s are the estimated Eigen values (characteristic roots) obtained from the Π markets T is the number of usable observations. The number of co-integrating vectors indicated by the tests is an important indicator of the existence of co-movement of the prices. As the number of co-integrating vectors increases, it implies the strength and stability of price linkages.

Error Correction Model: Even after confirming the existence of a long-term equilibrium in the market pairs, there is a possibility of short-run disequilibrium, due to which, the price change in one market may not get transmitted immediately to the other market and takes some time for such transmission. The error correction mechanism (ECM) first used by Sargan (1964) and later popularized by Engle and Granger (1987) corrects for disequilibrium.

Error Correction Model (ECM) which is given below in the following specification:

$$\Delta Y_{t-i} = \alpha_0 + \alpha_1 \Delta X_{t-i} + \alpha_2 e_{t-1} + t \quad (4)$$

Where;
$\Delta Y_{t-i}=Y_{t-1}-Y_{t-2}$
α_0=Constant term
α_1, α_2 = Speed of price transmission
e_{t-1} = Lagged error term of the co-integration model &
t= White noise error-term

In this manner, the speed of adjustment towards the long-run path was ascertained as otherwise the integration between the market pairs may not be perfect. In the above equation the magnitude of α_2 explains the speed at which the price approaches equilibrium and it is expected to be negative, so that the equilibrium is restored in the long-run.

Granger Causality Test: Granger Causality test: Granger causality test provides testing whether variable X_t causes variable Y_t and vice versa. All permutations are possible: unidirectional Granger causality from X_t to Y_t or from Y_t to X_t , bidirectional causality or absence of causality.

$$X_t = \sum_{i=1}^{n} \alpha_i Y_{t-i} + \sum_{j}^{n} 1\ \beta_j X_{t-j} + \mu_{1t}$$

$$Y_t = \sum_{i=1}^{n} \gamma_i Y_{t-i} + \sum_{j}^{n} 1\ \delta_j X_{t-j} + \mu_{2t}$$

Where, X and Y are the price series of different markets t is the time period $\alpha, \beta, \gamma, \delta$ are coefficients of respective price series μ_{1t} and μ_{2t} are the error terms.

RESULTS AND DISCUSSION

Augmented-Dickey Fuller test: Before starting any statistical test it is essential to check stationarity of price series. The Augmented Dickey Fuller (ADF) based unit root test procedure is used to check whether price series of groundnut market are stationary or not. Results of ADF unit root test for prices of groundnut is presented in Table 1. Results of ADF test showed that original series were non stationary based on the probability value which was greater than five per cent and the null hypothesis was accepted which indicate the presence of a unit root problem. After first order differencing series became stationary. Here, differencing was not required for prices of Yadgir market because probability value was found to be less than five per cent, so series were stationary at level. Number of lags was assumed one in Johansen cointegration method and vector error correction method.

Johansen cointegration: Based on the Johansen cointegration procedure, the integration among selected groundnut market in India was analyzed using E-views 11 programme. Trace statistic and Eigen value were recorded in Table 2. It was evident from the table that nine groundnut markets were found cointegrated among ten markets. Thus, it indicated that the model variables have a long-run equilibrium/co-movement among the market price series during the period under study. Existence of co-integration is necessary for long-term market efficiency, even if in geographical dispersion of markets groundnut prices were integrated. Anonymous (2021) obtained four co-integration equation indicated that variables had co-movement among prices in their study.

Vector Error Correction Model (VECM): The coefficient of error correction model for groundnut crop indicated that speed of adjustment at which price series return to equilibrium. The negative sign indicated that market price bounce back to equilibrium after shock in their own price and positive error correction coefficient showed that absence or long away from equilibrium. The results of the estimated model have been presented in Table 3.

The estimated negative short-term coefficient revealed in Adoni, Avalurpet Chomu, Kurnool, Laxmeshwar and Tindivanam groundnut markets were 5.00 per cent, 2.00 per cent, 16.00 per cent, 8.00 per cent, 11.00 per cent and 4.00 per cent disequilibrium, respectively and they got corrected within a month by changes in its own prices and remaining was influenced by other market forces. However, the coefficient of own lagged price of Avalurpet, Bikaner and Rajkot were found at five per cent level of significance. While, Kurnool and Laxmeshwar were found one per cent and ten per cent level of significance with impact of taking one month lag period. For Avalurpet, Bikaner, Kurnool, Laxmeshwar, and Rajkot groundnut markets speed of convergence of short run price movement along with long run equilibrium were found 22.00 per cent, 12.00 per cent, 30.00 per cent, 12.00 per cent and Rajkot 19.00 per cent, respectively. It was also revealed that the impact of its own price got corrected within one month lag period with its convergence speed.

In Avalurpet market price model the coefficient of own one month (-0.22) lagged price was negative and significant at five per cent level, coefficient of one month (0.17) lagged price of Bikaner was positive and significant at ten per cent level. While coefficient of one month lagged price Gondal (0.32) and Tindivanam (0.24) were found positively significant at five and one per cent, respectively. It means Avalurpet market prices were influenced by Bikaner, Gondal, Tindivanam and own market with one month lag period. Bikaner market prices were influenced by the price changes in other groundnut markets *viz.,* Adoni, Gondal, Tindivamam, Yadgir and own monthly lagged price in long run. These results are supporting by Anonymous (2021) who also found that groundnut prices in Bikaner market were in influenced by Prices in Tindivanam market. Chomu market prices were influenced by lagged prices of Bikaner, Gondal, Laxmeshwar, Rajkot and Yadgir. Gondal market prices model the coefficient of one month lagged price of Bikaner (0.32) and Chomu (-0.15) were positive and significant at one per cent level, while coefficient of Avalurpet (0.08) and Tindivanam (0.07) were positive and significant at five per dent and ten per cent level, respectively. So, it was revealed from the results that prices in Gondal market were influenced by one month lag prices of Avalurpet, Bikaner, Chomu and Tindivanam markets.

Kurnool market prices were influenced by lagged prices Adoni, Avalurpet, Yadgir at positively one per cent level of significance. While, it was influenced by one month lag prices of Tindivanam market at positively five per cent level of significance. Prices of Kurnool market was also influenced by Rajkot and own market prices at negatively one per cent level of significance. Price discovered in Rajkot markets were transmitted to Chomu, Kurnool, Laxmeshwar, Tindivanam and Yadgir markets.

Granger causality between market pairs: Granger causality test was applied in order to find out the dominating

market for price formulation as well as the direction of information flow. The results are presented in Table 4. Gondal market caused bidirectional price transmission with Bikaner, Kurnool, Laxmeshwar, Rajkot and Yadgir. It was also found Gondal markets had unidirectional price transmission with Avalurpet, Chomu and Tindivanam. The wholesale prices in Gondal market has no influence at all on the wholesale prices in Adoni market. The wholesale prices in Rajkot market had a bidirectional prices transmission with market namely, Adoni, Bikaner, Gondal, Kurnool, Laxmeshwar and Yadgir. These results are in line with Venujayakanth *et al.* (2017) who found that Rajkot markets had bidirectional price transmission with Kurnool market.

Bikaner market has bidirectional causality with all selected the markets. Bidirectional causality was found for the pair of Avalurpet markets with Adoni, Bikaner, Kurnool, Laxmeshwar and Yadgir. Unidirectional causality were found for the pair of Avalurpet market with Chomu and Tindivanam markets indicated that price of Avalurpet market influence the price of Chomu and Tindivanam market. Chomu markets have bidirectional relationship with Adoni and Laxmeshwar markets. Kurnool market influenced the groundnut price in Chomu, Laxmeshwar and Tindivanam market. Price discovery in Kurnool market was transmit to Chomu, Laxmeshwar and Tindivanam markets. It was also found that Kurnool market had bidirectional relationship with Adoni, Avalurpet, Bikaner, Gondal, Rajkot and Yadgir. Thus, a strong integration of major groundnut markets in India confirmed that the price of one market influenced the price of other markets. Yadgir markets was found with bidirectional relation with Adoni, Avalurpet, Bikaner, Gondal, Kurnool, Laxmeshwar, Rajkot and Tindivanam. Price transmission revealed that bidirectional relationships exist within domestic markets which indicated the price transmission happening in short run adjustments and presence of long run equilibrium existed among the groundnut markets in Andhra Pradesh, Tamil Nadu, Rajasthan, Gujarat and Karnataka. Thus, it implies that strong integration existed between selected of major groundnut markets in India.

Table 1 ADF unit root test for prices of groundnut

Groundnut markets	Augmented Dickey Fuller Test	
	Level	First difference
Rajkot	-1.68 (0.43)	-14.24** (0.00)
Gondal	-2.03 (0.27)	-10.77** (0.00)
Bikaner	-1.77 (0.39)	-12.61** (0.00)
Chomu	-1.81 (0.39)	-15.63** (0.00)
Adoni	-1.75 (0.40)	-12.24** (0.00)
Kurnool	-1.86 (0.34)	-12.89** (0.00)
Yadgir	-4.08 (0.00)	-
Laxmeshwar	-1.44 (0.55)	-14.17** (0.00)
Tindivanam	-1.85 (0.35)	-13.39** (0.00)
Avalurpet	-1.55 (0.40)	-14.18** (0.00)

Note: ** Significant at 5 per cent level; Figure in parenthesis indicates MacKinnon (1996) p value

Table 2 Johansen's co-integration test results for groundnut markets of India

Hypothesized No. of CE(s)	Eigen value	Trace Statistic	0.05 Critical Value	Prob**
None *	0.47	588.53	239.23	0.00
At most 1 *	0.37	449.17	197.37	0.00
At most 2 *	0.33	348.41	159.52	0.00
At most 3*	0.31	259.96	125.61	0.00
At most 4 *	0.26	180.27	95.75	0.00
At most 5 *	0.18	115.21	69.81	0.00
At most 6 *	0.13	70.23	47.85	0.00
At most 7 *	0.09	38.00	29.79	0.00
At most 8*	0.06	15.52	15.49	0.04
At most 9	0.01	1.66	3.84	0.19

Trace test indicates 9 co-integrating eqn(s) at the 0.05 level; * denotes rejection of the hypothesis at the 0.05 level; **MacKinnon-Haug-Michelis (1999) p-values

Table 3 Vector Error Correction Model (VECM) estimates for selected groundnut markets

Error Correction	D(AD)	D(AV)	D(BK)	D (CM)	D(GD)	D(KR)	D (LX)	D (RJ)	D (TD)	D (YD)
CointEq1	-0.05	-0.02	0.03	-0.16	0.07	-0.08	-0.11	0.06	-0.04	0.14
	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)	(0.04)	(0.06)
	[1.74**]	[0.73]	[1.19]	[5.75***]	[3.26***]	[3.42***]	[3.39***]	[3.24***]	[1.06]	[2.34**]
D(AD(-1))	-0.01	0.17	0.09	0.01	0.06	0.19	0.13	-0.03	0.24	-0.02
	(0.08)	(0.10)	(0.06)	(0.07)	(0.05)	(0.06)	(0.08)	(0.05)	(0.11)	(0.16)
	[0.19]	[1.69]	[1.45*]	[0.16]	[1.09]	[2.92***]	[1.58*]	[0.65]	[2.20**]	[0.16]
D (AV(-1))	0.00	-0.22	-0.04	-0.05	0.08	0.15	-0.04	0.00	0.33	0.52
	(0.06)	(0.08)	(0.05)	(0.06)	(0.04)	(0.05)	(0.07)	(0.04)	(0.09)	(0.13)
	[0.03]	[2.61***]	[0.75]	[0.94]	[1.70**]	[2.78***]	[0.61]	[0.02]	[3.48***]	(3.74***)
D (BK(-1))	0.07	0.17	-0.12	0.20	0.32	-0.06	0.03	0.18	0.05	-0.17
	(0.09)	(0.11)	(0.07)	(0.08)	(0.06)	(0.07)	(0.09)	(0.06)	(0.13)	(0.19)
	[0.76]	[1.49*]	[1.64**]	[2.28**]	[5.04***]	[0.88]	[0.35]	[2.85***]	[0.44]	[0.90]
D (CM(-1))	-0.07	-0.07	0.00	0.03	-0.15	0.09	0.12	-0.18	-0.27	-0.05
	(0.07)	(0.09)	(0.06)	(0.06)	(0.05)	(0.05)	(0.07)	(0.04)	(0.10)	(0.15)
	[0.99]	[0.83]	[0.03]	[0.49]	[2.96***]	[1.60*]	[1.59*]	[3.77***]	[2.62***]	[0.32]
D (GD(-1))	-0.01	0.32	-0.17	0.28	0.06	0.20	0.10	0.21	0.51	0.08
	(0.12)	(0.15)	(0.09)	(0.11)	(0.08)	(0.09)	(0.12)	(0.08)	(0.16)	(0.24)
	[0.09]	[2.09**]	[1.78**]	[2.48**]	[0.73]	[2.07**]	[0.79]	[2.67***]	[3.05***]	[0.33]
D (KR (-1))	0.18	0.04	-0.00	0.07	-0.03	-0.30	0.05	0.06	-0.05	-0.37
	(0.10)	(0.13)	(0.08)	(0.09)	(0.07)	(0.08)	(0.11)	(0.07)	(0.14)	(0.21)
	[1.74***]	[0.30]	[0.03]	[0.80]	[0.41]	[3.55***]	[0.52]	[0.84]	[0.36]	[1.73**]
D (LX(-1))	0.07	-0.14	0.07	0.17	-0.03	0.06	-0.12	0.01	-0.07	-0.07
	(0.07)	(0.10)	(0.06)	(0.07)	(0.05)	(0.06)	(0.08)	(0.05)	(0.11)	(0.16)
	[0.90]	[1.41]	[1.14]	[2.30**]	[0.68]	[0.95]	[1.53*]	[0.32]	[0.66]	[0.43]
D (RJ (-1))	-0.10	-0.09	0.03	-0.45	0.11	-0.29	-0.23	-0.19	-0.35	0.59
	(0.14)	(0.18)	(0.11)	(0.13)	(0.09)	(0.11)	(0.14)	(0.09)	(0.19)	(0.29)
	[0.75]	[0.53]	[0.31]	[3.41***]	[1.13]	[2.60***]	[1.59*]	[2.06**]	[1.76**]	[2.02**]
D (TD(-1))	-0.03	0.24	0.15	-0.02	0.07	0.11	0.06	0.11	-0.13	-0.29
	(0.06)	(0.07)	(0.05)	(0.05)	(0.04)	(0.04)	(0.06)	(0.04)	(0.08)	(0.12)
	[0.51]	[3.10***]	[3.18***]	[0.37]	[1.63*]	[2.22**]	[0.96]	[2.86***]	[1.58*]	[2.30**]
D (YD (-1))	0.03	0.02	0.06	-0.04	-0.02	0.11	0.02	0.01	0.10	-0.14
	(0.03)	(0.04)	(0.02)	(0.03)	(0.02)	(0.02)	(0.03)	(0.02)	(0.04)	(0.06)
	[1.04]	[0.54]	[2.49**]	[1.56*]	[0.98]	[4.26***]	[0.68]	[0.66]	[2.23**]	[2.09**]
C	12.01	16.89	12.18	15.07	7.80	3.53	7.94	11.21	16.62	9.02
	(20.28)	(25.93)	(16.61)	(19.14)	(14.17)	(16.39)	(21.33)	(13.69)	(28.48)	(41.85)
	[0.59]	[0.65]	[0.73]	[0.78]	[0.55]	[0.21]	[0.37]	[0.81]	[0.58]	[0.21]

Note: AD- Adoni, AV- Avaluepet, BK- Bikaner, CM- Chomu, GD- Gondal, KR- Kurnool, LX-Laxmeshwar, RJ-Rajkot, TD-Tindivanam and YD-Yadgir; *, ** and ***denotes significance at 10 per cent, 5 per cent and 1 per cent levels, respectively

Table 4 Pair wise Granger causality test of groundnut price for selected groundnut markets

Null Hypothesis	Obs.	F- Statistic	Prob.	Dir.
AVALURPET does not Granger Cause ADONI	215	8.94***	0.00	Bi
ADONI does not Granger Cause AVALURPET		23.86***	0.00	
BIKANER does not Granger Cause ADONI	215	9.98***	0.00	Bi
ADONI does not Granger Cause BIKANER		15.55***	0.00	
CHOMU does not Granger Cause ADONI	215	4.61**	0.03	Bi
ADONI does not Granger Cause CHOMU		30.99***	0.00	
GONDAL does not Granger Cause ADONI	215	2.15	0.14	Uni
ADONI does not Granger Cause GONDAL		23.84***	0.00	
KURNOOL does not Granger Cause ADONI	215	10.10***	0.00	Bi
ADONI does not Granger Cause KURNOOL		23.56***	0.00	
LAXMESHWAR does not Granger Cause ADONI	215	8.56***	0.00	Bi
ADONI does not Granger Cause LAXMESHWAR		24.93***	0.00	
RAJKOT does not Granger Cause ADONI	215	9.63***	0.00	Bi
ADONI does not Granger Cause RAJKOT		13.52***	0.00	
TINDIVANAM does not Granger Cause ADONI	215	0.63	0.42	Uni
ADONI does not Granger Cause TINDIVANAM		29.53***	0.00	
YADGIR does not Granger Cause ADONI	215	29.79***	0.00	Bi
ADONI does not Granger Cause YADGIR		23.70***	0.00	
BIKANER does not Granger Cause AVALURPET	215	19.34***	0.00	Bi
AVALURPET does not Granger Cause BIKANER		8.24***	0.00	
CHOMU does not Granger Cause AVALURPET	215	0.64	0.42	Uni
AVALURPET does not Granger Cause CHOMU		48.73***	0.00	
GONDAL does not Granger Cause AVALURPET	215	13.81***	0.00	Uni
AVALURPET does not Granger Cause GONDAL		1.60	0.20	
KURNOOL does not Granger Cause AVALURPET	215	6.33**	0.01	Bi
AVALURPET does not Granger Cause KURNOOL		10.53***	0.00	
LAXMESHWAR does not Granger Cause AVALURPET	215	6.74***	0.01	Bi
AVALURPET does not Granger Cause LAXMESHWAR		22.68***	0.00	
RAJKOT does not Granger Cause AVALURPET	215	14.19***	0.00	Uni
AVALURPET does not Granger Cause RAJKOT		1.50	0.22	
TINDIVANAM does not Granger Cause AVALURPET	215	2.62	0.10	Uni
AVALURPET does not Granger Cause TINDIVANAM		19.35***	0.00	
YADGIR does not Granger Cause AVALURPET	215	28.92***	0.00	Bi
AVALURPET does not Granger Cause YADGIR		33.11***	0.00	
CHOMU does not Granger Cause BIKANER	215	8.53***	0.00	Bi
BIKANER does not Granger Cause CHOMU		33.77***	0.00	
GONDAL does not Granger Cause BIKANER	215	5.28**	0.02	Bi
BIKANER does not Granger Cause GONDAL		35.15***	0.00	
KURNOOL does not Granger Cause BIKANER	215	18.88**	0.00	Bi
BIKANER does not Granger Cause KURNOOL		8.77***	0.00	
LAXMESHWAR does not Granger Cause BIKANER	215	19.86***	0.00	Bi
BIKANER does not Granger Cause LAXMESHWAR		22.89***	0.00	
RAJKOT does not Granger Cause BIKANER	215	16.65***	0.00	Bi
BIKANER does not Granger Cause RAJKOT		23.60***	0.00	
TINDIVANAM does not Granger Cause BIKANER	215	4.00**	0.04	Bi

Table 4 (contd..)

BIKANER does not Granger Cause TINDIVANAM		18.87***	0.00	
YADGIR does not Granger Cause BIKANER	215	20.32***	0.00	Bi
BIKANER does not Granger Cause YADGIR		39.64***	0.00	
GONDAL does not Granger Cause CHOMU	215	28.06***	0.00	Uni
CHOMU does not Granger Cause GONDAL		0.39	0.53	
KURNOOL does not Granger Cause CHOMU	215	58.55***	0.00	Uni
CHOMU does not Granger Cause KURNOOL		0.51	0.47	
LAXMESHWAR does not Granger Cause CHOMU	215	34.62***	0.00	Bi
CHOMU does not Granger Cause LAXMESHWAR		8.19***	0.00	
RAJKOT does not Granger Cause CHOMU	215	34.87***	0.00	Uni
CHOMU does not Granger Cause RAJKOT		0.40	0.52	
TINDIVANAM does not Granger Cause CHOMU	215	40.36***	0.00	Uni
CHOMU does not Granger Cause TINDIVANAM		0.63	0.42	
YADGIR does not Granger Cause CHOMU	215	0.31	0.57	Uni
CHOMU does not Granger Cause YADGIR		50.34***	0.00	
KURNOOL does not Granger Cause GONDAL	215	9.68***	0.00	Bi
GONDAL does not Granger Cause KURNOOL		9.49***	0.00	
LAXMESHWAR does not Granger Cause GONDAL	215	12.36***	0.00	Bi
GONDAL does not Granger Cause LAXMESHWAR		25.20***	0.00	
RAJKOT does not Granger Cause GONDAL	215	4.77**	0.03	Bi
GONDAL does not Granger Cause RAJKOT		7.78***	0.00	
TIINDIVANAM does not Granger Cause GONDAL	215	0.00	0.94	Uni
GONDAL does not Granger Cause TIINDIVANAM		16.13***	0.00	
YADGIR does not Granger Cause GONDAL	215	5.52**	0.01	Bi
GONDAL does not Granger Cause YADGIR		34.66***	0.00	
LAXMEHWAR does not Granger Cause KURNOOL	215	1.13	0.28	Uni
KURNOOL does not Granger Cause LAXMEHWAR		23.93***	0.00	
RAJKOT does not Granger Cause KURNOOL	215	13.11***	0.00	Bi
KURNOOL does not Granger Cause RAJKOT		9.82***	0.00	
TINDIVANAM does not Granger Cause KURNOOL	215	1.33	0.25	Uni
KURNOOL does not Granger Cause TINDIVANAM		11.20***	0.00	
YADGIR does not Granger Cause KURNOOL	215	22.55***	0.00	Bi
KURNOOL does not Granger Cause YADGIR		25.28***	0.00	
RAJKOT does not Granger Cause LAXMESHWAR	215	28.61***	0.00	Bi
LAXMESHWAR does not Granger Cause RAJKOT		6.61***	0.01	
TINDIVANAM does not Granger Cause LAXMESHWAR	215	15.49***	0.00	Bi
LAXMESHWAR does not Granger Cause TINDIVANAM		11.02***	0.00	
YADGIR does not Granger Cause LAXMESHWAR	215	13.20***	0.00	Bi
LAXMESHWAR does not Granger Cause YADGIR		32.99***	0.00	
TINDIVANAM does not Granger Cause RAJKOT	215	0.39	0.53	Uni
RAJKOT does not Granger Cause TINDIVANAM		14.27***	0.00	
YADGIR does not Granger Cause RAJKOT	215	12.48***	0.00	Bi
RAJKOT does not Granger Cause YADGIR		42.44***	0.00	
YADGIR does not Granger Cause TINDIVANAM	215	40.59***	0.00	Bi
TINDIVANAM does not Granger Cause YADGIR		16.84***	0.00	

Note: ** and ***denotes significance at 5 per cent and 1 per cent levels, respectively; Uni: Unidirectional, Bi: Bidirectional

The study has examined cointegration, error correction and causality in major groundnut markets of India. ADF test showed that original series were non stationary indicates the presence of a unit root problem. After first order differencing series became stationary. The results of overall cointegration test have indicated that different wholesale groundnut markets in the country are well-integrated and have long-run price association across them. The estimated negative short-term coefficient revealed in Adoni, Avalurpet Chomu, Kurnool, Laxmeshwar and Tindivanam groundnut markets got corrected within a month by changes in its own prices and remaining was influenced by other market forces. Gondal market caused bidirectional price transmission with Bikaner, Kurnool, Laxmeshwar, Rajkot and Yadgir. Price discovery in Kurnool market was transmit to Chomu, Laxmeshwar and Tindivanam markets. It was also found that Kurnool market had bidirectional relationship with Adoni, Avalurpet, Bikaner, Gondal, Rajkot and Yadgir. The study of selected groundnut markets has shown that efficiency of marketing has not yet reached an optimal level as all markets were not bidirectional integrated. The reasons for this could be bad market intelligence, a slow transition between market information and bad physical infrastructure.

ACKNOWLEDGEMENTS

The authors are thankful to Department of Agricultural Economics, Anand Agricultural University and Centre for Agricultural Market Intelligence' under NAHEP-CAAST at Anand Agricultural University for providing necessary facilities.

REFERENCES

Anonymous 2021. *Commodity Report (Groundnut).* Centre for Agricultural Market Intelligence, NAHEP-CAAST, Anand.

Chauhan J S, Choudhury P R and Singh K H 2021. Production, varietal improvement programme and seed availability of annual oilseeds in India: Current scenario and future prospects. *Journal of Oilseeds Research*, **38**(1): 1-18.

Dickey D A and Fuller W A 1979. Distribution of the estimators for autoregressive time Series with a unit root. *Journal of American Statistical Association*, **74**: 427-431.

Engle R F and Granger C M 1987. Co-integration and error correction: *Representation, Estimation and Testing. Econometrica*, 251-276.

Jha R, Murthy K V B and Sharma A 2005. Market integration in wholesale rice markets in India. *Working Paper 3.* Australian National University, Canberra.

Johansen S and Juselius K 1990. Maximum likelihood estimation and inference on cointegration with applications to the demand for money. *Oxford Bulletin of Economics and Statistics*, **52**(2): 169-210.

Kadirvel P, Kumar C, Basavaraj P S, Geethanjali S, Reddy Y R, Rahul V D and Senthilvel S 2021. Current scenario of marker-assisted selection in breeding of minor oilseed crops of India. *Journal of Oilseeds Research*, **38**(4): 303-319.

Kar A, Atteri R B and Kumar P 2004. Marketing infrastructure in Himachal Pradesh and integration of Indian apple markets. *Indian Journal of Agricultural Marketing*, **18**(3): 243-261.

MacKinnon J G, Haug A A and Michelis L 1999. Numerical distribution function of likelihood ratio tests for co-integration. *Journal of Applied Econometrics*, **14**: 563-577.

Mahesh V, Grover R K and Geetha R S 2018. Market integration of selected cotton markets in Haryana. *Agriculture Science Digest*, **38**(4): 260-264.

Nayak A, Lokesha H and Gracy C P 2020. Co-integration of groundnut markets in India with special reference to Karnataka state. *Current Journal of Applied Science and Technology*, **39**(18): 14-20.

Reddy B S, Chandrashekhar S M, Dikshit A K and Manohar N S 2012. Price trend and integration of wholesale markets for onion in metro cities of India. *Journal of Economics and Sustainable Development*, **3**(70): 120-130.

Sargan J D 1964. Wages and Prices in the United Kingdom: A study in Econometric Methodology, In: P E Hart, G Mills and J K Whitaker (Eds.), *Econometric Analysis for National Economic Planning,* Butterworths, London.

Shenoy A 2008. The Integration of the Indian wheat sector into the global market. *Working Paper 353.* Stanford Centre for International Development, Stanford University, Stanford.

Venujayakanth B, Dudhat A S, Swaminathan B and Ardeshana N J 2017. Price integration analysis of major groundnut domestic markets in India. *Economic Affairs*, **62**(2): 233-241.

Studies on genetic variability in sesame (*Sesamum indicum* L.)

S SASIPRIYA*, K PARIMALA, K B ESWARI AND M BALRAM

College of Agri., Prof. Jayashankar Telangana State Agril. University, Rajendranagar, Hyderabad-500 030, Telangana

(Received: April 19, 2022; Revised: May 25, 2022; Accepted: May 30, 2022)

ABSTRACT

A study was carried out using 45 genotypes of sesame to evaluate the genetic variability parameters at Seed Research and Technology Centre, Hyderabad during late *kharif,* 2017. Analysis of variance indicated the presence of highly significant differences among the genotypes for the traits under consideration. The genotype, Julang Sesame and NI8-8316 recorded the highest seed yield per plant. Seed yield per plant recorded the highest GCV and PCV followed by 1000-seed weight and number of seeds per capsule. Days to 50% flowering and capsule length showed comparatively lower GCV and PCV values. High heritability coupled with high estimates of genetic advance as per cent of mean was exhibited by 1000-seed weight followed by number of seeds per capsule, number of branches per plant and number of capsules per plant, suggesting a simple selection may reward their improvement. On the other hand, traits such as days to 50% flowering, plant height and capsule length recorded high values of heritability and moderate values of genetic advance as per cent of mean suggesting their governance by non- additive gene action.

Keywords: Sesame, Genetic variability, Heritability

Sesame (*Sesamum indicum* L.) is one of the oldest cultivated oilseed crops of India. It is a warm weather crop and often grown under marginal or stressed conditions. Distribution of genetic diversity in a plant species depends on its evolution and breeding system, ecological and geographical factors and often on human activities (Ramanatha and Hodgkin, 2002). Morphology has been a primary tool to estimate genetic differences among sesame genotypes. Several studies based on morphological markers have shown high genetic diversity in sesame populations (Arriel *et al.,* 2007; Kumhar and Rajani, 2021). Information on the extent and pattern of genotypic and phenotypic variability along with heritability of the traits present in the population plays a crucial role in further improvement of the crop (Rajitha *et al.,* 2021). Traditional landraces as well as related wild species are important sources of genetic diversity for breeders and form the backbone of agricultural production. Availability of natural diversity also aids in categorization and utilization of these germplasm in breeding programme. Therefore, the present study was aims to assess the genetic variability of sesame.

The material for the present study consisted of 43 germplasm lines with two checks namely Swetha Til and Rajeswari sown in the experimental farm at Seed Research and Technology Centre, Rajendranagar, Hyderabad. The experiment was laid out in a Randomized Block Design (RBD) with three replications during August, 2017. Each entry was sown with a spacing of 30 cm between rows and 10 cm between plants. All cultural practices were carried out as required throughout the season. Observations were recorded on days to 50% flowering, plant height (cm), number of branches per plant, number of capsules per plant, number of seeds per capsule, capsule length (cm), 1000-seed weight (g) and seed yield per plant (g). Data was collected for each genotype by selecting five plants at random from each replication for all the traits except for days to 50% flowering which was recorded on plot basis.

Corresponding author's E-mail: priyaskumar9@gmail.com

Estimation of components of variances and genetic variability parameters *viz.,* phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability in broad sense (H_2bs), genetic advance (GA) and genetic advance as per cent of mean (GAM) were carried out. The genotypic and phenotypic coefficients of variation were calculated according to the formulae given by Falconer (1981) whereas the categorization of the range of variation was done as proposed by Sivasubramanian and Madhavamenon (1973). Heritability (h^2) in broad sense was calculated according to the formula given by Allard (1960) and the range of genetic advance as per cent of mean was classified as suggested by Johnson *et al.* (1955).

Analysis of variance revealed the presence of highly significant differences among the genotypes for the traits studied (Table 1). It indicates the presence of considerable amount of genetic variability among the genotypes under study. The mean performances of 45 genotypes for seed yield and its components are presented in Table 2. It was observed that the genotype Julang Sesame scored the highest mean value for number of branches per plant, number of capsules per plant, number of seeds per capsule and 1000-seed weight. The genotype, NI8-8316 recorded the highest mean value for seed yield per plant and it also exhibited superior performance for three yield components *viz*., number of branches per plant, number of capsules per plant and number of seeds per capsule. Other best genotypes for seed yield and

yield components were KMS-4-323-B, SI-241, NIC-16220, PKDS-11, Savitri, Krishna, IC-205311, Nirmala, CT-27 and DS-1, suggesting that these genotypes can also be utilized as parents for hybridization programme. The genotypes, Kanpur Local, CT-60, IS-644-A, IC-310438-B, IS-469-1-84-A and IC-205071 recorded lower mean values for most of the traits compared to other genotypes.

Table 1 Analysis of variance for yield and yield component characters in sesame

Character	Mean sum of squares		
	Replications (df=2)	Treatments (df= 44)	Error (df= 88)
Days to 50% flowering	1.16	27.61**	1.57
Plant height (cm)	12.91	615.49**	64.53
Number of branches/plant	0.086	1.56**	0.060
Number of capsules/plant	17.95	394.10**	32.97
Capsule length (cm)	0.024	0.142**	0.01
Number of seeds/capsule	11.64	548.24**	13.50
Seed yield/plant (g)	0.12	2.99**	0.18
1000 seed weight(g)	0.014	0.59**	0.07

** Significant at 1% level

The genotypic and phenotypic coefficients of variation, heritability and genetic advance and genetic advance as per cent of mean were estimated for all the genotypes and results are furnished in Table 3. Seed yield per plant recorded the highest genotypic (25.25%) and phenotypic (27.64%) coefficient of variation followed by 1000-seed weight (GCV=24.19; PCV=24.66) and number of seeds per capsules (GCV=23.68; PCV=24.56). Similar results were reported by Tripathi *et al.* (2013) and Manjeet *et al.* (2020). Moderate estimates of GCV and a high estimate of PCV were recorded by number of branches per plant (GCV=18.58; PCV=19.67) and plant height (GCV=12.95; PCV=15.06). These results were in line with those of Bharathi *et al.* (2014), Chandramohan (2014) and Mahmoud *et al.* (2015). Low genotypic and phenotypic coefficients of variation were recorded for the character days to 50% flowering (7.79 and 8.47 %) and capsule length (8.38% and 9.36%). The results are in conformity with Bharathi *et al.* (2014) and Abate and Mekbib (2015).

The heritability estimates for the character, 1000-seed weight was high (96.2%) with high genetic advance as per cent of mean (48.90%) indicating the predominance of additive gene action. Hence, direct selection for this trait would be rewarding. Sabiel *et al.* (2015) and Begum et al. (2017) also recorded high heritability coupled with high genetic advance as per cent of mean for 1000-seed weight. Other traits like number of seeds per capsule (93.0% h^2, 47.04% GAM), number of branches per plant and number of capsules per plant were also recorded high heritability coupled with high genetic advance indicating the predominance of additive gene action in governing these traits. Hence, simple phenotypic selection for these traits would be rewarding. Iqbal *et al.* (2016) Abhijatha *et al.* (2017) and Begum *et al.* (2017) have also noticed high heritability coupled with high genetic advance as per cent of mean in their studies for these traits.

High heritability (86.4%) combined with moderate genetic advance as per cent of mean (14.76) was observed for days to 50% flowering and capsule length (80.30 h^2, 15.47 GAM) suggesting their governance by non-additive gene action. Saxena and Bisen (2017) also reported the similar results for 50% flowering and Chandramohan (2014) and Abate and Mekbib (2015) for capsule length.

The study revealed the presence of highly significant variation among the genotypes for the traits under study. From the results it was observed that the genotype Julang Sesame scored the highest mean value for the traits number of branches per plant, number of capsules per plant, number of seeds per capsule and 1000-seed weight followed by the genotype NI8-8316. The traits such as seed yield per plant, 1000-seed weight, number of seeds per capsules and number of branches per plant exhibited considerable amount of GCV and PCV coupled with high heritability and genetic advance as per cent of mean. Therefore, the emphasis should be given on these characters for predicting reliable selection results for the development of high yielding sesame genotypes. Simple selection could be practiced for the improvement of these traits.

Table 2 Mean performances of 45 sesame genotypes for yield and yield contributing characters

Genotypes	Days to 50% flowering	Plant height (cm)	No. of branches/ plant	No. of capsules/plant	Capsule length (cm)	No. of seeds/capsule	1000 seed weight (g)	Seed yield/plant (g)
Nirmala	37.66	94.27	4.56	75.90	2.73	79.01	1.90	4.99
Smarak	36.66	101.10	3.81	52.54	2.83	64.59	1.54	4.33
Krishna	36.33	96.72	4.15	57.94	2.48	67.16	2.55	4.50
TMV-7	37.00	90.82	3.11	56.30	2.69	45.37	1.53	2.87
RT-54	37.00	91.19	3.50	55.30	2.09	62.37	2.03	4.32
Rama	34.00	91.74	3.10	54.60	2.41	51.93	1.66	3.80
Chandana	34.00	102.04	4.08	54.30	2.49	61.81	2.17	4.47
DS-1	38.00	120.16	3.81	59.70	2.68	53.61	1.97	3.99
PKDS-11	37.33	115.13	4.42	56.60	2.61	58.16	2.23	4.48
Savitri	33.33	96.82	4.66	60.00	2.36	75.08	2.44	4.53
Guatama	39.00	110.51	3.85	56.90	2.32	41.96	2.31	3.97
IC-56196	36.66	107.88	3.90	53.64	2.66	49.54	1.69	3.98
IC-205439	34.00	96.27	4.05	52.50	2.27	53.98	1.61	3.79
IC-41945	31.66	116.81	4.02	49.67	2.62	50.18	1.79	3.64
IC-205311	37.33	100.40	4.45	68.36	2.44	75.69	2.03	4.60
IC-205071	37.33	103.50	2.80	46.95	2.51	43.82	1.52	3.35
KMR-43-A	37.66	133.12	3.96	48.70	2.46	53.22	1.21	3.33
CT-60	43.66	74.06	1.35	44.00	2.09	31.66	1.59	2.06
FRP-8351-B	39.66	91.36	3.50	54.60	2.22	54.66	2.24	4.08
IS-476	42.00	102.45	4.12	53.75	2.58	57.26	2.28	4.40
IS-195	42.33	89.70	3.95	53.20	2.36	50.33	2.11	3.97
NI8-8316	36.66	97.74	4.75	77.83	2.51	86.02	2.14	5.75
CT-40	37.00	108.23	3.40	56.02	2.74	51.22	1.60	3.62
IS-54039-B	37.33	110.87	3.36	49.53	2.57	44.63	1.89	3.49
NIC-16220	37.66	116.30	4.20	72.03	2.72	76.33	1.95	4.63
DS-37	36.66	106.84	4.15	50.45	2.67	44.82	2.32	3.90
AT-238	33.66	89.36	3.55	52.70	2.83	51.12	1.69	3.62
KMR-38	36.33	104.84	4.35	55.50	2.58	45.00	1.24	3.39
ES-33477	41.00	122.69	3.86	48.59	2.36	48.97	2.14	3.65
Kanpur local	36.00	103.51	3.47	52.85	2.17	47.93	1.21	2.88
IS-644-A	42.33	105.34	4.45	29.61	2.59	49.16	0.92	0.78
IC-310438-B	38.00	109.36	4.64	21.54	2.06	40.00	0.55	0.58
IS-112	33.00	78.60	3.30	52.35	2.19	47.49	1.56	3.06
Julang Sesame	41.66	107.39	4.95	88.29	2.46	88.83	2.69	5.64
KMS-4-323-B	43.00	111.28	4.43	69.60	2.84	77.40	1.97	4.69
SI-241	36.33	132.88	4.58	81.00	2.80	83.06	2.24	5.28
CT-27	36.66	97.92	3.90	56.60	2.48	60.16	2.44	4.50
EC-208652	40.66	123.10	4.05	57.49	2.29	59.77	2.31	4.46
IS-469-1-84-A	33.33	81.66	1.55	45.90	2.25	32.42	1.33	2.74
FFAT-10-20	42.33	92.45	3.24	49.35	2.57	50.49	1.51	3.60
IS-54034-B	37.00	102.40	3.76	53.63	2.49	44.66	1.53	3.55
Gowri	37.33	130.58	3.86	55.63	2.81	50.73	1.62	3.95
Madhavi	41.33	141.43	4.03	50.24	2.79	57.40	1.80	3.75
Rajeshwari (C)	41.66	104.72	3.15	51.95	2.22	56.33	1.59	3.46
Swetha Til (C)	42.00	101.47	3.05	55.01	2.56	61.12	1.51	3.74
Mean	37.81	104.59	3.80	55.53	2.50	56.36	1.82	3.82
SEm±	0.72	4.63	0.14	3.31	0.06	2.12	0.05	0.24
CV (%)	3.32	7.68	6.46	10.33	4.15	6.52	1.82	11.25
CD at 5%	2.03	13.03	0.39	9.31	0.16	5.96	0.14	0.69

Table 3 Genetic variability parameters in 45 sesame genotypes

Character	Coefficient of variation		Heritability (%)	Genetic advance	Genetic advance as per cent mean
	Genotypic (GCV)	Phenotypic (PCV)			
Days to 50% flowering	7.79	8.47	86.40	5.58	14.76
Plant height (cm)	12.95	15.06	74.00	24.01	22.95
Number of branches per plant	18.58	19.67	89.20	1.376	36.15
Number of capsules per plant	19.75	22.29	78.50	20.02	36.05
Capsule length (cm)	8.38	9.36	80.30	0.387	15.47
Number of seeds per capsule	23.68	24.56	93.00	26.51	47.04
Seed yield per plant (g)	25.25	27.64	83.40	1.81	47.51
1000 seed weight (g)	24.19	24.66	96.20	0.89	48.90

REFERENCES

Abate, M and Mekbib F 2015. Study on genetic divergence in low-altitude sesame (*Sesamum indicum* L.) germplasm of Ethiopia based on agro morphological traits. *Journal of Agricultural, Biological, and Environmental Statistics*, **2**(3): 78-90.

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

Allard R W 1960. *Principles of Plant Breeding,* John Wiley and Sons, New York, USA, pp. 485.

Arriel N H C, Mauro A O D, Arriel E F, Helena S, Trevisoli U, Costa M M, Bárbaro I M and Muniz F R S 2007. Genetic divergence in sesame based on morphological and agronomic traits. *Crop Breeding and Applied Biotechnology*, **7**: 253-261.

Begum T, Iqbal A and Dasgupta T 2017. Genetic variability and divergence among genotypes of sesame (*Sesamum indicum* L.). *Bangladesh Journal of Botany*, **46**(3): 955-962.

Bharathi D, Rao V T, Chandramohan Y, Bhadru D and Venkanna V 2014. Genetic variability studies in sesame (*Sesamum indicum* L.). *International Journal of Applied Biology and Pharmaceutical Technology*, **5**(4): 31-33.

Chandramohan Y 2014. Variability and genetic divergence in sesame (*Sesamum indicum* L.). *International Journal of Applied Biology and Pharmaceutical Technology*, **5**(3): 222-225.

Falconer D S 1981. *Introduction to Quantitative Genetics.* Oliver and Boyd, London, pp. 340.

Iqbal A, Akhtar R, Begum T and Dasgupta T 2016. Genetic estimates and diversity study in sesame (*Sesamum indicum* L.). *IOSR Journal of Agriculture and Veterinary Science*, **9**(8): 1-5.

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

Kumhar S R and Rajani B 2021. Genetic analysis and diversity studies in sesame (*Sesamum indicum* L.). *Journal of Oilseeds Research*, **38**(4): 329-336.

Mahmoud M W S H, Elezz A A and Hassan T H A 2015. Genetic variability, heritability and correlation coefficients of yield and its components in sesame. *Egyptian Journal of Plant Breeding*, **19**(4): 1101-1116.

Manjeet, Verma P K, Sheoran R K, Nain M and Avtar R 2020. Evaluation of sesame (*Sesamum indicum* L.) genotypes for genetic variability based on different traits under rainfed conditions. *Electronic Journal of Plant Breeding*, **11**(1): 54-59.

Ramanatha R and Hodgki T 2002. Genetic diversity and conservation and utilization of plant genetic resources. *Plant Cell, Tissue and Organ Culture*, **68**: 1-19.

Rajitha D, Srikanth T, Padmaja D and Kiran Babu T 2021. Genetic variability and heritability studies among genotypes of sesame (*Sesamum indicum* L.). *Journal of Oilseeds Research*, **38**(1): 43-48.

Sabiel S A I, Ismail M I, Abdalla E A and Osman A A 2015. Genetic variation in sesame genotypes (*Sesamum indicum* L.) grown in the semi-arid zone of the Sudan. *SABRAO Journal of Breeding and Genetics*, **47**(3):214-220.

Saxena and Bisen R 2017. Genetic variability, heritability and genetic advance for the phenotypic traits in sesame (*Sesamum indicum* L.). *International Journal of Pure Applied Sciences*, **2**: 1126-1131.

Sivasubramanian S and Madhavamenon P 1973. Combining ability in rice. *Madras Agriculture Journal*, **60**: 419-421.

Tripathi A, Bisen R, Ravindra P, Ahirwal, Paroha S, Sahu R and Ranganatha A R G 2013. Study on genetic divergence in sesame (*Sesamum indicum* L.) germplasm based on morphological and quality traits. *The Bioscan*, **8**(4): 1387-1391.

Biological control of charcoal rot of sesame caused by *Macrophomina phaseolina*

PREETI VASHISHT[1], H S SHARAN[2] AND A S RATHI

CCS Haryana Agricultural University, Hisar-125 004, Haryana

(Received: June 2, 2022; Revised: June 21, 2022; Accepted: June 24, 2022)

ABSTRACT

The potential of bio-agents for the management of sesame root rot caused by *Macrophomina phaseolina* was evaluated under *in vitro* conditions. The different bio-agents used for the management of root rot of sesame were *Trichoderma viride, Trichoderma harzianum* and *Pseudomonas fluorescens.* The growth of *T. viride, T. harzianum* and *P. fluorescens* was observed in dual culture. The maximum mycelial growth inhibition was showed by *T. harzianum* by 66.94% followed by *T. viride* by 59.9% and then by *P. fluorescens* by 59.9%. The volatile and non-volatile compounds produced by different bio-agents inhibited the colony growth of *M. phaseolina.* Maximum mycelial growth inhibition was showed by *T. harzianum* by 59.4% by the production of volatile compounds followed by *T. viride* and *P. fluorescens.* By the production of non-volatile compounds the maximum mycelial inhibition was done by *T. harzianum* by 59.9%, again followed by *T. viride* and *P. fluorescens.* Biological control has become an alternate and most important part of plant disease management as chemical pesticides possess harmful effects on environment and human health.

Keywords: Biological control, *Macrophomina phaseolina, Pseudomonas,* Sesame, *Trichoderma*

Sesame (*Sesamum indicum* L.) is one of the important crop among edible oilseed crops having good nutritional, biomedical and religious value. India contributes 2nd largest sesame acreage of above 17.77 million hectare with production and productivity 8 million tonnes and 448 kg/ha, respectively (Anonymous, 2020). The crop is attacked by several pathogens causing serious diseases and act as major damaging factor to sesame crop cultivated in the whole world with severe losses of 7 million tones yearly (Ara *et al.,* 2017). *Macrophomina phaseolina* (Tassi) Goid is a pathogen with an exceptionally broad host range that includes over 500 plant species including sesame (Jayaramachandran *et al.,* 2021). The important diseases of sesame include charcoal rot (*Macrophomina phaseolina*), Fusarium wilt (*Fusarium oxysporum* f.sp. *sesami*), Phytophthora blight (*Phytophthora parasitica*) and phyllody (*phytoplasma*). The charcoal rot disease in sesame causes considerable yield losses upto 5-100% (Vyas, 1981; Sangeetha *et al.,* 2021). The antagonistic actions of different bio agents influence the incidence and severity of disease by the pathogen. Some work on effect of volatile and non-volatile compounds of some antagonistic fungi or bio agents on plant pathogens has been reported and reports are also available on mycelial growth inhibition by dual culture technique. The objective of this study was to examine the interaction between different bio-agents and the mycelial growth of *M. phaseolina*.

Macrophomina phaseolina was isolated from the infected plants on potato dextrose agar (PDA) medium. Isolation and maintenance of *T. viride* and *T. harzianum* was done on PDA medium and nutrient agar was used for the *P. fluorescens.* The antagonistic effect of three bio-agents was studied against *M. phaseolina* by using Dual culture technique (Morton and Strouble, 1955). The bio-agents used for study were: *T. harzianum, T. viride, P. fluorescens.* The fungus was cultured on PDA and bacterium was cultured on NA, however, the antagonistic effects of the bio-agents were studied on PDA. Twenty ml of melted PDA medium was poured into sterile petri plate and allowed to solidify. Then five mm mycelial disc was cut from the margin of the actively growing colony from seven days old culture of *M. phaseolina* with a sterile cork borer and placed near the periphery on one side of the PDA, while an antagonistic fungi was placed on the other side of PDA plate just opposite to the first disc i.e. at an angle of 180°. Similarly, antagonistic bacteria obtained from three days old culture was streaked five centimeters long on the PDA medium at the two centimetre mark from periphery of the petri plate. Simultaneously, five mm mycelial discs of *M. phaseolina* were cut from the margin of actively growing colony with a sterile cork borer and placed near the periphery on opposite side of bacterial streak i.e. at an angle of 90°. The plates were incubated at 27°C for five days. Each treatment was replicated four times as CRD and appropriate controls were maintained. The extent of antagonistic activity by fungal and bacterial antagonists was recorded on fifth day by measuring the growth of *M. phaseolina* in dual culture plate and control plate. The per cent inhibition of *M. phaseolina* was calculated as suggested by Vincent (1947).

$$\text{Growth inhibition (\%)} = \frac{(C-T)}{C} \times 100$$

Corresponding author's E-mail: dhimanpreeti45@gmail.com

Where: I=Per cent inhibition of mycelial growth; C=Radial mycelium growth of *M. phaseolina* in control; T=Radial mycelium growth of *M. phaseolina* in treatment

The effect of non-volatile compounds of isolates of bio-agents *viz., Trichoderma* spp. and *P. fluorescens* agents on mycelial growth of *M. phaseolina* was evaluated under *in vitro* conditions. In this experiment the liquid solution of respective bio-agents was mixed in PDA before pouring into the petri plate under aseptic conditions. Then after solidification of media, a bit of pathogen was inoculated from 5-7 days old culture and incubated for 4-5 days. Each treatment was replicated four times as CRD and the effect of non-volatile compounds of bio-agents on mycelial growth of *M. phaseolina* by fungal and bacterial bio-agents was recorded on fifth day by measuring the growth of *M. phaseolina* and per cent inhibition of mycelial growth was recorded using the Vincent formula as mentioned above.

Table 1 Effect of different bio-agents on per cent mycelial growth inhibition of *M. phaseolina in vitro*

Treatment	Per cent mycelial growth inhibition
T. viride	59.16 (50.26)
T. harzianum	66.94 (54.89)
P. fluorescens	30.83 (33.70)
CD (p = 0.05)	2.27

*Mean of four replications; The figure in parenthesis are angular transformed value

Table 2 Effect of non-volatile compounds of bioagents on mycelial growth of *M. phaseolina*

Treatment	Per cent mycelial growth inhibition
T. viride	55.27 (48.00)
T. harzianum	59.99 (50.74)
P. fluorescens	51.38 (45.77)
CD (p = 0.05)	2.17

*Mean of four replications; The figure in parenthesis are angular transformed value

Table 3 Effect of volatile compounds of bio-agents on mycelial growth of *M. phaseolina*

Treatment	Per cent mycelial growth inhibition
T. viride	53.00(46.73)
T. harzianum	59.44(50.42)
P. fluorescens	47.77(43.70)
CD (p = 0.05)	2.49

*Mean of four replications; The figure in parenthesis are angular transformed value

The effect of volatile compounds of isolates of two bio-agents *viz. Trichoderma* spp. and *P. fluorescens* agent on mycelial growth of *M. phaseolina* was evaluated under *in vitro* conditions by Paired Plate Technique. The media was poured into the petri plates under aseptic conditions and left for solidification. Then in one plate bit of pathogen was inoculated from 5-7 days old culture and in another plate the bit of bio-agent was inoculated and both were covered one upon the other by paired plate technique. Then the plates were incubated for 4-5 days in a BOD incubator. Each treatment was replicated four times as CRD and effect of volatile compounds of bio-agents on mycelial growth of *M. phaseolina* by fungal and bacterial bio-agents was recorded on fifth day. The observation on percent growth inhibition of test fungus was recorded and the efficacy of volatile compounds of bio-agents was evaluated by using Vincent formula.

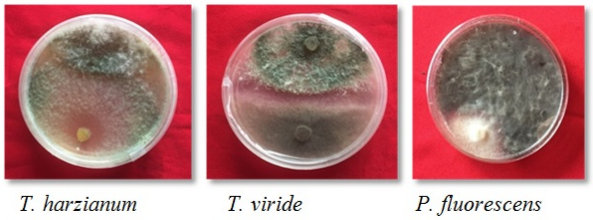

Fig. 1. Effect of different bio-agents on per cent mycelial growth inhibition of *M. phaseolina in vitro*

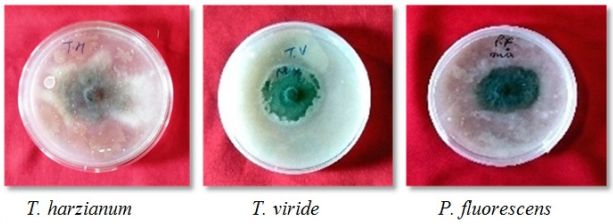

Fig. 2. Effect of non-volatile compounds of bio-agents against *M. phaseolina*

Biological control has become an alternate and most important part of plant disease management as chemical pesticides possess harmful effects on environment and human health. The bio-agents *viz., T. viride, T. harzianum* and *P. fluorescens* were tested for the inhibition of mycelial growth under *in vitro* conditions by using dual culture technique. These bio-agents were capable of inhibiting mycelial growth of *M. phaseolina* to various extents. *T. harzianum* was found most effective in inhibiting the growth of *M. phaseolina* by 66.9 per cent followed by *T. viride* by 59.1 per cent while *P. fluorescens* was found to be least effective (30.8%) against the mycelial inhibition *in vitro.* The bio-agents were tested for their inhibition of mycelial growth of *M. phaseolina* under in vitro conditions by secretion of non-volatile compounds. The data was recorded that *T. harzianum* showed maximum antifungal activity with 59.9 per cent inhibition of mycelial growth of *M. phaseolina* followed by *T. viride* with 55.2 per cent inhibition of radial growth , while the bacterial bio-agent *P. fluorescens* inhibited 51.3 per cent of mycelial growth of the test fungus over control by the secretion of non-volatile compounds. The bio-agents were tested for their inhibition of mycelial growth of *M. phaseolina* in vitro by secretion of voltalie compounds. Data

revealed that *T. harzianum* was found to be most effective with 59.4 per cent inhibition of mycelial growth of *M. phaseolina* followed by *T. viride* with 53.0 per cent inhibition of radial growth, while the bacterial bio-agent *P. fluorescens* inhibited 47.7 per cent of mycelial growth of the test fungus over control by the secretion of volatile compounds. Bio-control agents are useful organisms that reduce the adverse effects of plant pathogens and enhance positive response to plants.

REFERENCES

Anonymous 2020. *Area, production and productivity of sesamum in India.* Ministry of Agriculture and Farmers Welfare, Government of India.

Ara A, Akram A, Ajmal M, Akhund S, Nayyar B G, Seerat W, and Chaudhary S M 2017. Histopathological studies of sesame (*Sesamum indicum*) seedlings infected with *Fusarium oxysporum. Plant Pathology and Quarantine*, **7**(1): 82-90.

Dhingra O D and Sinclair J B 1977. An annotated bibliography of *Macrophomina phaseolina.* Universidale Federal de Vicosa, Minas Gerais, Brazil.

Jayaramachandran M, Ravichandran V and R Vaithiyalingan 2021. Assessment of genetic variability and resistance against stem and root rot caused by *Macrophomina phaseolina* in segregating generations of sesame (*Sesamum indicum* L.). *Journal of Oilseeds Research*, **38**(1): 115-120.

Morton D J and Strouble W H 1955. Antagonists and stimulatory effects of soil micro organisms upon *Sclerotium* sp. *Phytopathology*, **45**: 417-420.

Sangeetha A, Subrahmaniyan K, Meena B and Gupta K. 2021. Screening of elite lines of sesame (*Sesamum indicum* L.) against major diseases. *Journal of Oilseeds Research*, **38**(3): 280-285.

Vincent J M 1927. Distortion of fungal hyphae in presence of certain inhibitors. *Nature,* **15**: 850.

Vyas S C 1981. Diseases in Sesamum in India and their control. *Pesticides*, **15**: 9-10.

Seasonal incidence and effect of weather parameters on insect pests of linseed (*Linum usitatissimum* L.)

T BOOPATHI*, A L RATHNAKUMAR AND M SUJATHA

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

(Received: June 9, 2022; Revised: June 28, 2022; Accepted: June 29, 2022)

ABSTRACT

The most destructive enemy of linseed in India are insect pests. Twelve insect pests that caused damage in linseed under Hyderabad (India) conditions were recorded during 2020-2021. Percent incidence and population (per 10 plants) of *Liriomyza trifolii* varied from 43.2±7.20 to 69.7±5.53 and 0 to 2.8±0.20, respectively. Populations (per 10 plants) of *Bemisia tabaci,* leafhopper, *Nezara viridula* and *Creontiades* sp. reached maximum during first week of January 2021 (22.2±3.18), last week of January 2021 (13.6±0.68), first week of January 2021 (2.6±2.36) and last week of February 2021 (2.2±0.37), respectively. *Dasyneura lini* population (per 10 plants) varied between 0 to 2.2±0.49 and reached maximum during second week of February 2021 (2.2±0.49). *Spodoptera exigua* population reached maximum during third week of January 2021 (2.0±0.89 per 10 plants), whereas population (per 10 plants) of *Helicoverpa armigera* reached highest during third week of January 2021 (2.6±0.98). Other insect pests such as *Aulacophora* sp., *Monolepta signata, Hyposidra talaca* and tussock caterpillar also caused more damage to linseed. Among abiotic factors, the maximum temperature showed a negative correlation with all insect pests except *Creontiades* sp. and *H. talaca.* The abiotic factors jointly had a highly significant impact on population of insect pests. The model to predict insect pests incidence in linseed was developed by linear regression model which would offer forecasting for short term period.

Keywords: Insect pests, Linseed, Population, Incidence, Weather factors

Linseed (*Linum usitatissimum* L.) is a significant ancient oilseed crop cultivated throughout America, Europe, and Asia for either seed oil or fibre or for both purposes (dual purpose flax). It is grown primarily in south western Asia for its oil, including Turkistan, Afghanistan, and India. Its added value has late paved the way for its diverse nutraceuticals and medicinal uses (Nair *et al.,* 2021; Dwivedi *et al.,* 2021). Linseed is an extremely nutritious source of high-order linolenic acid (source of fatty acids Omega-3 and Omega-6), complete protein (all 8 vital amino acids), minerals, vitamins, and complex carbohydrates (Sahoo, 2016). World production of linseed in 2020 was 3.37 million tonnes from a cultivated area of 3.54 million ha with average productivity of 951 kg/ha (FAOSTAT, 2020). India ranks fifth in the area after Kazakhstan, Russian Federation, Canada and China. Our domestic production of 1.47 lakh tons is made from a region of 3.38 lakh ha in the world arena with a low productivity of 435 kg/ha (FAOSTAT, 2020). Among the multiple variables responsible for low linseed yield, insect pests, are extremely damaging, causing severe harm and are accountable for reducing linseed crop yield (Malik, 2006).

The population buildup of any insect is very intimately associated with the weather parameters prevailing during preceding and corresponding periods. The pest status does not remain static throughout the year but changes accordingly based on abiotic factors like temperature, relative humidity, rainfall, rainy days, etc. Since the information available on this aspect is meager, studies to understand the role of weather factors in influencing insect pests incidence is need of the hour in Telangana (India). This will not only help in taking right management decisions but also in their execution at right time. Hence, the present study was undertaken to study the role and reliability of weather factors for predicting insect pests incidence. Further, the effect of weather data range for accurate assessment of insect pests incidence was also explored.

The present study was carried out during 2020-2021 in the research farm of ICAR-Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad, Telangana, India at an altitude of 540 m, 17º19'17" N latitude and 78º24'51" E longitude and has a tropical agroclimate. For the seasons 2020-2021, field experiments were conducted in linseed (var. Neelam). The net plot size was 4 m × 5 m with spacing of 10 cm × 30 cm plant to plant and row to row, respectively in Randomized Completely Block Design (RCBD) with four replications. All the recommended agricultural practices were followed in raising the crop. No plant protection measure was taken throughout the crop season. Observations on the incidence of insect pests were recorded at weekly interval starting from initial appearance to final disappearance or up to harvest. Observations on the incidence of *Liriomyza trifolii* (Burgess), *Bemisia tabaci* (Gennadius), leafhopper, *Nezara viridula* (L.), *Creontiades* sp., *Dasyneura lini* L., *Spodoptera exigua* (Hübner), *Helicoverpa armigera* Hübner, *Aulacophora* sp., *Monolepta signata* (Olivier), *Hyposidra talaca* (Walker) and tussock caterpillar were recorded from 10 randomly selected plants by counting number of immature and adults of per plant.

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

During the season, average daily temperatures in the open field ranged from 27.7 to 36.1°C with relative humidity ranging from 73 to 100%; low rainfall during the observation period. Data were estimated weekly in the canopy area between 7.0 and 10.0 h. A weather record from January to March 2021 was obtained from the Meteorological Unit, PJTSAU, Rajendranagar, Hyderabad, India. Daily reported weather variables include mean minimum and maximum temperature, morning and evening humidity and rainfall; these variables were collected and recorded at the weather station.

The weekly data on incidence of insect pests of linseed were subjected to correlation and regression analyses with average weekly weather data to find out the influence of abiotic factors on insect pests infestation. The variables showing significant correlation with insect pests incidence were further analyzed with regression analyses to measure the present variability in insect pests incidence explained by each weather variable (Ryan, 1997). This technique essentially helps in identifying weather factor(s), which are significantly correlated with insect pests incidence. As a next step, a statistical model was developed, by regressing weekly incidence of insect pests of linseed with all the weather parameters. Further, a measure of goodness-of-fit, the values of co-efficient of determination (R^2) was calculated for developed models (Agostid'no and Stephens, 1986). The model diagnostics was performed using Durbin-Watson value and the p-value. The Durbin Watson (DW) statistic was a test for autocorrelation in the residuals from a statistical model. A value of 2.0 indicates there was no autocorrelation detected in the sample. Values from 0 to less than 2 point to positive autocorrelation and values from 2 to 4 means negative autocorrelation. The linear modeling was performed using the SPSS version 26.

Twelve insect pests (Fig. 1) such as *L. trifolii, B. tabaci,* leafhopper, *Creontiades* sp., *N. viridula, M. signata, D. lini, Aulacophora* sp., *H. armigera, S. exigua, H. talaca,* and tussock caterpillar that caused damage in linseed under Hyderabad conditions were recorded during 2020-2021. Among them, *L. trifolii, B. tabaci,* leafhopper, *S. exigua* and *H. armigera* were the major insect pests of linseed. Seasonal incidence of 12 insect pests of linseed was determined under Hyderabad conditions during 2020-2021 (Fig. 2). Percent incidence and population (per 10 plants) of *L. trifolii* varied from 43.2±7.20 to 69.7±5.53 and 0 to 2.8±0.20, respectively (Fig. 2a). Percent incidence and population (per 10 plants) of *L. trifolii* reached highest during first week of February 2021 (69.7±5.53), first week of January 2021 (2.8±0.20), respectively. Populations (per 10 plants) of *B. tabaci* (Fig. 2b), leafhopper (Fig. 2c), *N. viridula* (Fig. 2d) and *Creontiades* sp. (Fig. 2e) reached maximum during first week of January 2021 (22.2±3.18), last week of January 2021 (13.6±0.68), first week of January 2021 (2.6±2.36) and last week of February 2021 (2.2±0.37), respectively. *S. exigua* (Fig. 2f) population reached maximum during third week of January 2021 (2.0±0.89 per 10 plants). Population (per 10 plants) of *H. armigera* (Fig. 2g) ranged from 0 to 2.6±0.98 and reached highest during third week of January 2021 (2.6±0.98). *D. lini* (Fig. 2h) population (per 10 plants) varied between 0 and 2.2±0.49 and reached maximum during second week of February 2021 (2.2±0.49). Other insect pests such as *Aulacophora* sp. (Fig. 2i), *M. signata* (Fig. 2j), *H. talaca* (Fig. 2k) and tussock caterpillar (Fig. 2l) also caused damage to linseed and their incidence was very negligible. Overall, the maximum temperature varied between 27.7 to 36.1°C and mean minimum temperature between 15.7 to 20.0°C. Weekly morning relative humidity ranged from 17.2% to 49.0% and mean evening relative humidity between 73.6% and 100%. Amount of rainfall greatly varied from week to week, ranging from 0 to 0.5 mm per week (Fig. 3). A decrease in maximum (36.1 to 27.7°C) and minimum (20.0 to 18.4°C) temperatures, increase in morning (17.2 to 49.0%) and evening (73.6 to 98.4%) RH coupled with 0.5 mm rain during study periods, favoured the population build-up of leaf miner, whiteflies and stink bug. A decrease in maximum (36.1 to 30.6°C) and minimum (20.0 to 18.6°C) temperatures, increase in morning (17.2 to 38.9%) and evening (73.6 to 100.0%) RH and no rain during study periods, favoured the population build-up of leafhopper, *S. exigua, H. armigera, M. signata* and *H. talaca.*

Population of *L. trifolii* had a strong positive relationship with morning (r = 0.718) and evening (r = 0.748) RH (Table 1). However, maximum temperature had a moderate negative relationship with leaf miner incidence (r = -0.688). *B. tabaci* incidence was a strong positive relationship with morning RH (r=0.885) and a moderate positive relationship with evening RH (r=0.675) and rainfall (r=0.618). But, maximum temperature had a moderate negative relationship with whitefly incidence (r=-0.677). Leafhopper population had was a strong positive relationship with evening RH (r=0.777) and a moderate positive relationship with morning RH (r=0.492). While, a moderate negative relationship with maximum temperature (r=-0.426) was documented. *N. viridula* population had a moderate and weak positive relationship with rainfall (r=0.571) and morning RH (r=0.361), respectively. However, a moderate negative relationship with maximum temperature (r=-0.466). Incidence of *Creontiades* sp., *S. exigua, H. armigera, Aulacophora* sp., tussock caterpillar and *D. lini* had a weak relationship with all-weather parameters. Incidence of *M. signata* had a strong negative relationship with minimum temperature (r=-0.886). However, other weather parameters had a weak relationship with *M. signata* incidence. Incidence of *H. talaca* had a moderate negative relationship with morning RH (r=-0.577). However, other weather parameters had a weak relationship with *H. talaca* incidence.

As a next step, a statistical model was developed, by regressing weekly incidence of insect pests of linseed with all

the weather parameters. In the present study, all the weather factors jointly had a highly significant impact on incidence of insect pests in linseed. Perusal of Table 2 indicated that about 82% of the variation in leaf miner incidence was collectively explained when all the weather parameters are incorporated in the model. Similarly, about 84%, 79%, 71%, 34% and 82% of the variation in incidence of *B. tabaci,* leafhopper, *Creontiades* sp., *H. armigera* and *D. lini* were collectively explained when all the weather parameters are incorporated in the model. Though the developed model resulted in considerably high R^2 value except *H. armigera,* one of the regression coefficients corresponding to weather factors was not significantly related to incidence of *B. tabaci,* leafhopper, *Creontiades* sp., *H. armigera* and *D. lini* as indicated by the t-test statistic value. About 92%, 72%, 90%, 92%, 73%, 23% of the variation in incidence of *N. viridula, S. exigua, Aulacophora* sp., tussock caterpillar, *M. signata* and *H. talaca* were collectively explained when all the weather parameters are incorporated in the model. Though the developed model resulted in considerably high R^2 value, one of the regression coefficients corresponding to weather factors were significantly related to incidence of *N. viridula, S. exigua, Aulacophora* sp., tussock caterpillar, *M. signata* and *H. talaca* as indicated by the t-test statistic value.

In the current investigation, 12 insect pests of linseed were noticed to damage the linseed crop. Earlier, Asghar *et al.* (2017) reported that eight insect species caused damage to linseed which was less than the current investigation. *L. trifolii, B. tabaci,* leafhopper, *H. armigera* and *S. exigua* were found to the important insect pests of linseed. Similarly, Asghar *et al.* (2017) observed army worm, mirid bug, whitefly, leafhoppers, sting bug, thrips and cotton aphid to be the major insect pests causing huge damage to linseed. Humayun *et al.* (2013) reported seven insect species, *viz.,* linseed budfly, *Caliothrips indicus* B., *Empoasca kerri,* linseed caterpillar, semilooper, gram pod borer and green stink bug causing damage at various growth stages of linseed crop. Among these, bud fly and thrips were of major importance.

Patel and Thakur (2005) reported that *Caliothrips indicus, Thysanoplusia orichalcea, H. armigera, B. tabaci, Myzus persicae, S. exigua, Chromatomyia horticola, Amrasca* spp. and *D. lini* infest linseed. Incidence of other insect pests (*Aulacophora* sp., *M. signata, H. talaca* and tussock caterpillar) were found in very negligible numbers. Earlier, Patel and Thakur (2005) noted the other insects were found in very low numbers or in traces. Asghar *et al.* (2017) reported that maximum army worm and mirid bug populations were recorded during first week of February. However, in the current investigation, *S. exigua* and *Creontiades* sp. reached maximum during last week of January. Similarly, Pradhan *et al.* (2018) noted that the population of linseed caterpillar larvae remained active from third week of December to first week February, with the peak activity recorded during the third week of January. The highest *D. lini* incidence was found in the second week of February in the present study, which is similar to that previously reported by Asghar *et al.* (2017). However, Yadav *et al.* (2017) reported that highest *D. lini* incidence was found during last week of February. It is inferred that the maximum percent incidence of *L. trifolii* was observed during first week of February. Similarly, the maximum percent leaf miner incidence was recorded in last week of February in both protected and unprotected treatments (Yadav *et al.,* 2017). Pradhan *et al.* (2018) reported *D. lini* incidence from first week of January to last week of February with peak activity during last week of February.

Leafhopper populations reached maximum during last week of January. However, Pradhan *et al.* (2018) observed that leafhoppers were noticed during the third week of December to second week of February with peak incidence during third week of January. Populations of *N. viridula* reached maximum during first week of January. Similarly, Pradhan *et al.* (2018) reported that green stink bugs were noticed during second week of January to last week of January with peak incidence during third week of January.

A decrease in maximum and minimum temperatures and increase in morning and evening RH during study periods, favoured the population build-up of *L. trifolii, B. tabaci, N. viridula,* leafhopper, *S. exigua, H. armigera, M. signata* and *H. talaca.* Patel and Thakur (2005) reported that maximum and minimum temperatures of 28.1°C and 12°C were found suitable for pest multiplication.

In the present investigation, *L. trifolii* population had a strong positive relationship with morning (r=0.718) and evening (r=0.748) RH. Incidence of *Creontiades* sp., *S. exigua, H. armigera, Aulacophora* sp., tussock caterpillar and *D. lini* had a weak relationship with all the weather parameters. However, it also had a strong negative correlation with morning and evening RH (Mishra and Shamshad, 2007; Sahoo, 2016) and sunshine hours (Singh *et al.,* 2013). Ekka *et al.* (2017) reported the peak activity of *D. lini* was observed during 12^{th} and 10^{th} standard meteorological weeks. During this period, minimum and maximum temperatures, morning and evening relative humidity and sunshine hours were found favourable for maximum activity of the pest. Direct effect of maximum and minimum temperature and sunshine hour on its correlation with *D. lini* was very high and positive. Humayun *et al.* (2013) reported there was a highly significant positive correlation between the *D. lini* damage and maximum temperature and highly significant negative correlation with morning relative humidity. Leafhopper population had a strong positive relationship with evening RH and a moderate positive relationship with morning RH. However, Pradhan *et al.* (2018) reported that incidence of leafhopper had negative and non-significant correlation with morning and evening relative humidity.

Table 1 Correlation, coefficient and t-value (1 tailed) between weather parameters and population of insect pests of linseed during 2020-2021

Weather parameters	Leaf miner (% damage)	Leaf miner (population)	Whiteflies	Leafhopper	Stink bug	Mirid bug	*Spodoptera*	*Helicoverpa*	Pumpkin beetle	Tussock caterpillar	Flea beetle	Looper	Bud fly
Correlation													
Maximum temperature (°C)	-0.606	-0.688	-0.677	-0.426	-0.466	0.363	-0.252	-0.135	-0.326	-0.131	-0.129	0.234	-0.121
Minimum temperature (°C)	-0.395	-0.003	0.158	-0.175	0.154	0.063	0.144	0.029	0.117	-0.394	-0.886	-0.465	-0.158
Morning RH (%)	0.353	0.718	0.885	0.492	0.361	-0.245	0.343	0.255	0.323	0.026	-0.293	-0.577	0.143
Evening RH (%)	0.230	0.748	0.675	0.777	-0.038	-0.390	0.329	0.423	0.283	0.192	-0.105	-0.562	0.306
Rainfall (mm)	0.334	0.175	0.618	-0.212	0.571	0.309	-0.125	-0.208	0.335	-0.331	-0.169	-0.349	-0.182
t-value (1 tailed)													
Maximum temperature (°C)	-0.797	-1.549	0.169	0.129	-3.235	1.201	0.796	0.702	-4.237	1.708	0.285	1.155	0.435
Minimum temperature (°C)	0.293	1.295	0.004	-0.328	2.793	-0.780	-0.903	0.724	4.463	-2.253	-2.035	-2.063	-0.516
Morning RH (%)	-0.303	-0.559	0.902	0.300	-0.956	0.137	1.885	0.635	-4.454	2.102	-0.550	1.616	0.427
Evening RH (%)	0.091	0.628	-0.630	0.293	-0.426	0.071	-1.898	0.786	4.225	-1.853	0.682	-2.065	-0.231
Rainfall (mm)	0.146	-0.181	-0.453	-0.857	0.578	1.004	-2.365	0.534	4.105	-2.330	0.590	-1.874	-0.502

RH: relative humidity

Table 2 Prediction model summary of insect pests of linseed

Model summary	Leaf miner (% damage)	Leaf miner (population)	Whiteflies	Leafhopper	Stink bug	Mirid bug	*Spodoptera*	*Helicoverpa*	Pumpkin beetle	Tussock caterpillar	Flea beetle	Looper	Bud fly
R	0.681	0.906	0.918	0.888	0.961	0.842	0.846	0.586	0.947	0.958	0.856	0.481	0.905
R^2	0.463	0.820	0.843	0.789	0.923	0.709	0.715	0.344	0.896	0.917	0.733	0.232	0.818
Adjusted R^2	-0.432	0.520	0.581	0.438	0.794	0.225	0.240	-0.750	0.723	0.779	0.287	-1.049	0.515
SE of the estimate	9.846	0.660	4.804	3.365	0.451	0.696	0.635	0.981	0.188	0.123	0.236	0.095	0.511
F-value	0.518	2.734	3.219	2.246	7.173	1.463	1.505	0.314	5.185	6.630	1.644	0.181	2.701
P-value	0.757	0.219	0.182	0.269	0.068	0.401	0.391	0.878	0.103	0.075	0.362	0.952	0.222
Durbin-Watson	2.556	2.640	2.184	2.746	2.425	2.507	3.150	3.150	2.892	2.187	2.751	3.114	2.993

N. viridula population had a moderate and weak positive relationship with rainfall and morning RH, respectively. But, Pradhan *et al.* (2018) reported that green stink bug showed negative non-significant correlation with all-weather parameters individually. In the present study, all the weather factors jointly had a highly significant impact on incidence of insect pests in linseed.

The objective of this study was to develop a reasonable prediction model for insect pests incidence using reliable and dependable weather variables that have direct influence on their incidence. By using the model developed in the present study, it could be possible to workout insect pests incidence with minimum temperature and RH. This method is highly useful for estimating the insect pests incidence and saves precious time by avoiding field observations. The knowledge of the spatial distribution of the insect pests would also deeply abet in the targeting the control measures. However, further research is suggested to evaluate the efficiency of integrating the forecasting model into the existing control programme in terms of its impact in reducing the insect pests incidence and also the cost of control interventions.

ACKNOWLEDGEMENT

The first author gratefully acknowledges the Director, ICAR-Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad-500 030, Telangana, India for funding this study.

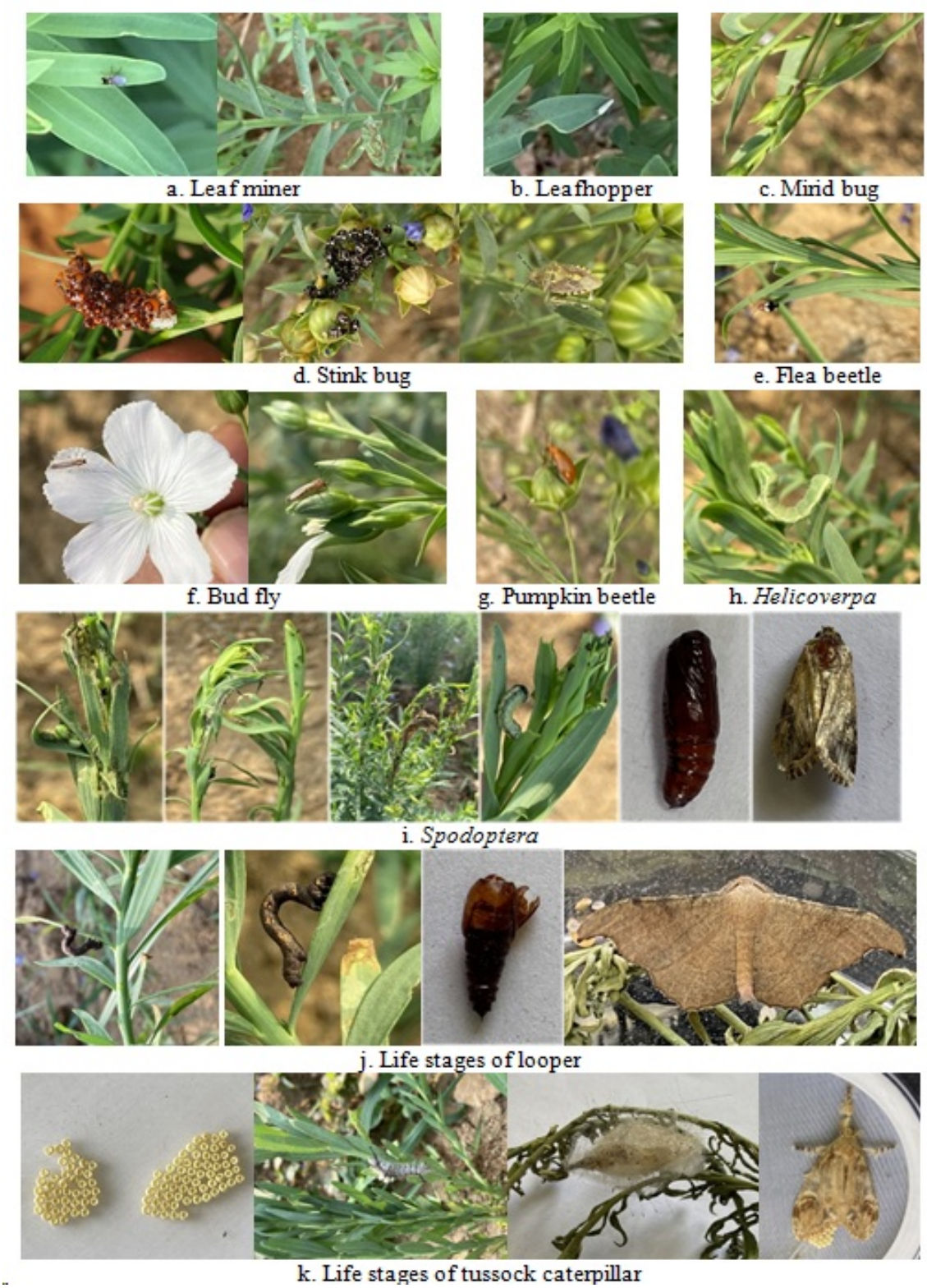

Fig. 1. Insect pests of linseed and their damage symptoms

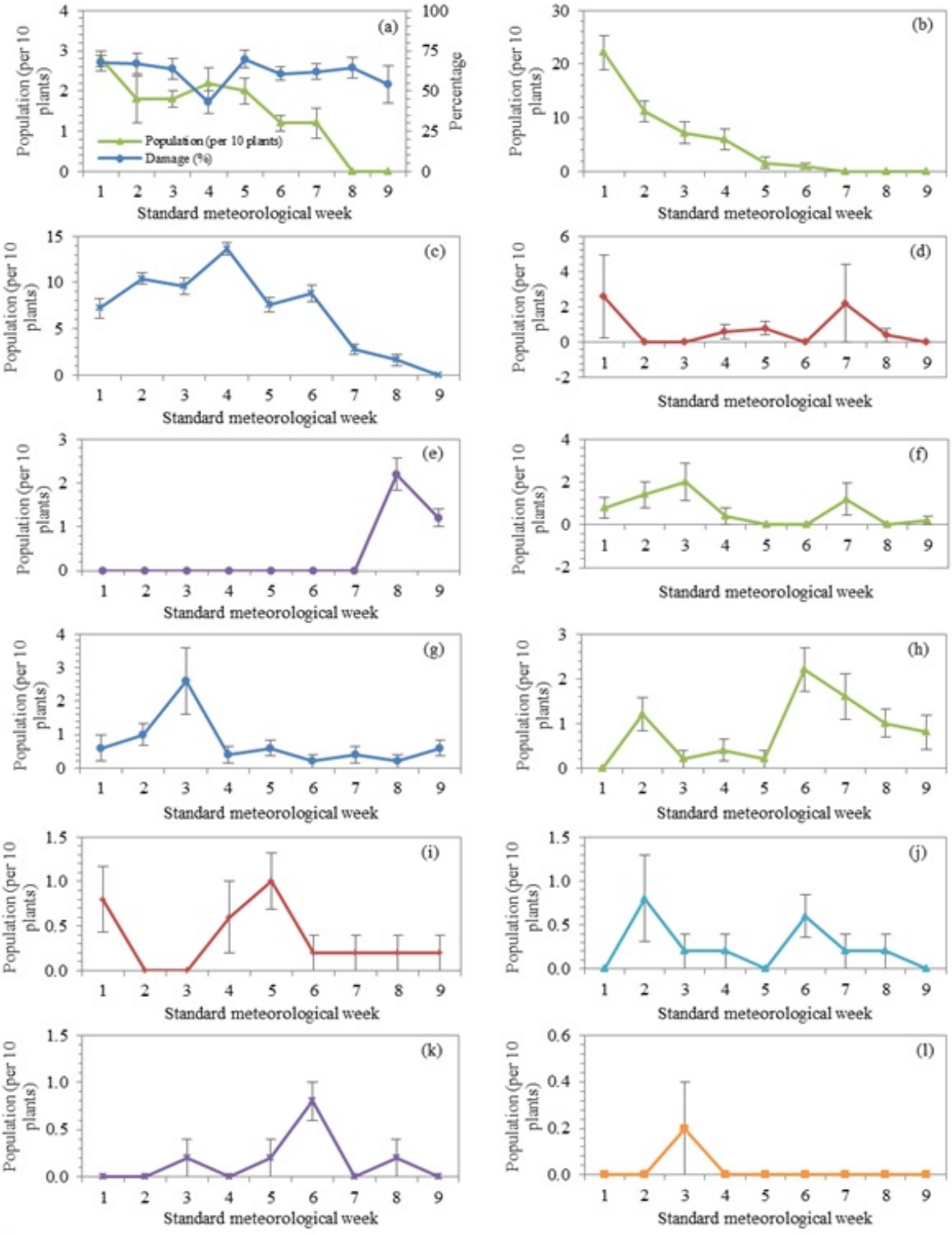

Fig. 2. Seasonal incidence of insect pests, (a) leaf miner, (b) whiteflies, (c) leafhopper, (d) stink bug, (e) mirid bug, (f) *Spodoptera,* (g) *Helicoverpa,* (h) bud fly, (i) pumpkin beetle, (j) flea beetle, (k) tussock caterpillar and (l) looper of linseed during 2021.
Error bars represent standard error of the means as determined by Tukey's post hoc test at P ≤0.001

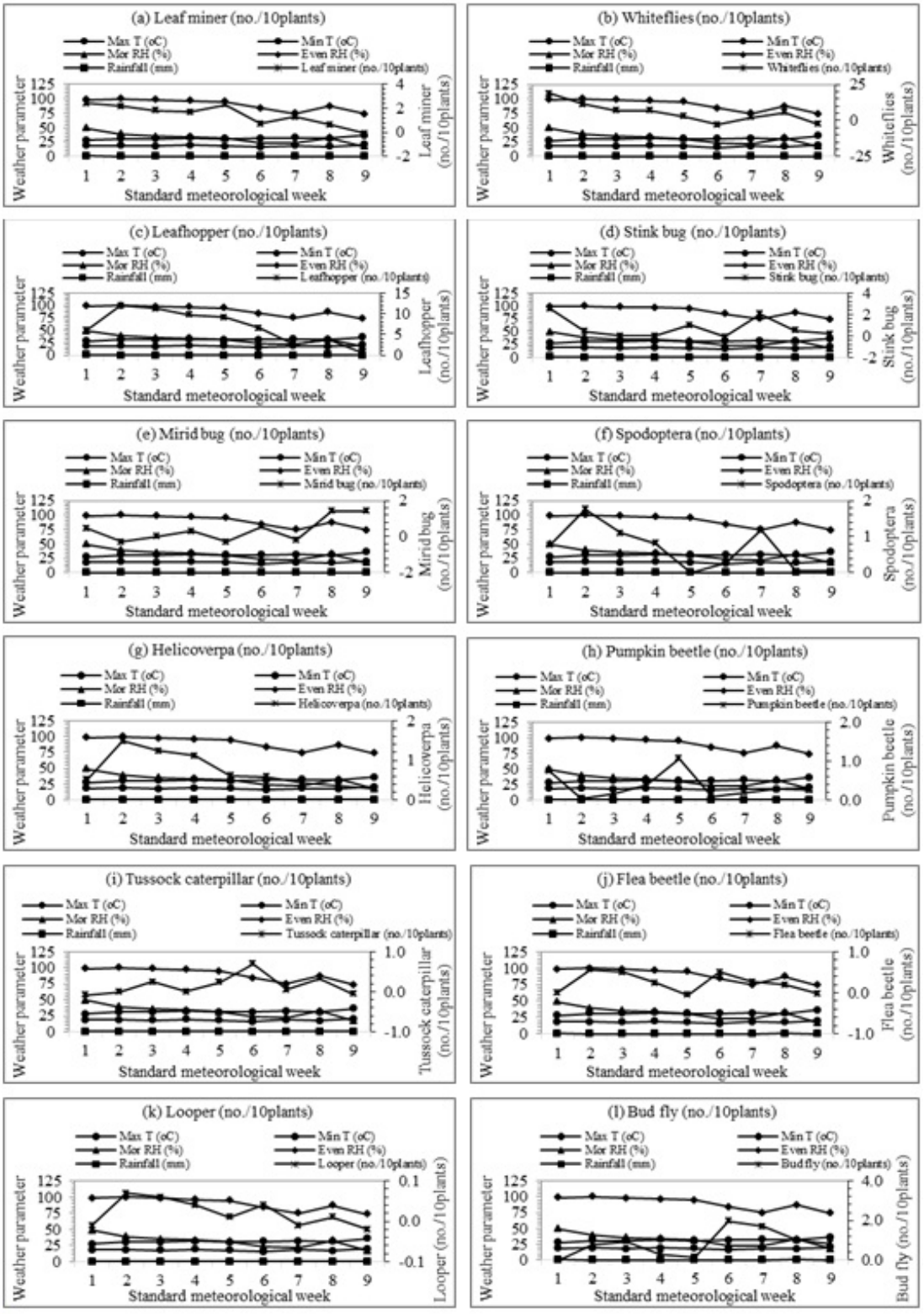

Fig. 3. Weather parameters and predicted values of seasonal incidence of insect pests of linseed during 2021

REFERENCES

Agostid'no R B and Stephens M A 1986. *Goodness of Fit Techniques.* Marcel Dekker, New York.

Asghar F, Lanjar A G, Chang B H, Magsi F H, Asghar K, Rajput A, Keerio A 2017. Insect biodiversity in different varieties of linseed. *European Academic Research*, **4**(10): 8306-8335.

Dwivedi S K, Satyaraj G R K and Panda S 2021. Foliar application of plant growth regulators on growth, yield and economics of linseed (*Linum usitatissimum* L.). *Journal of Oilseeds Research*, **38**(2): 195-198.

Ekka R K, Meena R S and Laichattiwar M A 2017. Seasonal incidence of linseed bud fly, *Dasineura lini* Barnes in linseed ecosystem. *Agriculture Update*, **12**: 1328-1331.

FAO 2020. Agriculture Production Database. Food and Agricultural Organization. https://www.fao.org/faostat/en/#data/QCL, accessed on May 10, 2022.

Humayun S M A, Gupta R, Chandrakar G and Rana N 2013. Seasonal incidence of key insect pests of linseed, their natural enemies and determination of ETL of *Dasyneura lini. Green Farming*, **4**(5): 643-646.

Malik YP 2006. Yield losses due to bud fly, Dasyneura lini Barnes in linseed. *Journal of Oilseeds Research*, **23**(2): 363.

Mishra M K and Shamshad A 2007.Seasonal and varietal incidence of insect-pests of linseed. *Indian Journal of Entomology*, **69**(3): 288-292.

Nair B, Zanwar A, Mehta N, Payasi D, Mogali S, Rathnakumar A L, Boopathi T and Sujatha M 2021. Value Added Products of Linseed. All India Coordinated Research Project on Linseed, ICAR-Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad, Telangana, India. 39 p.

Patel R K and Thakur B S 2005. Insect pest complex and seasonal incidence in linseed with particular reference to bud fly (*Dasineura lini* Barnes). *Journal of Plant Protection and Environment*, **22**: 102-107.

Pradhan V, Painkra G P, Painkra K L and Bhagat P K 2018. Seasonal incidence of major insect pests in linseed. *Journal of Plant Development Sciences*, **10**(10): 579-581.

Ryan T P 1997. *Modern Regression Methods.* John Wiley and Sons, Inc., New York. p. 515.

Sahoo S K 2016. Effect of climatic variability on population dynamics of insect pests and natural enemies in linseed (*Linum usitatissimum* L.). *Internat. Journal of Bio-resource & Stress Management*, **7**(2): 247-251.

Singh S, Ali S and Kumar S 2013. Population dynamics of insect-pests of linseed. *Annals of Plant Protection Sciences*, **21**(2): 426- 427.

Yadav A, Yadav T and Kumar R 2017. Population dynamics of major insect pests of linseed (*Linum usitatisimum* Linn.) and assessment of seed yield losses caused by them. *Plant Archives*, **17**(1): 745-752.

Comparative economic analysis of soybean [*Glycine max* (L.) Merr.] cultivation under natural, organic and conventional methods in Karnataka, India

H K SANJAY KUMAR*, G B LOKESH, AMRUTHA T JOSHI, K SURESH, SATYANARAYANARAO, SUNIL KULKARNI AND D G SATHIHAL

University of Agricultural Sciences, Raichur-584 104, Karnataka

(Received: March 17, 2022; Revised: April 25, 2022; Accepted: April 28, 2022)

ABSTRACT

Soybean plays an important role in edible oil economy and it a rich source of proteins (40%), carbohydrates (35%) and edible oil (20%), besides several minerals and vitamins. This study was carried out used both primary and secondary data in North-Eastern Transition Zone of Karnataka during 2020-21 by adopting multistage sampling procedure with the total sample size of sixty farmers with the main objective of analysing the economic viability of natural farming via alia organic and conventional farming. The major finding of the study was that conventional farming gave the highest net returns of ₹15464 and a B:C ratio of 1.84 compared to organic and natural farming. The cost of cultivation of natural farming was ₹16062 and it was less than conventional farming (13.10%) and organic farming (14.94%). The net return was highest in conventional farming and was higher than organic (12.77%) and natural farming (19.92%). The study suggests policy measures such as research and development activities should be focus more towards sustainable crop variety and technology to improve the yields under natural farming. There is a need of government policy support for certification and setting premium minimum support price for natural products in order to encourage the farmers for natural farming.

Keywords: Comparative economics, Conventional farming, Natural farming, Organic farming, Soybean

The demand for oilseeds, edible oils and oilcake meals, has been growing rapidly in the country owing to growth in per capita income, increasing population and urbanisation (Birthal *et al.*, 2010). During the last three decades, India's oilseed production has more than tripled, from 9.37million tons in 1980-81 to 36.10 million tons in 2020-21. Annual *per capita* consumption of edible oils has increased from 4 kg in 1981 to 19.7 kg in 2019-20. India is one of the major consumers of oilseeds and their products accounting for approximately 10.2 per cent of global consumption of edible oils as well as oilcake meals. Further, *per capita* consumption of edible oils has been increasing at 4 per cent annually. This increase in demand for oilseeds and their products has been accompanied by increase in their domestic production.

Soybean [*Glycine max* (L.) Merr.] plays an important role in edible oil economy and is the fastest growing oilseed crop globally. During 1961-1921, global area under soybean increased at an annual compound rate of 3.65 per cent and production by about 4.32 per cent, higher than the growth in area and production of most other food crops. Soybean accounts for 37.4 per cent of the global area under oilseeds, and contributes to 28 per cent of vegetable oil production (Sharma and Dupare, 2016). Cultivation of soybean in India started in the year 1963. It has 34 per cent share in total oilseed production in the country. India ranks fourth (9.12%) in soybean area in the world with an area of 11.40 m ha, and ranks fifth in production with 13.78 mt. In India, Maharashtra (6.20 mt) is the major producer of soybean which accounts for 45 per cent of total production of the country followed by Madhya Pradesh (5.27 mt), Rajasthan (1.18 mt) and Karnataka (0.36 mt). The area under the crop was highest in Madhya Pradesh (6.68 m ha), followed by Maharashtra (4.35 m ha). The overall productivity of the country was 10.55 q/ha during 2020-21.

The conventional farming has helped India not only to produce enough food for own consumption but also generated surplus for exports. However, the increasing population and income would lead to further increase in demand for food and also for raw materials for industry (Shrine, 2019). The adverse effects of conventional practices are increasingly visible not only on the farm but also on the health of all living beings and have been well documented all over the world. Their negative effects on the environment are manifested through soil erosion, water shortages, salination, soil contamination, genetic erosion, etc, Sustainable agriculture is necessary to attain the goal of sustainable development (Sharma *et al.,* 2019).

According to the Codex Alimentarius Commission, a joint body of World Health Organization (WHO), "organic agriculture is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity." In other words, organic agriculture is based on minimizing the use of external inputs, avoiding the use of synthetic fertilizers and pesticides. Organic agriculture in India has its roots in traditional agricultural practices that evolved in countless villages and farming communities over

*Corresponding author's E-mail: gblokesh@yahoo.com

the millennium. India is a home to 30 percent of the total organic producers in the world. Still, it accounts for just 2.59 percent (1.5 million hectares) of the total organic cultivation area of 57.8 million hectares. Organic farming movement was initiated in Karnataka by the innovative farmers of the state and the movement gained momentum during 1990s. The State witnessed a steady growth in the Organic Sector with an increased certified area from a mere 2,500 ha during 2004-05 to 93,963 ha as on March 2016. Karnataka stands 5th in the country in terms of total organic certified area and 3rd in terms of certified production (Anonymous, 2017).

The idea of natural farming advocated by Mokichi Okada in 1935, aims at practicing agricultural production without interrupting the natural eco-system without the use of chemical fertilizers and other agricultural chemicals. Masanobu Fukuoka was the originator of the natural farming method. In his book "The One-Straw Revolution", he referred it to as "the Fukuoka method", "the nature way of farming" or "to do nothing farming". Zero Budget Natural Farming (ZBNF) is a derivative of natural farming developed in and primarily practiced in India. The government of Karnataka took initiative to introduce the ZBNF as a method to reduce the cost of agricultural operations and to arrange the awareness programmes in achieving maximum benefits to farmers during 2018. An agriculturist, Subhash Palekar has done research and written extensively on this method. The phrase 'Zero Budget' refers to zero net cost of production of all crops and the inputs used for seed treatment and other inoculations are locally available in the form of cow dung, cow urine, etc. (Shrine, 2019). Karnataka is among the few states which have adopted for validation of Natural Farming (NF) to reduce cost of production of farmers and double their income. In this background this study was carried out in Kalyan Karnataka region with specific objectives of analyzing the comparative economics of soybean cultivation under conventional, organic and natural farming and identifying the most suitable farming practices for farmers to enhance crop yield, net returns and other economic benefits.

The study was conducted in Agro-climatic Zone-1 of Karnataka, which constitutes two districts namely Bidar, and parts of Kalaburagi, where, the soybean is being cultivated largely. The annual rainfall in this zone varies from 830-890 mm. About 63 per cent of the rainfall is received during kharif season. The elevation ranges between 800-900 m in major areas. The soils are shallow to medium black, clay in major areas and lateritic in the remaining areas. The important crops grown are greengram, blackgram, redgram, jowar, soybean, bajra, cotton and sugarcane. The geographical area of this zone is 0.871 mha.

Sampling design: Multistage sampling procedure was adopted, in the first stage, Bidar and Kalaburgi districts (Zone 1) were chosen and in the second phase two taluks were selected from each district, namely, Bidar and Aurad taluks from Bidar district and Kalaburgi and Sedam taluks from Kalaburgi district. In the third stage, from the selected taluks, one cluster from each taluk and from each cluster one village was chosen randomly. Rajgera and Medpalli villages from Bidar and Aurad taluks, Melkunda and Bedarchad from Kalaburgi and Sedam taluks were selected for the study. From each selected village, 15 farmers (5 farmers each from chemical farming, organic farming and natural farming methods) were selected. Therefore, from such selected clusters fifteen respondents were selected and it added up to thirty respondents from Bidar district and thirty respondents from Kalaburgi district, thus the total sample size added up to sixty.

The study was based on both primary and secondary data. Primary data was collected from sample farmers through personal interview method with the help of well-structured pretested schedule. The data covered general characteristics of farmers, land holding, assets, cropping pattern, type of farming, costs, returns, yields, constraints etc. Primary data pertains to the year 2019-2020. The secondary information required for the study, in relation to the area under conventional, organic and natural farms and other related information were collected from RSKs and Agricultural Research Stations of respective districts, information regarding zero budget natural farming scheme was collected from Dept. of Agriculture, Govt. of Karnataka and University of Agricultural Sciences, Raichur. The data and information related to Zero budget natural farming is only for the year 2019-20 as the scheme was launched in 2018-19.

Analytical techniques employed: Different analytical methods were adopted to measure various parameters. In order to analyze growth in area, production and productivity of soybean crop compound growth rate was estimated using the function as under.

$$Y = a\, b^{T} e^{u} \qquad \ldots\ldots\ldots\ldots\ldots (1)$$

Where,

Y = Dependent variable
a = Intercept term
b = (1 + r) and r is the compound growth rate
T = Time
e^{u}= error term

In the logarithmic form the function could be expressed as,

$$\text{Log } Y = \log a + T \log b + u \ldots\ldots\ldots\ldots\ldots (2)$$

Log a, and Log b were obtained using the Ordinary Least Squares (OLS) procedure and (Antilog of log (b - 1)) *100 provided the per cent growth rate.

Cost accounting method: The cost accounting method (Followed by CACP) was adopted for estimating costs and

returns of a soybean crop. Various cost concepts were used as defined below:

Cost A_1: It included - value of hired human labour, value of hired and owned bullock labour, value of hired and owned machine labour, value of seed (both farm seed and purchased), value of manures (owned and purchased) and fertilizers, depreciation on machineries, land revenue, interest on working capital and miscellaneous expenses (mulching etc.,)

Cost A_2: Cost A_1 + rent paid for leased-in land
Cost B_1: Cost A_1 + interest on fixed capital (excluding land)
Cost B_2: Cost B_1 + rental value of owned land + rent for leased-in land
Cost C_1: Cost B_1 + imputed value of family labour
Cost C_2: Cost B_2 + imputed value of family labour, and
Cost C_3: Cost C_2 + 10 per cent of cost C2 as management cost.

Terminologies and definition used in natural farming: In order to account real economic cost of natural farming, imputed cost of raw materials and labour cost for preparation of four pillars of natural farming was considered. The details are

a) Beejamrutha: The cost of materials used in preparation of beejamrutha such as desi cow dung, cow urine, lime, water and labour cost was estimated by imputation since these are not traded in the open market.

b) Jeevamrutha: The cost for materials used in preparation of jeevamrutha such as desi cow dung, desi cow urine, jaggery, gram flour, water and labour cost for preparation was estimated.

c) Brahmastra: The cost of preparation of brahmastra was estimated by considering the cost for materials used in preparation of brahmastra such as leaves of different plants (Neem, Guava, Custard apple, Lantana camera and Datura) and desi cow urine was estimated for one acre of land.

d) Neemastra: The cost for materials used in preparation of neemastra such as desi cow dung, desi cow urine, neem leaves and water was estimated for an acre. This was treated as cost for preparation of neemastra.

e) Agniastra: The cost for materials used in preparation of agniastra such as desi cow urine, garlic, green chilli, tobacco and neem leaves were estimated for an acre. This was treated as cost for preparation of agniastra.

f) Neem leaf extract: The cost for materials used in preparation of neem leaf extract such as desi cow urine, desi cow dung, neem leaf and neem seeds were estimated for an acre. This was treated as cost for preparation of neem leaf extract.

g) Mulch material: The cost for purchase of crop residue such as maize stalk was determined. This was treated as cost for mulch material in this study.

Trends in area production and productivity of soybean: The compound growth rate of area, production and productivity of soybean is presented in Table 1. Compound annual growth rate of soybean area was at 3.65 percent at all India level while for Karnataka (8.97 %) and study districts *viz.,* Bidar (33.05%) and Kalaburagi (42.58%) the growth in soybean area was high compared to all India level and was significant at 5 per cent level. These results were obtained as soybean was recently introduced in the study districts. In case of growth in production, India was 4.32 per cent, Karnataka state was having 4.65 per cent and Bidar district was 34.67 per cent, Kalaburagi district production was 51.27 per cent and are significant at 5 per cent level. This indicates that, the growth in production was merely influenced by area expansion.

With regard to the growth of soybean productivity at all India level it was 0.63 per cent which was significant at 5 per cent level, Karnataka was recorded a productivity of 0.92 per cent which was non significant, where in productivity of Bidar district was 1.69 per cent and Kalaburagi district was 3.12 per cent which was significant at 5 percent level . The productivity growth is not stabilised for Karnataka and study districts may be due to vagarious rainfall and weather condition. Similarly, the existing varieties of soybean were not helping in increasing the yield levels and hence it calls for technological breakthrough in soybean. Similar results were reported while studying growth rates, decomposition analysis and instability of groundnut crop production in Andhra Pradesh by Sita Rambabu *et al.* (2014).

Socio-economic characteristics of respondents in the study area: In order to understand the socio economic background of respondents followed different farming practices, brief details their brief details were presented in this section. Table 2 revealed that, large proportions of the respondents practicing conventional (37.50%), organic (40.00%) and natural farming (37.50%) were in the age group of 31 to 40 years comprising of 38.33 per cent of the total respondents. It was followed by 41 to 50 years category of conventional (22.50%), organic (30.00%) and natural farming (20.00%) farmers comprising of 24.17 per cent of the total respondents, followed by young generation of below 30 years of age, who were involved to the extent of 20.83 per cent in conventional (22.50%), organic (15.00%) and natural farming (25.00%).

It was also revealed from the Table 2 that, 34 per cent of the total respondents were illiterates which was 47.50 per cent, 17.00 per cent and 37.50 per cent in conventional, organic and natural farming practicing farmers respectively. It could be noted that around 25 per cent of the respondents completed their primary education in conventional (25.00%), organic (22.50%) and natural farming (27.50%) practicing respondents. It is seen about 24.17 percent of total respondents completed their high school education 7 per cent, 14 per cent and 8 per cent of them belong to conventional, organic and natural farming practicing farmers respectively. And above high school education correspond 16.67 per cent of the total respondents with 10 per cent, 25 per cent and 15 per cent among conventional, organic and natural farming practicing farmers respectively. The literacy rate of organic farmers was high compared to conventional and natural farming practicing farmers. This could be due to higher exposure, awareness and accountability towards better health, society and environment. Majority of the conventional and natural farming respondents were illiterate, this could be due to poor social and economic conditions in the rural society and lack of financial support and motivation from the family members.

Table 1 Trends in area, production and productivity of soybean (1999-2000 to 2019-20)

Particulars	CAGR (%)			
	All India	Karnataka	Bidar	Kalaburgi
Area	3.65	8.97*	33.05*	42.58
Production	4.32	4.65	34.67*	51.27*
Productivity	0.63**	0.92	1.69	3.12**

** Significant @ 5% level.

The information on distribution of conventional, organic and natural farming respondents according to their social class is furnished in Table 2. In case of conventional farming farmers, about 35 per cent belonged to Other Backward Classes' (OBCs) followed by Scheduled Caste (25.00%), Scheduled Tribe (20.00%) and General category (20.00%). Among organic farmers, about 32.50 per cent belonged to Other Backward Classes (OBCs) category followed by Scheduled Tribe (25.00%), Scheduled Caste (22.50%) and General category (20.00%). Similarly, about 35 per cent of the natural farming respondents belonged to Other Backward Classes (OBCs) followed by General category (27.50%), Scheduled Caste (20.00%) and Scheduled Tribe (17.50). Overall, out of total respondents, 34.17 percent belonged to Other Backward Classes (OBCs) followed by both Scheduled Caste and General category (22.50 % each) and Scheduled Tribe (20.83%).

It was found that majority of conventional farming respondents had a small family with an average family size of four members per family. Organic farming respondents belonged to medium family size with an average family size of seven members per family. Similarly, natural farming respondents belonged to small family size with an average family size of five members per family.

A glance at the Table 2 showed that, majority of the sample respondents in conventional, organic and natural farming were having agriculture as their main occupation (88.33%). Only five conventional, six organic and three natural farming respondents had diversified their livelihood security. The annual income of conventional, organic and natural farming respondents as presented in Table 2 were ₹241806, ₹ 259895 and ₹ 250795, respectively. The average annual income of organic farming respondents was slightly higher when compared to conventional and natural farming respondents.

Area and farming experience of sample respondents: The information about the area and farming experience of the sample respondents of different farming methods are elicited and presented in the Table 3. Under the conventional farming method, farming experience of all the respondents was more than six years. In organic farming method, majority of the respondents were under the farming experience category of four to six years (54.83%), followed by more than six years (31.99%), two to three years (8.60%) and lastly one year (4.58%). In the case of natural farming method, all the respondents were under one year category. It was due to the fact that all the respondents were members of zero budget natural farming project in Zone 1 and it was implemented during 2019-20.

Economics of soybean cultivation under different farming methods: The economic analysis of soybean cultivation during 2019-20 has been presented in Table 4. The comparative estimates of soybean cultivation on different cost concepts basis has been studied. Table 4 shows the breakup of cost incurred on cultivation of soybean. Among all cost concepts, Cost A1is operational cost and Cost B_2 is considered as total cost of cultivation. Since the rent of leased in land and maintenance cost are zero, Cost A_1 and Cost A_2 are equal, respectively.

The table shows that total cost of cultivation (Cost B_2) of soybean was found highest in organic farming which amounted to ₹ 18493 per acre followed by conventional (₹17837/acre) and natural farming (₹ 15253/acre). The highest cost in organic farming system was due to more expenses on purchase of organic manures and use of low cost naturally prepared inputs under natural farming which had resulted in lowest cost of cultivation over other systems. Further, Cost A_1 (operational cost) was also found to be highest on organic farming (₹ 15484/acre) and lowest on natural farming (₹ 12230/acre). Cost C_2, which includes imputed value of family labour, was worked out to be

₹18487, ₹ 19043 and ₹ 15853 per acre on conventional, organic and natural farming, respectively. These results were contradicted with the findings obtained by Satpute *et al*. (2009).

A comparison of various income measures from soybean cultivation are given in Table 4. The table reveals that among all farming systems, higher yield was found in conventional farming (8.56 q/acre) followed by organic farming (7.90 q/acre) and natural farming (7.10 q/acre). Consequent to the yield, gross returns was also found to be higher in conventional (₹33950/acre) followed by organic (₹ 32548/acre) and natural farming (₹ 28155/acre). The net returns were found to be higher in conventional farming (₹ 15463/acre) followed by organic farming (₹ 13505/acre) and natural farming (₹ 12302/acre). Returns per rupee of investment (B:C ratio) over cost A_1 was higher in natural farming(2.30) followed by conventional farming (2.28) and organic farming (2.10). Benefit- cost ratio over cost B_2 was found to be higher in conventional farming (1.90) followed by natural (1.85) and organic farming (1.76).These results are contradictory with the findings obtained by Naik *et al.* (2020). By considering the yield of soybean, highest yield was achieved in conventional farming (8.56) followed by organic farming (7.90) and natural farming (7.10).

Table 2 Socio-economic characteristics of respondents in the study area

Sl. No.	Particulars	Conventional farms (n1=40)	Organic farms (n2=40)	Natural farms (n3=40)	Overall (n=120)
1	**Age (No.)**				
a	Below 30 years	9(22.50)	6(15.00)	10(25.00)	25(20.83)
b	31-40 years	15(37.50)	16(40.00)	15(37.50)	46(38.33)
c	41-50 years	9(22.50)	12(30.00)	8(20.00)	29(24.17)
d	Above 50 years	7(17.50)	6(15.00)	7(17.50)	20(16.67)
2	**Education (No.)**				
a	Illiterate	19(47.50)	7(17.00)	15(37.50)	41(34.00)
b	Primary (1-7)	10(25.00)	9(22.50)	11(27.50)	30(25.00)
c	High school (8-10)	7(17.50)	14(35.00)	8(20.00)	29(24.17)
d	Pre-University and above	4(10.00)	10(25.00)	6(15.00)	20(16.67)
3	**Social profile (No.)**				
a	SC	10(25.00)	9(22.50)	8(20.00)	27(22.50)
b	ST	8(20.00)	10(25.00)	7(17.50)	25(20.83)
c	OBC	14(35.00)	13(32.50)	14(35.00)	41(34.17)
d	General	8(20.00)	8(20.00)	11(27.50)	27(22.50)
4	**Average family size (No.)**				
a	Family size	4.00	7.00	5.00	5.33
5	**Occupation (No.)**				
a	Agri. as main	35.00(87.50)	34.00(85.00)	37.00(92.5)	106.00(88.33)
b	Agri. as subsidiary	5.00(12.50)	6.00(15.00)	3.00(7.50)	14.00(11.67)
6	**Average Annual income**				
a	Agricultural	163246(67.51)	170295(70.43)	155345(59.77)	162962.00(64.98)
b	Non Agricultural	78560(32.49)	80390(29.57)	104550(40.23)	87833.33(35.02)
	Total	241806(100)	250685(100)	259895(100)	250795.33(100)

Figures in the parentheses indicate percentage to the total

Table 3 Area and farming experience of sample respondents in different farming methods

Farming experience	Conventional farms (n1=40)			Organic farms (n2=40)			Natural farms* (n3=40)		
	No.	%	Area (ac)	No.	%	Area (ac)	No.	%	Area (ac)
1 year	-	-	-	2	4.58	10.24	40	100	40.00
2-3 years	-	-	-	4	8.60	19.23	-	-	-
4-6 years	-	-	-	21	54.83	122.64	-	-	-
>6 years	40	100	265.00	13	31.99	71.50	-	-	-
Total	40	100	265.00	40	100	223.50	40	100	40.00

*NF scheme implemented in 2019-20

Table 4 Cost and returns structure of soybean cultivation in the study area (₹ per acre)

Sl. No.	Particulars	CF	OF	NF
Cost A1				
1	Labour cost			
	Men labour	2133	2902	2435
	Women labour	1700	2461	1900
	Machine labour	1213	1280	1073
	Bullock pair	2713	1650	2061
Total Labour cost		7759	8293	7469
2	Seeds	1440	1393	1517
3	Manures and Fertilizers	0	0	0
i	Organic Manures	747	1816	0
ii	Chemical fertilizers	1261	0	0
iii	Growth promoters (naturals)	0	200	362
4	Plant Protection Chemicals	0	0	0
i	Bioagents/ Botonicals	0	946	440
ii	Chemicals	876	0	0
5	Miscellaneous expenses	1284	1280	1073
6	Depreciation	520	535	531
7	Land revenue	21	19	21
8	Interest on working capital (@ 7 %)	981	1002	817
Total Cost A1		14889	15484	12230
	Cost A1 + rent paid for leased-in land			
Cost A2	Rent paid for leased in land	0	0	0
	Total Cost A2	14889	15484	12230
	Cost A1 + interest on fixed capital			
Cost B1	Interest on fixed capital (@ 7 %)	228	233	234
	Total Cost B1	15117	15717	12464
	Cost B1+Rental value of owned land+ Rent paid for leased in land			
Cost B2	Rental value of owned land+ Rent paid for leased in land	2720	2776	2789
	Total Cost B2	17837	18493	15253
	Cost B1 + imputed value of family labour			
Cost C1	Cost B1	15117	15717	12464
	imputed value of family labour	650	550	600
	Total Cost C1	15767	16267	13064
	Cost B2 + imputed value of family labour			
Cost C2	Cost B2	17837	18493	15253
	imputed value of family labour	650	550	600
	Total Cost C2	18487	19043	15853
	Cost C2 + 10 per cent of cost C2 as management cost.			
Cost C3	Cost C2	17837	18493	15253
	10 per cent of cost C2	1784	1849	1525
	Total Cost C3	19621	20342	16778
Returns				
1	Main product (qtl)	8.56	7.9	7.10
2	Main product value (₹)	3966	4120	3966
3	By product value (₹)	0	0	0
4	Gross returns	33950	32548	28155
5	Returns over operational cost (A1)	19061	17064	15925
6	Returns over A2 (Farm Business Income)	19061	17064	15925
7	Returns over B2 (Family Labour Income)	16113	14055	12902
8	Returns over C2 (Net income)	15463	13505	12302
9	Returns over C3 (Returns to Management)	14330	12206	11377
10	B:C ratio over A1	2.28	2.10	2.30
11	B:C ratio over B2	1.90	1.76	1.85

CF - Conventional farming, OF- Organic farming, NF- Natural farming

Table 5 Comparison of yield, cost and returns of soybean grown under conventional, organic and natural farms (₹ per acre)

Particulars	Soybean				
	NF	CF	OF	Difference over CF	Difference over OF
Yield (Qtls)	7.10	8.56	7.90	-1.46 (1.76)	-0.80 (0.43)
Total cost	16062.50	18952.35	18885.50	-2889.85** (3.14)	-2823.00** (3.27)
Gross Returns	28155.05	33950.00	32548.00	-5794.95 (1.16)	-4392.95** (4.29)
Net returns	12092.60	15464.15	13662.50	-3371.55 (1.27)	-1569.90 (1.12)

Results for the economic analysis for different farming methods of soybean indicated that the highest total cost (₹ 18885.50) was found in organic farming because of more use of human labour and organic manures compared to conventional farming and natural farming. Net returns realized for soybean under the conventional farming was higher compared to natural farms even though cost of cultivation in natural farming was less. To realize better returns under natural farming, the farmers have to continue a minimum five years under natural farming practice, then after they could be realize better yield and net returns. Hence, yield maximizing production technologies needs to be developed for natural faming.

The 't' test values of total cost, gross returns and net returns of soybean under organic and natural farms indicated that total cost, gross returns under the natural farming practice was less than organic farming practice and significant ($p<0.05$). Similarly, total cost, gross returns and net returns of soybean under conventional and natural farms indicated that only total cost is significant (Table 5). The yield and price of soybean in all conventional, organic and natural faming was not is much different and significant in the study area due to good climatic conditions and soybean used mainly for industry but not for direct consumption.

Reasons for shifting to natural farming: The reasons given by the natural farm respondents behind shifting from conventional to natural farming were: to get benefits government schemes, to maintain soil health, self motivated to maintain harmful environmental impacts, by releasing harmful effect of chemicals on agriculture, to utilize natural resources in crop production, by looking at the successful natural farming adopted farmers. Majority of the respondents in the survey area were shifted to natural farming were influenced by the training programmes that are carried out in order to change the farmers' perception of the farmer on natural farming and some farmers shifted to take advantage of benefits of the scheme. The remaining respondents were self motivated in order to maintain the soil fertility and reduce environmental impacts that has been caused by the conventional farming. These results are in line with the study carried out by Khimajibhai (2007).

Policy options: This study revealed that among different farming methods for soybean cultivation conventional farming is economically better compared to organic and natural farming. The study suggests the following policy measures: (i) In order to encourage the natural farming for sustainable agriculture, research and extension activities need to be strengthened with more funds allocation. (ii) The research and development activities should focus more towards sustainable crop variety and technology to improve the yields under natural farming. (iii) Measures should be taken by the government to simplify the process of certification and set premium minimum support price for natural products in order to encourage the farmers for Natural farming.

ACKNOWLEDGEMENT

We would like to thank Nodal Officer and ORP Leader, North-Eastern Transition Zone (Zone-1) of Natural Farming project funded by Govt. of Karnataka for the financial assistance to conduct the survey and research.

REFERENCES

Anonymous 2015. *Bidar and Kalaburgi, Districts at a Glance,* Department of Economics and Statistics, Govt. of Karnataka.

Anonymous 2017. *Organic Farming Policy Report,* Department of Agriculture, Govt. of Karnataka, pp 1-23.

Birthal P S Parthasarathy Rao P Nigam S N Bantilan M C S and Bhagavatula S 2010. *Report on Groundnut and Soybean Economies of Asia Facts, Trends and Outlook.* International Crops Research Institute forthe Semi-Arid Tropics (ICRISAT), Patancheru,Hyderbad, India.

Naik A H Brunda S and Chaithra GM 2020. Comparative economic analysis of zero budget natural farming for *kharif* groundnut under central dry zone of Karnataka, *Indian Journal of Economics, Management and Trade*, **26**(6): 27-34.

Khimajibhai P R 2007. Economic analysis of natural farming in Gujarat state. M.Sc. (Agri.) Thesis, Junagadh Agricultural University, Junagadh (India).

Satpute T G More SS and Sanap D J 2009. Costs, returns and resource use efficiency in organic and inorganic soybean farming in Parbhani district. *Agri. Update,* **4**(2): 189-193.

Sharma P and Dupare BU 2016. Total factor productivity growth and returns from research investment on soybean in India. *Agricultural Economic Research Review,* **29**(1): 41-51.

Sharma R Aravind T and Sharma R 2019. Sustainable agriculture: Trends and opportunities for 21st Century. *Journal of Applied and Natural Science*, **11**(3):666-672.

Shrine S 2019. An economic analysis of energy use in zero budget natural farming, organic farming and conventional farming in rice production in Visakhapatnam district of Andhra Pradesh state. M. Sc. (Agri.) Thesis, ANGRAU (India).

Sitarambabu V Farukh Md and Solmon Raju Paul K 2014. Estimating growth rates, decomposition analysis and instability of groundnut crop production in Andhra Pradesh. *International Journal of Developmental Research,* **4**(1):85-87.

Thoenes P 2004. The role of soybeans in fighting world hunger. Paper presented at the VIIth World Soybean Research Conference, 1-5 Mar 2004, Foz do Iguassu, Brazil.

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 indic*a A.Juss.) seeds. Ph D Thesis, Indian Agricultural Research Institute, New Delhi.

Reference to unpublished work should normally be avoided and if unavoidable it may be mentioned only in the text.

Short Communication

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

Tables

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

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

Figures

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

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

Expression of Plant Nutrients on Elemental Basis

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

SI Units and Symbols

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

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

Names and Symbols of SI Units

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

Primary Units

length	l	time	t
metre	m	second	s
mass	m	electric current	I
kilogram	kg	ampere	A

Secondary Units

plane angle	radian	rad	Solid angle	steradian	sr

Unit Symbols

centimetre	cm	microgram	µg
cubic centimetre	cm^3	micron	µm
cubic metre	m^3	micronmol	µmol
day	d	milligram	mg
decisiemens	dS	millilitre	mL
degree-Celsium	°C [=(F-32)x0.556]	minute	min

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

Some applications along with symbols

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

Printed & Published by The Indian Society of Oilseeds Research,
ICAR-Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad-500030, India
Ph: (040) 24598113 / 24598170; Fax: (040) 24017969
Web site: http://www.isor.org.in; E-mail: oilseedsociety@gmail.com