THE INDIAN SOCIETY OF OILSEEDS RESEARCH

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

EXECUTIVE COUNCIL FOR 2015-2017

Editorial Board

MEMBERSHIP TARIFF

(w.e.f. 01.06.2014)

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

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

ANNOUNCEMENT

The Journal of Oilseeds Research has been rated at **3.97** by National Academy of Agricultural Sciences (NAAS) from January 1, 2016

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

JOURNAL OF OILSEEDS RESEARCH

Previous Issue : Vol. **32**, No. 2, pp.111-185

Vol. **33**, No. 1 March, 2016

CONTENTS

Review Article

Prospects and challenges in linseed (*Linum usitatissimum* L.) production: A review

S A BIRADAR, K AJITHKUMAR, B RAJANNA, A S SAVITHA, G V SHUBHA, I SHANKERGOUD, B M CHITTAPUR AND P K SINGH*

AICRP on Linseed, Main Agricultural Research Station, University of Agricultural Sciences, Raichur-584 104, Karnataka

(Received: January 9, 2016; Revised: March 19, 2016; Accepted: March 23, 2016)

ABSTRACT

Linseed or flax (*Linum usitatissimum* L.) is one of the most important industrial oilseed crops of India. It is grown either for the oil extracted from the seed or fibre from the stem. Every part of the linseed plant is utilized commercially either directly or after processing. Most of the oil is used in industry for the manufacture of paints, varnishes, inks and soaps and also used for edible purpose to a limited extent. The oil cake is a good feed for milch cattle and also used as manure. Linseed seed is widely used as a nutritive and functional ingredient in food products. Linseed in daily diet increases the level of α-linolenic acid (ALA) and omega-3 fatty acid which helps to reduce the risk of cardiovascular disease and cancer. AICRP on Linseed (ICAR) distributed in various agro-ecological situations in the country helped in introduction of new varieties adapted with appropriate production and protection technologies paved the way for introduction of the crop in different areas of the country and as component crop in cropping systems. It is possible to achieve higher yields and net monetary returns by adapting improved production technologies as demonstrated in FLDs conducted across the country. In this review, we have elucidated the production and protection technologies for improvement of linseed productivity in the country. The potential areas for future line of research are indicated for productivity improvement in linseed.

Keywords: Linseed, *Linum usitatissimum,* Production technology, Scope, Status

Linseed also referred as flax (*Linum usitatissimum* L.), is a self-pollinated crop widely adapted to temperate climates of the world. It is an annual plant belongs to the genus *Linum* and the family Linaceae. In fact, the name *Linum* is originated from the Celtic word lin or "thread", and the name *usitatissimum* is Latin for "most useful". It is believed that flax is originated in the Middle East or Indian regions. These ancient linguistic origins underscore the importance of flaxseed or linseed. The terms flax and linseed have particular meanings, depending on the region. In Europe, flax refers to the seed grown for fibre (linen) production, while linseed refers to oilseed flax grown for industrial and nutritional uses.

Linseed is one of the most versatile and useful crops that have been grown for thousands of years. It is cultivated as a commercial or subsistence crop in over 30 countries. Flax seeds are used for industrial, food and feed purposes. Seeds are rich source of both non-edible and edible oil. The industrial oil is an important ingredient in the manufacture of paint, varnish and linoleum. Edible linseed oil is used for human consumption and contains α-linolenic acid (ALA), a polyunsaturated fatty acid that has nutritional and health benefits (Neil and Alister, 2003). Apart from ALA, linseed is widely used as nutritional and functional food in the western world due to its high contents of therapeutic health promoting substances such as omega-3 fatty acid, soluble and insoluble fibre and lignans and its suitability to use with bread, breakfast cereals and other food products. In 2014, flax was approved by Flax Council of Canada, for a health claim to lower blood cholesterol, a major risk factor for heart disease by consuming ground or whole flaxseed. In most of the countries, linseed is cultivated mainly for its seed which is processed into oil and a high protein feed stock after oil extraction with the linseed straw generated as a by-product.

The stem fibre of flax is of considerable interest for the emerging bio-fibre industry. Flax fibre has good strength, light weight and gaining momentum as key ingredient in the manufacturing industry i.e. used for the production of paper, coarse textiles, rope, fibre board, molded panels and insulation material. Despite the potential uses of linseed fibre especially for composites and bio-based industries linseed fibre production is still economically marginal (Rennebaum *et al.,* 2002). This may be due to the wide use of conventional linseed cultivars which produce high seed and oil yield but low stem and fibre yield. However, recently there has been increased interest in breeding and growing dual purpose linseed cultivars which can be harvested for both seed and fibre (Foster *et al*., 1997).

*Project Coordinator (Linseed), CS Azad University of Agriculture & Technology, Kanpur-208 002, Uttar Pradesh

CROP SCENARIO IN INDIA

It is cultivated in the world over an area of 22.70 lakh ha with a production of 22.39 lakh t and productivity of 986 kg/ha. In India, it occupies an area of 3.38 lakh ha with a production of 1.47 lakh t and a productivity of 435 kg/ha (FAO, 2013). India ranks third in area after Canada and Kazakhstan which is almost equivalent but occupies fourth place after Canada, China and Kazakhstan in production. The productivity of 435 kg/ha is surpassed by almost all major linseed growing countries *viz.,* Canada (1728 kg/ha), USA (1659 kg/ha), UK (1500 kg/ha), China (1000 kg/ha) and Ethiopia (933 kg/ha). India contributes about 14.88 per cent and 6.57 per cent to world's area and production, respectively. The major part of linseed growing area lies in the states of Madhya Pradesh, Himachal Pradesh, Chhattisgarh, Uttar Pradesh, Maharashtra, Bihar, Odisha, Jharkhand, Karnataka and Assam accounting for more than 97 per cent of the total area. Although, the area is reducing owing to unorganized market intervention and socio-economic compulsion attached to the crop, there is a phenomenal improvement in productivity in the states of Rajasthan (1351 kg/ha), Bihar (850 kg/ha) and Nagaland (803 kg/ha) surpassing the productivity of Asia (728 kg/ha) as well as of world (986 kg/ha) (Anonymous, 2014).

Linseed is mostly grown under conserved moisture and limited nutrient conditions with poor management practices. Linseed production and productivity in India are very low, mainly due to its cultivation in residual moisture during *rabi* season where the crop experiences moisture stress at one or the other stages. However, its cultivation has been widely extended in irrigated areas because of higher yield potential and increased prices of oilseed in the market.

CROP IMPROVEMENT RESEARCH

Genetic resource management: The importance of the health-related properties of flax in human and animal nutrition may also stimulate further breeding and search for new traits in linseed germplasm collections. The availability of diverse germplasm, characterization data and evolutionary data is of greatest importance to realize the potential of linseed in agriculture. The importance of germplasm collections in early linseed breeding was documented by Dillman (1953). The use of landraces for fibre flax breeding was described by Zhuchenko and Rozhmina (2000). The total number of flax accessions in *ex situ* collections worldwide is estimated to be about 48,000 accessions, of which possibly 10,000 are unique. The results of recent germplasm characterization and evaluation projects conducted at the Canadian National Seed Gene Bank, Plant Gene Resources of Canada (PGRC) are presented in Table 1. The PGRC collection includes 3252 accessions of *L. usitatissimum* and 76 accessions of other species of the genus *Linum*. Only the flax collections preserved at the N.I. Vavilov Research Institute for Plant Industry (VIR) at St. Petersburg, Russia and at the All-Russian Flax Research Institute (VNIIL) at Torzhok, with about 6,000 accessions at each institute, exceed the Canadian collection in size. The majority of the PGRC accessions originated from the broad flax world collection established in the United States. The International Flax Data Base (IFDB) has been managed and coordinated by the AGRITEC Company since 1994 according to the rules published for the IFDB management (Pavelek, 1995; 1997; 1998).

Table 1 *Linum* L. taxa preserved at plant genetic resources of Canada

Species	No. of accessions	2n	Life form	Origin
L. altaicum Ledeb.	2	18	Perennial	W. Siberia
L. austriacum L.	3	18	Perennial	C. & E. Europe, W. Asia, Siberia
L. bienne Mill.	11	30	Winter-annual	W. Asia, Mediterranean, W. Europe
L. campanulatum L.	1	28	Perennial	W. Mediterranean
L. capitatum Kit. ex Schultes	1	34	Perennial	Balkan
L. decumbens Desf.	1	30	Annual	S. Europe
L. flavum L.	4	28 (30)	Perennial	S. & C. Europe, Caucasus
L. grandiflorum Desf.	7	16	Annual	Algeria
L. hirsutum L.	1	16	Perennial	C. & E. Europe, W. Asia
L. leonii F.W. Schultz	1	18	Perennial	France, Germany
L. lewisii Pursh	11	18	Perennial	N. America
L. narbonense L.	3	18 (20)	Perennial	Mediterranean
L. pallescens Bunge	1	30	Perennial	W. Siberia
L. perenne L.	10	18 (36)	Perennial	C. & E. Europe, W. Asia, Siberia
L. rigidum Pursh.	1	20	Perennial	N. America
L. strictum L.	3	18 (30, 32)	Annual	S. Europe, Mediterranean, W. Asia
L. tenuifolium L.	1	16	Perennial	West Asia, Mediterranean, C. Europe
L. trigynum L.	2	20	Annual	S. & C. Europe, Mediterranean, W. Asia

Indian region has been reported to be rich in diversity, especially in the cultivated forms. The National Bureau of Plant Genetic Resources (NBPGR), New Delhi has in its collection, a total of about 2627 accessions including 2495 indigenous, 132 exotic accessions and 51 released varieties were conserved in long term and medium term storage.

Fifty one improved varieties have been released and notified for general cultivation in different agro-climatic conditions by Central Variety Release Committee (CVRC) and States Variety Release Committee as per details enumerated below:

Seed type varieties:

Irrigated condition: K-2, Mukta, T-397, Neelum, Himalini, Triveni, Chambal, LC-54, Pusa-2, Pusa-3, Janki, Jawahar-23, Garima, Shubhra, Shekhar, RL-914, Suyog, Binwa, Him Alsi-1 and Deepika.

Rainfed condition: Hira, Jawahar-1, Jawahar-7, Jawahar-17, Neela, C-429, R-552, S-36, Sweta, Laxmi-27, Kiran, Padmini, JLS-9, Sheetal, NL 97, Sheela, Kartika, Indira Alsi-32 and Sharda.

***Utera* situation**: LC-185, Surabhi, Baner.

Double purpose varieties: Gaurav, Jeevan, Nagarkot, Shikha, Rashmi, Meera, Parvati, Him Alsi-2 and RLU-6.

List of important varieties with their salient features are given in Table 2.

Table 2 List of linseed varieties with their salient features (Singh *et al*., 2015)

Name of the variety	Year of release	Pedigree	Originating centre	Duration (days)	Average yield (kg/ha)	Oil content(%)	Recommended states	Special features
T-397	1984	T-491 x T-1103-1	Kanpur	120-125	1100 (I)	44	U.P, Bihar, Assam, M.P and Rajasthan	Tolerant to rust, wilt and drought
Shikha	1997	Hira x Crista	Kanpur	135-140	1233	42	U.P, Bihar, Assam, and West Bengal	Tolerant to rust and wilt
Padmini	1999	(EC41628 x EC77959) x (DPL 20 x Neelum)	Mauranipur	120-125	943 (R)	43	U.P, Bihar, Assam, M.P, M.H, Odisha and Rajasthan	Resistant to powdery mildew
JLS-9	1999	(RL-102 x R 7) x J-23	M.P	115-125	1250	42	M.P	Tolerant to rust, wilt and powdery mildew
Sheela	2001	Gaurav x Janki	Kanpur	155-160	1379	41	H.P, Punjab, Haryana and J&K	Tolerant to rust, wilt and powdery mildew
NL-97	2001	R-7 x RLC-4	Nagpur	115-120	641 (R)	42	Vidarbha region of M.H	Brown medium seeded
Suyog	2004	(Kiran x KL-168) x Kiran	Sagar	118-125	1509 (I)	41.4	U.P, Bihar, Assam, M.P, M.H, Odisha, Karnataka and Rajasthan	Tolerant to rust, wilt, bud fly and powdery mildew
Indira Alsi-32	2005	Kiran x RLC-29	Raipur	110-115	780 (R)	39.1	CG, M.H, Odisha and Karnataka	Tolerant to powdery mildew
Sharda	2006	(Shubra x J1) x (J1 x Kiran)	Mauranipur	100-105	762 (R)	41.3	CG, M.H, Odisha, A.P and Karnataka	Moderately resistant to wilt, powdery mildew and bud fly
Pratap Alsi-1	2007	Acc.750 x RL-29-8	Kota	129-135	1997 (I)	41.0	Rajasthan Kota command area	Moderately resistant to wilt, powdery mildew and bud fly
PKDL-41	2011	Kiran x Acc.443	Hoshangabad	115-120	1600 (I)	40	M.P, U.P and Rajasthan	Resistant to wilt, powdery mildew and bud fly
Pratap Alsi-2	2012	RL-914 x NL-93	Kota	129-135	1957 (I)	41.8	Rajasthan	Moderately resistant to wilt, powdery mildew, *Alternaria* blight and bud fly
Arpita	2014	RLC 29 x R 1871	Keonjhar	102-106	849 (R)	35.6	Odisha	Resistant to wilt and powdery mildew
Kota Barani Alsi-3	2015	RL-903 x Ayogi	Kota	119-124	1370 (R)	38.7	Rajasthan	Moderately resistant to powdery mildew, *Alternaria* blight and bud fly
Kota Barani Alsi-4	2015	Triveni x RL-1011	Kota	120-126	1100 (R)	40.3	U.P, M.P and Rajasthan	Moderately resistant to powdery mildew, *Alternaria* blight and bud fly

I=Irrigated condition; R=Rainfed condition

The oil content in germplasm ranged between 29.4 per cent and 42.6 per cent. IC564681 recorded the highest oil content (42.6%), while the accession IC564591 recorded the least (29.4%). With respect to linolenic acid (omega-3 fatty acid), IC564631 possessed the maximum (57.1%) and IC564687 recorded the minimum (39.5%). Linseed germplasm with high oleic acid content was identified with IC564627 recording the maximum of 32 per cent (Sivaraj *et al*., 2012).

Interspecific hybridization: There are about 200 species in the genus *Linum*. The chromosomal count of the species of this genus reveals much heterogeneity. Species having 8, 9, 10, 12, 14, 15, 16, 18, 30 and more than 30 haploid chromosomes have been found. The chromosome number of cultivated species, *L. usitatissimum* is n=15. Several interspecific crosses have been attempted, but so far only crosses between species possessing the same number of chromosomes have been successful. The F_1's of crosses of *L. usitatissimum* with some other species that have n=15 chromosomes are vigorous and quite fertile and have been used to introgress certain desirable characters such as resistance to linseed rust (*Melampsora lini*).

Gill and Yermanos (1966) determined the fatty-acid composition of the seed oil of 34 wild species and 266 lines of the cultivated flax. The oil of the *Linum* species contained the same fatty acids i.e. palmitic, stearic, oleic, linoleic and linolenic as found in the oil of cultivated varieties of flax. However, the variability in relative proportions of these fatty acids among wild species had a much broader range than that found among the varieties of cultivated flax.

The wide range of variability in the fatty-acid composition among the *Linum* species could be of great significance in the improvement of flax. In spite of competition, linseed oil is preferred in the paint industry owing to its quick-drying characteristics, resulting from its high linolenic acid. Some of the wild species were found to have a considerably higher iodine value than the cultivated types and can serve as useful parents in flax-breeding.

It may be noted that the high iodine value of the wild species in many cases is due to the high linolenic acid content and the low oleic acid content. This high iodine value may prove to be significant for the following reasons: white linseed-oil paint has been seen to turn yellow with time; on the other hand, the white paint manufactured by using safflower oil, high in linoleic acid maintains white colour for a much longer period. A high linoleic acid in linseed oil might have the good qualities of safflower oil to a certain degree as far as the quality of paint is concerned. On the other hand, a successful interspecific cross using the wild species such as *L. sulcatum* (linolenic acid 3%) can provide segregating materials, out of which low or no linolenic acid strains of flax could be selected and which could produce an acceptable edible oil and use would be a new outlet for linseed oil.

Interspecific hybridization can also increase genetic variability through change in the pollination of the cultivated species. Some of the *Linum* species *viz., L. grandiflorum, L. perenne* and *L. anstriacum* are self-incompatible. A large number of crosses were attempted between the cultivated linseed (*L. usitatissimum*) and the self-incompatible species, but no success was achieved. In crosses in which *L. usitatissimum* was used as the female parent, aborted seeds were obtained which were shriveled and incapable of germination (Gill, 1966). Embryological studies of the cross *L. usitatissimum* and *L. grandiflorum* revealed that the embryo degenerates after 7 days because of somatoplast sterility. Attempts are being made to rear the cross by embryo culture and by transferring the incompatibility mechanism to the cultivated species. The self-incompatibility, if introduced into the cultivated species, will force cross-pollination and increase the genetic variability.

Mutation breeding: Though mutation in linseed was reported as early as 1925 by Tammes, the nature, induction and utilization of induced mutations in linseed are poorly understood. Attempts have been made to induce mutations in linseed using both physical (George and Nayer, 1973; Rai and Das, 1975; 1976) and chemical mutagens (Bianu *et al.,* 1972; Pospisil, 1974). Chlorophyll mutations in linseed were reported as early as 1925 by Tammes. Deshpande (1939) isolated chlorophyll deficient seedlings in the normal population of NP-12. Levan (1944) after X-irradiation found three families segregating for chlorophyll mutations in diploid but none in tetraploid. Rai and Das (1975) irradiated three varieties (Hira, Mukta and Neelum) of linseed with 10, 20, 30 and 40 kR of gamma rays. Besides different types of chlorophyll mutants, increase in mutation frequency was indicated with increasing dose of irradiation. The observed cholorophyll mutants were late in flowering, had reduced plant height and lower number of capsules per plant. However, number of non-bearing tillers per plant in these mutants increased considerably when compared with normal plants. Sharov (1971) through chemical mutagenic treatment reported mutants which had 52-56 per cent greater resistance to *Fusarium oxysporum* and also high yield. George and Nayar (1973) after irradiation of variety Neelum obtained dwarf mutant (TL-1) which matured 30 days earlier than the normal plants. Interestingly, the mutants had higher 1000-seed weight and higher oil content of lighter colour.

The most recent modification of oil composition with induced mutations has been the development and release in Australia and Canada of linseed cultivars of 'Linola' type with favourable cooking quality oil as an alternative crop in rotation with wheat (Green, 1986; Dribnenki *et al.,* 1996). The Division of Plant Industry, CSIRO, Canberra, transformed linseed oil into edible oil by reducing linolenic

and raising linoleic acid levels similar to that in traditional sunflower oil. Three new linseed cultivars 'Wallaga', 'Eyre' and 'Argyle' have been released under the generic types called 'Linola' and are grown in Australia and New Zealand. Linola cultivars have golden yellow seeds. Eyre is derived from an F_8 bulk originating from a single-plant selection taken in the F_4 of the cross 'Glenelg'/CPI 84495//4*'Zero'. Zero is the low-linolenic acid genotype derived by EMS (ethyl methane sulphonate) mutagenesis of the Australian linseed cultivar 'Glenelg' and recombination of two mutated genes (Green, 1986).

Breeding for drought tolerance: The root system of a plant is important while considering drought tolerance breeding programme. Root characteristics such as root length, root biomass and root volume would determine the efficiency of water extraction from soil. The germplasm with better root system drags moisture and nutrients from deeper layers of soil. The linseed germplasm lines *viz.,* 68/56120 (33.8 cm), Bengal-46 (31.5 cm) and ES-13239 (28.5 cm) was observed for higher root length and for high root volume *viz.,* Bengal-46 (4.3 cc), Bengal-70 (3.7 cc), CI-2006 (3.5 cc), ES-13239 (3.2 cc) and CI-1924 (3.1 cc). Based on the mean *per se* performance, three promising lines *viz.,* Bengal-46, ES-13239 and EC-322659 were identified for significant high root length, root volume, fresh root weight, dry root weight and number of capsules, which may perform more efficiently under moisture stress conditions by utilizing moisture from the deeper layers of soil profile (Rajanna *et al*., 2014). Microarray analysis to capture transcriptome associated with induced drought in flax and identified 183 differentially expressed genes (DEGs) associated with diverse cellular, biophysical and metabolic programmes in flax.

The molecular characterization of new drought tolerant flax cell lines is available, from cultivar Sakha 2, can adapt the water deficit in new reclaimed lands. Shoot regeneration via somatic embryogenesis was achieved from hypocotyl explants on MS medium contained 4% maltose and supplemented with 0.5 mg/l NAA + 2 mg/l BA. 0.082, 0.165 and 0.247 Molar concentrations of mannitol were added to the induction media as a material capable of causing drought conditions in the media. The proliferated embryogenic calli on various levels of drought were sub-cultured to the same fresh media but supplemented with 2 mg/l BA for shoot recovery (Anonymous, 2013a).

Biotechnological approaches to linseed improvement: Linseed is one of the earliest domesticated crops with the highest contents of the essential omega-3 fatty acid (FA), α-linolenic acid (ALA) and bioactive phenolic compounds such as lignans, predominantly secoisolariciresinol diglucoside (SDG), phenolic acids and flavonoids. However, there are scanty genomic resources available in linseed. Development of DNA markers wherein three microsatellite enrichment methods coupled with the next generation sequencing was utilized to develop 290 SSR markers. Computational approach such as EST database mining was exploited to develop 927 genic SSR markers and further mined the linseed genome for glycosyltransferases where 137 genes belonging to 14 phylogenetically distinct groups were identified. Among the ten genes selected for transcript profiling, the LuUGT74S1 gene showed the highest expression in developmental seed stages indicating its putative in planta function as secoisolariciresinol glycosyl transferase and also mined linseed genome to identify miRNA, as they are known to play an important role in plant growth and development and NBS-LRR genes, the largest class of disease-resistance genes. This lead to identification of 116 conserved miRNAs and 147 NBS-LRR genes in linseed genome. India has a large collection of linseed germplasm (2239 accessions) and developed the core collection of Indian linseed (222 lines) using 12 morphological characters to analyze the Indian linseed diversity. GBS analysis of a subset of this population leads to identification of QTLs for yield in linseed. The developed core collection represents the diverse linseed accessions and can be utilized for wide applications in breeding (Gupta *et al*., 2014).

Genomic library was constructed in linseed genotype NL-97 using four restriction enzymes (Hae III, Alu I, Rsa I and SAU 3A-1). Three repetitive oligonucleotides i.e. (AT) 12, (CT) 14 and (AAC) 8 were used to capture microsatellite containing clones. Successful transformation was confirmed by restriction analysis. Further, sequencing of the transformants will be carried out in order to developing microsatellite markers which will be utilized in genetic mapping, diversity and cultivar identification (Anonymous, 2013a).

Flax was among the first commodity crop species to be genetically engineered by recombinant DNA technologies (McHughen, 2002). It was also among the first plant species to be genetically modified for imparting agronomic traits such as herbicide resistance (Jordan and McHughen, 1988; McHughen, 1989) and salt tolerance (McHughen, 1987). Flax has been transformed with resistance to several herbicides including glyphosate, glufosinate and sulfonylurea (McHughen, 2002). The only GE flax cultivar in the world, 'CDC Triffid', resistant to sulfonylurea herbicide, was considered for commercial release in Canada in 1998 (McHughen, 2002), but after commercialization for six years, it was deregistered at the request of the flax industry because of the European Union's (EU) concern with importing GE flaxseeds.

As a minor crop, flax has not benefited from intense breeding efforts and genetic engineering approaches to

improve yield, increase competition with weeds, and decrease maturation time. In contrast, China, India, and the Ukraine have recently adopted large-scale flax production strategies (FAO, 2007) and may become global competitors to the export market currently dominated by Canada. Recently, the fibre-flax growing region in the EU has been faced with the problem of low quality fibre which has led to a rapid decrease in the demand of this product and the area committed to growing the crop (Wrobel-Kwiatkowska *et al*., 2007). Governments and the flax industry in Canada and abroad have been slow to invest in genomics, molecular biology and genetic engineering to enhance the performance of this multipurpose crop.

The transformation of flax with a phosphonothricin acetyltransferase (PAT) gene conferring tolerance to the nonselective herbicide glufosinate was attempted and field tested (McHughen and Holm, 1995). The particle gun bombardment system was also used for genetic engineering of flax (Wijayanto, 1998; Wijayanto and McHughen, 1999). The GUS (β-glucuronidase) reporter gene was used to test different seed specific promoters in flax. The results suggested that the β-ketoacyl-CoA synthase (KCS) gene and the gene encoding napin (a major storage protein in *Brassica napus* L.) would not be expressed at high enough levels to be useful promoters, but USP (encoding an unknown seed protein from *Vicia faba* L.) and LeB4 (encoding a legumin protein from *Vicia faba*) promoters could be successfully used for heterologous gene expression in flax (Drexler *et al.,* 2003). Transgenic research of flax in India is still in its nascent stage.

PRODUCTION TECHNOLOGY

Production technology certainly be helpful in changing the production status of flax which will ultimately improve the economic status of the farmers of the country thus nutritional security.

Seed rate, row spacing and genotypes: The seed rate depends on method of sowing, genotype, soil moisture and fertility status of the soil. Row spacing as a non monetary input that can increase the yield by maintaining proper plant population with lower competition. Sunitha and Pooja (2013) reported that the effect of varieties was significant on seed and fibre yields during both the years of study. Seed yield of 'LCK8605' was higher followed by 'Gaurav' producing significantly higher than 'LCK8528'. Higher seed yield of 'LCK8605' was owing to more number of capsules/plant and seeds/capsule. For fibre yield 'LCK8528' was better due to more plant height and higher straw weight per unit area. Effect of seed rate has found significant only on fibre yield during both the years. Fibre yield increased significantly with every increase in seed rate. Thus maximum fibre yield was at highest seed rate of 60 kg/ha, this is due to more plant stand, plant height and straw weight per unit area. The interaction effect of varieties x seed rates was found non-significant in any case and thus all these varieties may be grown with similar rate of seed per unit area.

Sharma *et al.* (1996) reported that genotype KL-31 was recorded a significantly higher seed yield, straw yield, fibre yield, oil yield and total N uptake when compared with the variety DPL-21. Among the row spacings, 30 x 10 cm has recorded a significantly higher seed, straw, fibre and oil yield and total N uptake when compared with that of 10 x 10 cm. Gokhale *et al.* (2008) reported that growth characters like plant height, number of branches/plant and total dry matter accumulation was recorded significantly higher by the variety RLC-4 than Garima. The increased plant height was observed when linseed crop was sown at 22.5 cm and 30 cm spacing, whereas number of branches per plant and total dry matter accumulation was higher at 37.5 cm row spacing. The interaction effect between spacing and phosphorous levels on seed yield and straw yield was significantly superior at 22.5 cm and 75 kg P_2O_5/ha (Singh *et al.,* 1982).

Date of sowing: The sowing time for linseed varies from region to region. It depends on availability of soil moisture, irrigation and cropping system. Verma and Pathak (1993) revealed that the highest number of capsules/plant, seeds/capsules, test weight and seed yield/plant were recorded when sown during 8th October followed by 18th October. Yield reduction in delayed sowing was also due to high temperature, more incidence of insect pests and fungal diseases at bud and capsule formation stages. The highest straw yield and harvest index were recorded in 8th October and 18th October, whereas lowest was recorded when sown during 27th November. Early sowing (8th October) and prolonged vegetative and reproductive growth positively influenced the seed oil content. Therefore it declined with successive delay in sowing the oil content was reduced progressively till 27th November. Results indicated that Garima was found suitable for late sowing, while, Neelum was good for early sowing. Reduction in seed yield due to late sowing was less in Garima than the other varieties, perhaps due to earliness and genetic capability of the variety. Linseed sowing on 30th October with the variety NL-115 recorded a significantly higher grain yield when compared with late sowing and other varieties (Anonymous, 2013b). However, sowing of linseed after 20th October with the variety of NL-115 recorded a significantly lower incidence of powdery mildew disease than late sowing with other varieties.

Cropping system: Linseed is grown as monocrop, intercrop, sequence crop or *utera* crop. Linseed is also grown intercropped or mixed with chickpea, lentil, barley,

safflower, sorghum and wheat to stabilize production and increase the monetary returns under rainfed condition. Hiremath *et al.* (1990) reported that intercropping of wheat + linseed at 3:1 and 1:2 row proportions has recorded higher total seed yield, gross returns and higher LER when compared with the other row proportion and sole crops. Mishra *et al.* (2001) reported that chickpea genotype 'BG 256' in association of 'Neelum' linseed genotype planted under 6:2 row arrangement proved more sustainable with highest chickpea equivalent yield and economically viable system supported by different economic and biological parameters. Mishra and Masood Ali (2002) reported that intercropping of lentil with linseed under 6:2 row arrangement produced highest seed yield of both the crops which is supported by the higher product of relative crowding coefficient, land equivalent ratio and area time equivalent ratio. All the intercropping systems were found productive and economically viable. The mustard + linseed in 2:4 ratio produced the higher LER (1.16) and B:C ratio (2.52) over rest of planting geometry. Tanwar *et al.* (2011) reported that intercropping systems of linseed with chickpea were found more advantageous than sole cropping under reduced fertilizer application. The system productivity (chickpea equivalent yield), total LER, net returns and B:C ratio of chickpea + linseed intercropping under both the row arrangements (5:1 and 4:2) were significantly higher over sole linseed. Biradar *et al.* (2015) explored the performance of linseed genotypes in 4:2 row proportions of chickpea + linseed under rainfed condition. Among different intercropping treatments, the highest net returns (₹12,664/ha) and B:C ratio (2.32) were obtained with chickpea (JG-11) + linseed (Jawahar-23).

Nutrient management: Productivity of linseed is low because of its cultivation is restricted to nutrient and moisture starved conditions. Improved varieties of linseed respond well to use of fertilizers. Nitrogen requirement varies from soil to soil. Adequate supply of P increases the seed and oil yield. P hastens the root development and promotes deeper penetration which helps in utilization of subsurface moisture. Adequate quantity of K in soil is essential for normal and healthy development of linseed plant. Inadequate supply shortens the stem and fibre length. Application of sulphur led to increase in seed yield and oil yield. With each successive increase in the level of sulphur up to 60 kg/ha significantly increased the seed yield, oil yield and content of sulphur as well as total uptake of N, P and S by the crop (Mandol *et al.,* 2005). Among the sources of sulphur, gypsum proved significantly superior to other sources for seed and oil yields and uptake of nutrients. Badiyala and Chopra (2011) reported significantly higher seed yield of linseed when full dose of NPK was applied along with 5 tonnes/ha of FYM, while significantly lower seed yield recorded with 50% of recommended dose of fertilizer.

Water management: Linseed crop is grown under rainfed condition but it responds well to irrigation profitably and minimal irrigation at critical stages results in higher efficiency. Awasthi and Dubey (2011) reported two irrigations applied at 35 and 70 days after sowing (DAS) gave significantly higher seed yield than no irrigations and one irrigation either at 35, 50 or 70 DAS. This can be attributed to more plant stand, increased plant height, primary branches/plant, capsules/plant and straw yield with one irrigation at 35 DAS which at par with application of two irrigations. Increasing seed yield of linseed due to irrigation might be due to fact that water helped in better utilization of nutrients in soil. This can be attributed to more plant stand, plant height, primary branches/plant, capsules/plant and test weight. The interaction effect showed that RLC-46 and RLC-47 though produced comparable grain yield with two irrigations at 35 and 70 DAS but significantly superior over other combinations of varieties and irrigation schedules.

Weed management: Linseed is mainly grown under conserved moisture and limited nutrient supply with poor management practices. Weeds pose a major threat to linseed in robbing these limited resources. The initial growth of linseed is very slow, and the critical period of crop-weed competition is between 25 to 45 days after sowing. It is estimated that loss in seed yield may likely to go to the extent of 42-45 per cent under un-weeded condition. Excessive weed populations reduce availability of water and nutrients to the crop. This may also result in increased harvest difficulties. Competition with weeds can also reduce flax oil quality by lowering the iodine number. Besides, clean fields at harvest are critical for flax fibre production where the presence of weeds complicates processing of flax fibres and increases production costs. However, rarely the crop potential is realized under farmers' situation because of varied reasons.

The top 10 weeds found in linseed crop ranked by relative abundance are green foxtail, wild oats, wild buckwheat, redroot pigweed, volunteer wheat, lambsquarters, Canadian thistle, pale smartweed, Russian thistle and wild mustard (Soliman, 2010). Relative abundance of a weed species often varies among regions and this was also observed in the top 10 weeds in linseed among the eco-regions of the Canadian Prairies. Early removal of weeds is necessary to minimize crop losses caused by weed competition.

Herbicides are a key component of weed management programs in conventional flax production. Some of the pre- and post-emergence herbicides along with combination

products are registered for early season weed management in linseed. Among the different pre- and post-emergence herbicides of late, combination product like pendimethalin 30 EC + imazethapyr 2 EC (Valor 32 EC) at different doses are reported to provide excellent control of problematic weeds. Sandhu *et al.* (1988) revealed that application of fluchloralin (0.5 kg a.i./ha) as pre-plant incorporation; isoproturon (0.75 kg/ha) as pre-emergence; diclofopmethyl (0.70 kg a.i./ha) as post-emergence and methabenzthiazuron (1.0 kg a.i./ha) as pre-emergence application resulted in higher seed yield of linseed. Tomar *et al.* (1990) found that pre plant application of fluchloralin 1.0 kg/ha gave best performance and was comparable with a hand weeding at 30 DAS in respect of linseed seed yield (478 kg/ha). Pre-emergence application of metribuzin 0.25 kg/ha and oxadiazon 1.0 kg/ha indicated phytotoxic effect on crop as indicated by significant reduction in plant population of linseed per metre row length.

At Kanpur, post-emergence application of clodinafop @ 60 g a.i./ha recorded significantly higher seed yield (1520 kg/ha) over all other treatments and was on par with hand weeding (HW) at 20-25 DAS and 40-45 DAS (1615 kg/ha) (Anonymous, 2013b). Similarly at Palampur, experiment conducted under irrigated conditions showed pre-emergence application of pendimethalin 30 EC @ 1.0 kg a.i./ha out yielded significantly (1363 kg/ha) over all other treatments except hand weeding twice and clodinafop @ 60 g a.i./ha in linseed. Similarly at Kota, under irrigated conditions, post-emergence application of imazethapyr 10 EC @ 75 g a.i./ha recorded higher yield of linseed (1402 kg/ha), which was followed by pendimethalin 30 EC + imazethapyr 2 EC @ 0.75 kg a.i./ha as pre-emergence spray and imazethapyr 10 EC @ 100 g a.i./ha as post-emergence spray (1374 and 1347 kg/ha, respectively) and both were on par with each other, but differed significantly with hand weeding twice i.e., HW at 20-25 DAS and 40-45 DAS. Under irrigated conditions at Varanasi, pre-emergence application of pendimethalin 30 EC + imazethapyr 2 EC @ 0.75 kg a.i./ha produced higher seed yield of linseed (1563 kg/ha) over rest of the weed management treatments but it differed significantly with hand weeding twice (Anonymous, 2013b). In black clay soil under irrigated conditions at Raichur revealed that, among the herbicides, pendimethalin 30 EC + imazethapyr 2 EC @ 1.0 kg a.i./ha as pre-emergence spray recorded higher yield components *viz.,* number of capsules per plant (34.7), capsule weight (2.84 g/plant) and seed yield (852 kg/ha) over other herbicide treatments except clodinafop 15 WP @ 60 g a.i./ha. The same treatment also recorded higher straw yield (2340 kg/ha) and flax fibre yield (1227 kg/ha). Population of bacteria, fungi and actinomycetes were also higher with application of pendimethalin 30 EC + imazethapyr 2 EC @ 1.0 kg a.i./ha as pre-emergence spray. Weed-free and farmers' practice were comparable with one another with respect to nutrient uptake through seeds as well straw followed by pendimethalin 30 EC + imazethapyr 2 EC @ 1.0 kg a.i./ha as pre-emergence spray (Siddesh *et al.,* 2015).

Disease management

Powdery mildew (*Oidium lini*): Powdery mildew has been reported to cause damage to linseed crop in North India. Crop grown in rich soil and under prolonged humid weather conditions develop severe infection of this disease. Heavy infection may cause shriveling of grains. Occurrence of linseed powdery mildew was reported at Raichur, Kangra, Kanke, Mauranipur, Nagpur and Raipur. Highest disease score was reported from Raichur (2-95%) followed by Raipur (5-80%) and Palampur (25-80%) (Anonymous, 2014). Ajithkumar *et al.* (2014) conducted survey on linseed powdery mildew in northern districts of Karnataka revealed that during *rabi* disease incidence was maximum in Raichur district (57.5%) followed by Bidar (56 %) and Kalaburgi (52 %). Screening of linseed germplasm lines for powdery mildew resistance revealed that 17 lines (EC-41656, FR-3, Kanpur-41/2, GS-232, LS-35, LCK-11, POLF-16, POLF-17, OR-1-4, S-801, JRF-1(8), S-91-26, RL- 903, Meera, EC-322646, UDN-55 and IDSN-6) were highly resistant even after artificial inoculation, whereas 16 lines showed symptoms after the inoculation but the infection was not severe and recovery was rapid (Ajithkumar *et al.,* 2015). Khunti *et al.* (2009) reported that fungicidal treatments hexaconazole at 0.05 and 0.025 per cent, propiconazole at 0.025 and 0.0125 per cent, wettable sulphur were on par with carbendazim 0.05 per cent with average of 9.5 per cent disease intensity. The yield received from the treatment hexaconazole was highest (1330 kg/ha) and it was on par with carbendazim (1219 kg/ha).

Wilt (*Fusarium oxysporum* f.sp. *lini*): Wilt is one of the most serious diseases of linseed and has been reported from almost all the linseed growing countries. In India, the disease was first reported from Madhya Pradesh in 1923. Since then, it has been found in other linseed growing areas also. Barnwal *et al.* (2011) recorded 87 per cent wilt incidence in Rajasthan and the extent of damage largely depends upon the incidence of the disease and the time of attack during the crop season. In severe cases of the disease the crop may be completely destroyed. Long rotation of crop to reduce the incidence of the disease may not be effective as the fungus survives for long periods in soil or on other hosts. The linseed varieties *viz.,* RR 8, NP 12, NP 21, NP 124, NP 58, NP (RR) 5, RR 80, RR 82, RR 202(1) and PP (RR) 12 were identified as wilt resistant (Kulkarni *et al.,* 1969). Fungicidal management by dressing the seed is helpful in reducing the infection. Padmavathi *et al.* (2015) have recommended seed treatment with thiram (3 g/kg seed) or carbendazim (1 g/kg

seed) or thiophonate methyl M (2.5 g/kg seed) or *Trichoderma viride/T. harzianum* (4 g/kg seed) for the management of wilt.

Rust (*Melampsora lini*): The rust disease is of wide occurrence in almost all the linseed-growing parts of the world. The rust infections are generally heavy in the regions of northern hills, Bihar, West Bengal; Eastern and Western Uttar Pradesh in India. Some of the varieties *viz*., RR 5, RR 9, RR 10, RR 37, RR 38, EE 40, RR 45, RR 197, RR 262 and RR 272 were reported immune or resistant to all the races of rust prevalent in India (Vasudeva, 1962). Seed dressing with oxycarboxin (2.5 g/kg seed) and foliar spray with benomyl (1 g/l) or tridemorph (0.5 g/ml/l) or tridemorph + mancozeb (2.5 g/l) were found effective in decreasing rust infection (Padmavathi *et al.*, 2015; Singh *et al.*, 2015).

Alternaria leaf spot (*Alternaria lini* and *A. linicola*): In India, the *Alternaria* disease was first reported by Dey (1933) from Kanpur in Uttar Pradesh. The disease was found to cause heavy damage, especially in low lying, ill-drained fields with the yield losses ranging from 28-60 per cent. The management of the disease is possible with late varieties for the wet tracts. Seed treatment with thiophonate methyl M (2.5 g/kg seed) or iprodione (2 g/kg seed) and foliar spray with iprodione (2 ml/l) or mancozeb (2.5 g/l) or calixin (1 ml/l) two times at 10 days interval minimize the infection (Kumar *et al*., 2015).

Dry root rot (*Rhizoctonia solani*): The dry root rot disease caused by *R. solani* is one of the most destructive pathogen in arid regions and has wide host range. In India, it has reported from Andhra Pradesh, Bihar, Gujarat, Karnataka, Maharashtra, Madhya Pradesh, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal. Screening of linseed varieties against dry root rot along with susceptible check (Chambal) revealed that the two varieties Jeevan and Padmini proved resistant to the dry root rot disease and the varieties Jawahar 23, Kiran, T-397, R 552 and Surabhi were moderately resistant. Among organic amendments tested, neem cake was found to be superior over others with least per cent seedling mortality (24.85) followed by suppressive soil (27.05) and groundnut cake (32.45). Fungicides *viz*., hexaconazole and carbendazim both treated at 2 g per kg seeds were found superior in reducing per cent mortality of plants (Patil, 2005).

Insect pests management:

Bud fly (*Dasineura lini*): Bud fly is a serious pest of linseed in Asia particularly in India, Bangladesh and Pakistan (Biswas and Das, 2011). Incidence of bud fly in linseed was reported first time in India by Pruthi and Bhatia (1937) from Pusa (Bihar), who also noticed infestation of this pest on flower buds of pigeonpea during *kharif* season as an alternate host. In India, this pest causes up to 90 per cent losses in seed yield in Indo-Gangetic plains, central and southern plateau region. Complete failure of this crop due to this pest has also been observed under epidemic conditions (Malik, 1999). Biological suppression of maggots of bud fly takes place inside the flower buds mainly by a chalcid, *Systasis dasyneurae.* The extent of parasitization was up to 50 per cent larvae during early February at the initial stage of bud fly infestation. A chalcid, *Ecrizotomorpha taskiri* has been observed hyperparasitizing on the larvae of *S. dasyneurae.* The grub and adult stages of coccinellid particularly *Coccinella septempunctata* and *Menochilus sexmaculatus* predate voraciously on the full grown maggots of bud fly outside the bud on their way for pupation. The extent of predation was reported up to 15 per cent during late February to March (Malik, 1997). IPM components like deep summer ploughing to expose bud fly maggots, crop rotation, sowing during last week of October to first fortnight of November, intercropping with chickpea (3:1) or mustard (5-6:1), keeping light trap or attractant like jaggery (1 kg/75 l of water) to lure and kill adult flies and need based application of NSKE (5%) or imidacloprid 17.8SL @ 100 ml/ha or spinosad 45SC @ 165 ml/ha found effective against bud fly (Malik *et al*., 2009; Kumar *et al*., 2015).

NUTRITIVE VALUES OF LINSEED

Linseed is a best source of omega-3 fatty acid and it is essential as it cannot be synthesized by the body, must be supplemented directly from foods. This imparts in cholesterol lowering, cardiovascular benefits by affecting prostaglandins and leukotrienes related blood clotting and inflammatory disorders like rheumatoids arthritis. The composition of linseed in 100g contains, energy 450kcal, total fat 41g, ALA 23g, protein 20g, total carbohydrates 29g and total dietary fibre 28g (Morris, 2007) (Table 3). It also source of antioxidants, minerals like Se, Zn, Mg, K and essential vitamins. Flaxseed contains highest arginine and tryptophan when compared with sunflower which are essential amino acids to reducing the healing time of injuries and protein biosynthesis (Table 4). Flaxseed contains highest vitamin B_6 and beta carotene when compared with sunflower which is essential to maintain the epithelial tissue health. Flax is rich in magnesium when compared with soybean which acts as co-factor in muscle contraction. Ganorkar and Jain (2013) gave the fatty acid content of linseed. Flax oil contains saturated fatty acid 9 per cent, mono-unsaturated fatty acid 18 per cent, omega-6 fatty acid 16 per cent and omega-3 fatty acid 57 per cent which is very important from the health point of view. Flax contains highest lignan content when compared with the other plant sources which acts as antitumor, antimitotic and antioxidant to reduce the cardiovascular diseases and cancer (Table 5).

Table 3 Composition of linseed (Dave Oomah, 2001)

Form of flax	Weight (g)	Common measure	Energy K cal	Total Fat (g)	ALA (g)	Protein (g)	Total CHO (g)	Total Dietary fibre (g)
Proximate analysis	100	-	450	41.0	23.0	20.0	29.0	28.0
Whole seed	180	1cup	810	74.0	41.0	36.0	52.0 3.0	50.0
	11.0	1 tbsp	50	4.5	2.5	2.2	1.2	3.0
	4.00	1 tsp	18	1.6	0.9	0.8		1.1
Milled seed	130	1 cup	585	53.0	30.0 1.8	26.0	38.0	36.0
	8.00	1 tbsp	36	3.3	0.6	1.6	2.3	2.2
	2.70	1 tsp	12	1.1		0.5	0.8	0.8
Flax oil	100	-	884	100.0	57.0 8.0	-	-	-
	14.0	1 tbsp	124	14.0	2.8	-	-	-
	5.00	1 tsp	44	5.0		-	-	-

Table 4 Amino acid composition of selected oilseeds (Baoxiu Qi *et al*., 2004)

Amino acid	Flax	Soybean	Sunflower
	g/100 g protein		
Arginine	9.2	7.32	8.18
Cystine	1.1	1.5	1.77
Histidine	2.2	2.77	2.60
Isoleucine	4.0	4.56	4.09
Leucine	5.8	7.81	6.41
Lysine	4.0	6.29	3.56
Methionine	1.5	1.44	2.29
Phenylalanine	4.6	5.26	4.62
Threonine	3.6	3.96	3.72
Tryptophan	1.8	1.26	1.19
Valine	4.6	4.64	4.95

Table 5 Levels of lignan in different plant sources (Chen Jaun *et al*., 2007)

Plant source	Lignan	Level (mg/kg: dry weight)
Flaxeed	SECO	3699
	Matairesinol	10.9
	Matairesinol	7 to 28.5
	SDG	11900 to 25900
Sesame seed	Sesamin	1547 to 8852
	Sesamolin	0.1 to 4765
Cereals	SECO	0 to 1.3
	Matairesinol	0 to 1.7
Vegetables	SECO	0.1 to 38.7
	Matairesinol	Trace-0.2
Legumes	SECO	0 to 15.9
	Matairesinol	0 to 2.6
Fruits	SECO	Trace-30.4
	Matairesinol	0 to 0.2
Berries	SECO	1.4 to 37.2
	Matairesinol	0 to 0.8
Tea	SECO	15.9 to 81.9
	Matairesinol	1.6 to 11.5

SDG - secoisolariciresinol diglucoside; SECO - secoisolariciresinol

Matthews *et al*. (2000) reported that fish contains 100 per cent omega-3 fatty acid but lacks in omega-6 fatty acid. Among the vegetables, flax contains 57 per cent of omega-3 and 14 per cent of omega-6 fatty acid which is highest in flax when compared with others. Kristensen *et al.* (2012) reported that flax drink lowered the total and LDL cholesterol by 12 and 15 per cent when compared with the control, where as smaller decline were observed for flax bread in comparison to control, but there was no effect on HDL cholesterol this is due to flaxseed fibres may be useful for lowering blood cholesterol (LDL and HDL are the lipoproteins present in blood) (Table 6). Preethi and Chimmad (2010) reported that omega rich flax can improves the shelf life of supplementary food and also it increases the quality of food when compared with the control.

Table 6 Omega-6 and omega-3 content of various vegetable oils and foods (Noemi, 2014)

Oil	-6 content (%)	-3 content (%)
Safflower	75	0
Sunflower	65	0
Corn	54	0
Cotton seed	50	0
Sesame	42	0
Peanut	32	0
Soybean	51	7
Canola	20	9
Walnut	52	10
Linseed	14	57
Fish	0	100

PROSPECTS

The genetic improvement in linseed has so far been carried out through conventional breeding methods such as introduction, single plant selection and to limited extent hybridization. The recent techniques have shown the possibilities for utilizing novel techniques such as male sterility, haploidy, interspecific hybridization, mutation and tissue culture for the genetic upgrading of this crop. Breeding methods such as recurrent selection is suggested to break undesirable linkages. The biometrical procedures such as diallel crosses, line x tester analysis need to be extended

to derive basic information on the various polygenic traits and assess the type and magnitude of variability to be used in selection and hybridization.

Breeding varieties resistant to insect pests and diseases particularly rust, wilt and powdery mildew need to be continued on priority for linseed improvement. It is suggested to breed varieties for multiple resistance. There is urgent need to identify 'hot spots' and develop efficient screening techniques including the identification of resistant source and cataloguing of genes governing resistance to various disease and pests.

The linseed yields are low (100 kg/ha) under *utera* conditions, there is a need to develop high-yielding genotypes under such conditions. The research on breeding varieties for rainfed conditions and those responsive to intercropping need to be intensified emphasis should be given to develop efficient plant types responsive to intensive management conditions. Breeding for various physiological traits need to be undertaken and appropriate selection indices developed on the basis of various characteristics like photosynthetic efficiency, harvest index, etc.

Research on induced mutations could be used to create new genetic variability. The induced mutants could further be utilized in hybridization to develop high-yielding varieties resistant to various diseases and possessing oil of superior quality.

The haploid method of breeding is suggested to shorten the number of generation required to produce new linseed varieties. Methods need to be devised for producing haploids in the wide range of genotypes and to raise the frequency of haploids either through hybridization and selection or by anther-culture technique. The procedures for the easy identification, chromosome doubling and vegetative multiplication of haploids could further be extended to new genotypes and in developing linseed varieties in a much shorter period.

The research on interspecific hybridization needs to be intensified to tailor the useful variability for fatty acid composition from wild species to the cultivated varieties. In the genus *Linum* which has about 200 species (n=8 to 43), interspecific crosses have been obtained between some species having the same chromosome number. Special efforts are required for the incorporation of increased iodine value through species hybridization so as to enhance the quality of oil. The genetic variability to develop varieties with iodine value as high as 175 for industrial purposes needs to be exploited. The approach of interspeciffic hybridization could produce an acceptable edible oil, a new provision for linseed oil. Interspecific hybridization coupled with embryo culture and somatic cell hybridization could go a long way in transferring desirable genes to the cultivated species and in understanding the genomic relationship among various species of *Linum*.

Research need to be orientated to exploit heterosis and develop hybrid varieties of linseed. This would require the development of cytoplasmic male sterile lines with open corolla so as to facilitate cross-pollination. In linseed, a few completely male sterile lines with open corolla have become available; the next step for producing hybrid linseed is to identify environmental conditions conducive to cross-pollination and hybrid seed production using these lines. The selection of restorer and maintainer lines with wind pollination could also prove useful.

Linseed/flax seed is emerging as one of the nutritive and functional ingredient in food products. Including flax in daily diet increases the level of ALA and omega-3 fatty acid which helps to reduce the risk of cardiovascular disease and cancer. It is possible to achieve higher yield of linseed and monetary returns by adapting improved production technologies.

REFERENCES

Ajithkumar K, Biradar S A, Rajanna B and Govindappa M R 2014. Survey and surveillance of powdery mildew in linseed growing areas of Northern Karnataka. *Journal of Mycopathological Research*, **52**(1): 59-63.

Ajithkumar K, Biradar S A and Rajanna B 2015. Screening of linseed germplasms for resistance against powdery mildew caused by *Oidium lini* Skoric. *Journal of Mycopathological Research*, **53**(2): 247-251.

Anonymous 2014. Annual Report of Linseed, All India Coordinated Research Project on Linseed, Project Coordinating Unit (Linseed), Kanpur, pp. 270.

Anonymous 2013a. Annual Report, ICAR- National Bureau of Plant Genetic Resources, New Delhi, India.

Anonymous 2013b. Annual Report of Linseed, All India Coordinated Research Project on Linseed, Project Coordinating Unit (Linseed), Kanpur, pp. 270.

Awasthi U D and Dubey S D 2011. Effect of nitrogen and moisture conservation practices on yield, uptake, water-use efficiency and quality of linseed (*Linum usitatissimum*). *Indian Journal of Agricultural Sciences*, **81**(4): 383-385.

Badiyala D and Chopra P 2011. Effect of zinc and FYM on productivity and nutrient availability in maize (*Zea mays*) - linseed (*Linum usitatissimum*) cropping sequence. *Indian Journal of Agronomy*, **56**(2): 88-91.

Baoxiu Qi, Tom Fraser, Sam Mugford, Gary Dobson, Olga Sayanova, Justine Butler, Johnathan A Napier, Keith Stobart A and Colin M Lazarus 2004. Production of very long chain polyunsaturated omega-3 and omega-6 fatty acids in plants. *Nature Biotechnology,* **22:** 739-745.

Barnwal M K, Kumar Rajeev and Kumar Binod 2011. Integrated management of *Alternaria* blight, *Melampsora* rust and fungal wilt of linseed (*Linum usitatissimum*) in field. *Journal of Mycology and Plant Pathology*, **41**(1): 53-56.

Bianu M, Marki A and Ochesanu C 1972. The flexuous stem-a new gene in *Linum usitatissimum* induced by the alkylating agents. *Botanique*, **25**: 171-175.

Biradar S A, Ajithkumar K, Rajanna B and Shubha G V 2015. Economic feasibility of intercropping of linseed and chickpea under rainfed condition (*Linum usitatissimum*). *Green Farming,* **6**(3): 601-603.

Biswas G C and Das G P 2011. Insect and mite pests diversity in the oilseed crops ecosystem in Bangladesh. *Bangladesh Journal of Zoology,* **39**(2): 235-244.

Chen Juan, Liu Xia and Shi Yan-Ping 2007. Determination of the lignan secoisolariciresinol diglucoside from flaxseed (*Linum usitatissimum* L.) by HPLC. *Journal of Liquid Chromatography and Related Technologies,* **30**(4): 533-544.

Dave Oomah 2001. Flaxseed as a functional food source, *Journal of the Science of Food and Agriculture,* **81**(9): 889-894.

Deshpande R B 1939. A note on the occurrence of chlorophyll deficiency in linseed. *Current Science,* **8:** 168-169.

Dey P K 1933. An *Alternaria* blight of linseed plant. *Indian Journal of Agricultural Science,* **3:** 881-896.

Dillman A C 1953. *Classification of Flax Varieties in USDA.* Technical Bulletin No. 1054, United States Department of Agriculture, Washington DC.

Drexler H S, Scheffler J A and Heinz E 2003. Evaluation of putative seed specific promoters for *Linum usitatissimum*. *Molecular Breeding,* **11:** 149-158.

Dribnenki J C P, Green A G and Atlin G N 1996. Linola -989 low linolenic flax. *Canadian Journal of Plant Science,* **76**: 329-331.

FAO 2007. Food and Agriculture Organization Statistical Databases. Available at http://faostat.fao.org/site/567/default.aspx#ancor (accessed 1 Sept. 2008; verified 11 Aug. 2009). FAO, Rome, Italy.

FAO 2013. Food and Agriculture Organization Statistical Databases. Available at http://faostat.fao.org/site/567/default.aspx#ancor. FAO, Rome, Italy.

Foster R, Pooni H S and Mackay I J 1997. Quantitative evaluation of *Linum usitatissimum* varieties for dual-purpose traits. *Journal of Agricultural Science, Cambridge,* **129**: 179-185.

Ganorkar P M and Jain R K 2013. Flaxseed – a nutritional punch. *International Food Research Journal,* **20**(2): 519-525.

George K P and Nayar K K 1973. Early dwarf mutants in linseed induced by gamma rays. *Current Science,* **42:** 137-138.

Gill K S and Yermanos D M 1966. Cytogentic studies of the genus *Linumu* L. hybrids among taxa with 9 as haploid chromosome number. *Crop Science,* **7:** 627-630.

Gill K S 1966. Evolutionary relationships among *Linum* species. Ph.D. Thesis, University of California, Riverside. pp. 243.

Green A G 1986. A mutant genotype of flax *(Linum usitatissimum*) containing very low levels of linolenic acid in its seed oil. *Canadian Journal of Plant Science,* **66:** 499-503.

Gupta V S, Kadoo N Y, Giri A P, Pardeshi V S, Barvkar V T, Kale S M, Rajwade A V and Shrivastava R L 2014. Genomics based tools for ω-3 fatty acid rich oil seed crop, linseed. In: *Proceedings of* 4th *International Workshop on Next Generation Genomics and Integrated Breeding for Crop Improvement*, 19-21 February, 2014, ICRISAT, Patancheru, India, pp. 23.

Hiremath S M, Hosmani M M, Hosur O R and Sudhakar B N 1990. Intercropping of linseed with wheat. *Karnataka Journal of Agricultural Sciences*, **3**(1& 2): 102-104.

Jordan M C and McHughen A 1988. Glyphosate tolerant flax plants from *Agrobacterium* mediated gene transfer. *Plant Cell,* **7**: 281-284.

Khunti J P, Bhoraniya M F and Vora V D 2009. Management of powdery mildew and cercospora leaf spot of mung bean by some systemic fungicides. *Legume Research,* **28**(1): 65-67.

Kristensen M, Jensen M G, Aarestrup J, Petersen K E N, Lise S, Mikkelsen M S and Astrup A 2012. Flaxseed dietary fibers lower cholesterol and increase fecal fat excretion, but magnitude of effect depend on food type. *Nutrition and Metabolism*, **9**: 8.

Kulkarni N B, More B B and Patil P L 1969. Occurrence of new race of *Fusarium oxysprum* Schl. f. *lini* (Bolley). Snyder and Hansen inciting linseed wilt in India. *Mycopathology and Applied Mycology,* **38**: 243-246.

Kumar G D S, Duraimurugan P, Sharma A K, Dhiraj Singh, Billore S D and Jain N K 2015. *Handbook on Technologies for Oilseeds Production in Rajasthan*, ICAR-Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad, pp. 108.

Levan A 1944. Experimentally induced chlorophyll mutants in flax. *Hereditas,* **30**: 225-230.

Malik Y P 1997. New record of two coccinellids as predators of bud fly*, Dasyneura lini* Barnes in linseed. *Journal of Oilseeds Research,* **14**(2): 338.

Malik Y P 1999. Major insect pests of linseed and their management approaches. In: *IPM System in Agriculture* : *Oilseeds*, Upadhyay R K, Mukerji K G and Rajak R L (Eds.), Aditya Books Pvt. Ltd, New Delhi.

Malik Y P, Chandra R, Srivastava R L and Saxena M C 2009. Evaluation of neem based biorational insecticides against budfly, *Dasineura lini* infestation in linseed, *Linum usitatissimum* L. *Journal of Oilseeds Research*, **26**: 481-482.

Matthews K R, Homer D B and Thies F 2000. Effect of whole linseed (*Linum usitatissimum*) in the diet of finishing pigs on growth performance and on the quality and fatty acid composition of various tissues. *British Journal of Nutrition*, **83**(6): 637-643.

Mondal S S, Arup Ghosh and Debabrata Acharya 2005. Effect of seeding time of linseed (*Linum usitatissimum*) in rice (*Oryza sativa*)-based paira cropping system under rainfed lowland conditions. *The Indian Journal of Agricultural Sciences,* **75**(3): 123-127**.**

McHughen A 1987. Salt tolerance through increased vigor in a flax line (STS-II) selected for salt tolerance *in vitro*. *Theory and Applied Genetics,* **74**: 727-732.

McHughen A 1989. Agrobacterium mediated transfer of chlorsulfuron resistance to commercial flax cultivars. *Plant Cell Report*, **8**: 445-449.

McHughen A 2002. *Transgenic Linseed Flax.* Marcel Dekker, New York.

McHughen A and Holm F A 1995. Development and preliminary field testing of a glufosinate-ammonium tolerant transgenic flax. *Canadian Journal of Plant Science,* **75**: 117-120.

Mishra J P and Masood Ali 2002. Effect of intercropping patterns on biological and economic sustainability of linseed (*Linum usitatissimum* L.) with lentil (*Lens culinaris*) genotypes under rainfed condition. *Indian Journal of Agricultural Sciences,* **72**(10): 577-580.

Mishra J P, Masood Ali and Arya R L 2001. Genotypic compatibility in relation to row ratio in the intercropping of linseed (*Linum usitatissimum* L.) and gram (*Cicer arietinum)* under rainfed condition. *Indian Journal of Agricultural Sciences,* **71**(6): 359-362.

Morris D H 2007. Flax - A health and nutrition primer. 4thedn. Downloaded from *http:www.flaxcouncil.ca* on 14/2/2014.

Neil D, Westcott and Alister D Muir 2003. Flax seed lignan in disease prevention and health promotion. *Phytochemistry Reviews,* **2**: 401–417.

Noemi R, Richard P H, Johnathan A N and Olga S 2014. Successful high-level accumulation of fish oil omega-3 long-chain polyunsaturated fatty acids in a transgenic oilseed crop. *The Plant Journal,* **77**(2): 198-208.

Padmavathi P, Alivelu K, Prasad R D, Duraimurugan P, Murthy I Y L N, Suresh M, Khadtare S V, Shinde S K 2015. *Handbook on Technologies for Oilseeds Production in Maharashtra*. ICAR-Indian Institute of Oilseeds Research, Hyderabad, pp. 108.

Patil M B 2005. Biology and management of *Rhizoctonia* in major crops of Northern Karnataka. Ph. D. Thesis, University of Agricultural Sciences, Dharwad.

Pavelek M 1995. Further development of international flax data base and special descriptors for more detail evaluation of agronomic and processing characters. In: *Breeding for Fibre and Oil Quality in Flax: Proceedings of the Third meeting of the International Flax Breeding Group,* 7-8 November 1995, St. Valéry en Caux, France. Centre technique pour l'étude et l'amélioration du lin (CETEAL), Paris, France. pp. 1-13.

Pavelek M 1997. Discussion for IFDB standard varieties. *Euroflax Newsletter*, **1**(7): 17-20.

Pavelek M 1998. Analysis of current state of international flax data base. In: *Proceedings of the Symposium "Bast Fibrous Plants Today and Tomorrow, Breeding, Molecular Biology and Biotechnology Beyond 21st Century"*, 28-30 September 1998, VIR, St. Petersburg, Russia. Institute of Natural Fibres, Poznań, Poland. pp. 36-44.

Pospisil B 1974. The significance of chemical muatgens in breeding flax. *Genetic Slechteni,* **10**: 187-196.

Preethi B M and Chimmad B V 2010. Utilization of linseed for value addition to supplementary food. *Karnataka Journal of Agricultural Sciences*, **23**(5): 765-768.

Pruthi H S and Bhatia H L 1937. A new cecidomiid pest of linseed in India. *Indian Journal of Agricultural Sciences,* **7**(5): 797-808.

Rai M and Das K 1975. Gamma ray induced chlorophyll mutations in linseed. *Indian Journal of Genetics and Plant Breeding,* **35**: 462-466.

Rai M and Das K 1976. Potentiality and genetic variability in irradiated population of linseed. *Indian Journal of Genetics and Plant Breeding,* **36**: 20-25.

Rajanna B, Shankergoud I, Biradar S A and Ajithkumar K 2015. Studies on response of root and other morphological characteristics under water stress condition in linseed (*Linum usitatissimum* L.). In: *Proceedings of 2nd International Conference on Bio-resource and Stress Management*, 7-10 January 2015, PJTSAU, Rajendranagar, Hyderabad, India. pp. 311.

Rennebaum H, Grimm E, Warnstorff K and Diepenbrock W 2002. Fibre quality of linseed (*Linum usitatissimum* L.) and the assessment of genotypes for use of fibres as a by-product. *Indian Crops Production,* **16**: 201-215.

Sandhu K S, Dalwinder S and Mehra S P 1988. Weed control in linseed (*Linum usitatissimum* L.) through herbicides. *Journal of Research Punjab Agricultural University,* **25**(4): 521-528.

Sharma A, Hunsigi G, Sharma A and Hunsigi G 1996. Performance of two linseed genotypes at different spacing and nitrogen levels under irrigated condition. *Karnataka Journal of Agricultural Sciences,* **9**: 16-20.

Sharov I 1971. The mutation spectrum of fibre flax induced by chemical mutagens. *Refrat. Zh,* **8**: 55-119.

Siddesh G, Chittapur B M, Biradar S A, Koppalkar B G and Mahadevswamy 2015. Evaluation of bioefficacy of herbicides in linseed. In: *Proceedings* of *International Symposium on Weed Science,* 20-22 November 2015, New Delhi.

Singh P P, Nema V P and Singh S 1982. Response fertility levels, row spacings and seed rate on seed yield of linseed (*Linum usitatissimum* Linn.). *JNKVV Research Journal,* **16**: 7-10.

Singh P K 2015. *Linseed: Technology for Increasing Production.* ICAR Project Coordinating Unit (Linseed), Kanpur. 35 pp.

Sivaraj N, Sunil N, Pandravada S R, Kamal Venkateswarn, Vinod Kumar and Varaprasad K S 2012. Variability in linseed (*Linum usitatissimum*) germplasm collections from peninsular India with special reference to seed traits and fatty acid composition. *Indian Journal of Agricultural Sciences*, **82**(2): 102-105.

Soliman I E 2010. Efficacy of some weed control treatments on dodder (*Cuscuta epilinum*), annual weeds, growth characters and yield and its components of flax (*Linum usitatissimum* L.). *Alexandria Journal of Agricultural Research,* **55**(1): 21-29.

Sunita M and Pooja V 2013. Flaxseed-Bioactive compounds and health significance. *IOSR Journal of Humanities and Social Science,* **17**(3): 46-50.

Tanwar S P S, Rokadia P and Singh A K 2011. Effect of row ratio and fertility levels on chickpea (*Cicer arietinum*) and linseed (*Linum usitatissimum*) intercropping system. *Indian Journal of Agronomy*, **56**(3): 217-222.

Vasudeva R S 1962. Diseases of linseed. In: *Linseed*, Riccharia R H (Ed), Indian Central Oilseeds Committee, Hyderabad, India, pp. 119-122.

Verma K P and Pathak P K 1993. Response of linseed (*Linum usitatissimum* L.) varieties to different dates of sowing. *Indian Journal of Agronomy*, **38:** 160-163.

Wijayanto T 1998. Gene transfer to flax (*Linum usitatissimum* L.) using particle bombardment. M.Sc. Dissertation, University of Saskatchewan, Saskatoon, SK, Canada.

Wijayanto T and McHughen A 1999. Genetic transformation of *Linum* by particle bombardment. *In Vitro Cell Division Biology in Plant,* **35:** 456-465.

Zhuchenko A A ans Rozhmina T A 2000. Mobilization of flax genetic resources. *VILAR and VNIIL*, Starica.

Profitability, input demand and output supply of mustard production in Bangladesh

SANZIDUR RAHMAN* AND MOHAMMAD MIZANUL HAQUE KAZAL[1]

School of Geography, Earth and Environmental Sciences, University of Plymouth, Plymouth, PL4 8AA, England, UK

(Received: February 21, 2016; Revised: March 23, 2016; Accepted: March 24, 2016)

ABSTRACT

This paper estimates profitability, input demand and output supply of mustard production at the farm-level in Bangladesh utilizing a survey data of 206 mustard farmers from two regions of Bangladesh by applying a profit function approach. Mustard production is profitable at the farm level (Benefit Cost Ratio = 1.34) with no adverse influence of farm size on yield and profitability. Mustard farmers are also responsive to changes in market prices of inputs and outputs. Mustard price is the most dominant determinant of output supply and input demand. A 1% increase in mustard price will increase output supply by 0.62% and increase demand for mechanical power, fertilizer and labour by 1.06%, 1.05% and 1.01%, respectively but will decrease seed demand by 3.96%. The fixed factors have no role except land fragmentation substantially reducing seed demand. Policy implications include price policy to improve mustard price and tenurial reform aimed at improving land fragmentation and smooth functioning of the hired labour market in order to increase production and profitability of mustard in Bangladesh.

Keywords: Bangladesh, Input demand, Mustard, Output supply, Profitability, Translog profit function

Rapeseed-mustard (*Brassica* spp.) or mustard is a major oilseed crop in the world which is grown in 53 countries across six continents including India which is the second largest producer after China (Boomiraj *et al*., 2010). Mustard is also the most dominant oilseed crop in Bangladesh and has experienced expansion in area, production and yield over time while facing fierce competition of land for production of cereals, e.g., rice, wheat and maize. For example, the total cropped area of mustard has decreased from 317,800 ha in 2001 to 294,206 ha in 2014; but the total production increased from 238,000 t to 296,000 t; and yield from 0.75 t/ha to 1.20 t/ha during the same period (MoA, 2008; BBS, 2016). In fact mustard alone covers 80% of the total area under oilseed crops (Miah *et al.,* 2015). The country is producing about 0.36 million tonnes of edible oil per year as against the total requirement of 1.4 million tonnes (Mallik, 2013). As a consequence, Bangladesh remains as a net importer of oils and the demand for oil will increase substantially in the future in response to increase in population and changes in dietary habits and nutritional awareness. For example, import of mustard oil has increased from BDT 2.42 million in 2006 to BDT 50.59 million in 2014, which is extraordinarily high (BBS, 2016). One of the main reasons may be the replacement of high volume of palm oil import as observed during 2006 with mustard and soybean oils for consumption as observed during 2010 (BBS, 2014). Mustard is a predominantly winter crop and is sown during mid-October to November and harvested during late January to end of February. Given the future scenario of climate warming, it is recognised that the winter crops, such as mustard, other oilseeds and vegetables, are likely to be relatively more vulnerable to rising temperatures, which will add further pressure on increased demand for oils. For example, Boomiraj *et al*. (2010) noted that mustard production in India is likely to reduce in the future under both irrigated and non-irrigated condition and recommended adaptation of late sowing strategy and/or developing longer duration varieties to cope.

A limited number of socio-economic investigations were made on mustard cultivation in Bangladesh largely focusing on factors influencing adoption of modern technology and/or perception of the farmers. For example, Miah *et al.* (2015) noted that the adoption of improved varieties is not encouraging in Bangladesh as only about 40 per cent of the surveyed farmers has adopted. Hossain *et al.* (2013) examined farmers' perception on cultivating mustard between the two main rice crops, i.e., Aman rice (monsoon) and Boro rice (dry winter). They noted that farmers have high level of perception about the crop and that profitability of the technology, knowledge on mustard cultivation and risk orientation explained 71 per cent of the variations in perception, implying that profitability of mustard production is a major issue.

Studies on profitability of mustard production at the farm level in Bangladesh are not widely available although results from experimental stations are available. For example, Mondal *et al.* (2008) conducted a field experiment research at the regional station of the Bangladesh Agricultural Research Institute (BARI) located in Jessore district by varying tillage and mulching options in mustard production and reported productivity ranging from 1.9 to 2.7 t/ha and

*E-mail: srahman@plymouth.ac.uk
[1]Department of Poverty Studies, Sher-e-Bangla Nagar University, Dhaka, Bangladesh

Benefit Cost ratio (BCR) of 1.06 to 1.97. Similarly, Azam *et al*. (2013) conducted experiments of varying zinc fertilizer doses on mustard in the same research station and reported its significant influence on productivity ranging from 1.17 t/ha in control plots to 1.42 t/ha in treatment plots with corresponding BCR of 1.34 and 1.57, respectively. But such results are not comparable to farm level conditions as these estimates are obtained under controlled experimental conditions.

Most importantly, the nature of responsiveness of the mustard farmers to changes in input and output prices are not known at all. This information is important because Bangladesh farmers not only need to be more efficient in their production activities, but also to be responsive to market indicators, so that the scarce resources are utilized efficiently to increase productivity as well as profitability in order to ensure supply to the urban market (Rahman, 2003) and increase farmers' welfare. Furthermore, the government of Bangladesh is seeking to diversify its agricultural sector to other cereals (i.e., wheat and maize) as well as non-cereals (e.g., potatoes, vegetables, and spices, etc.). In fact, the Fifth Five Year Plan (1997-2002) emphasized and set specific objectives to attain self-sufficiency in foodgrains production and increased production of other nutritional crops and earmarked 8.9 per cent of the total agricultural allocation to promote crop diversification (PC, 1998). Subsequently, the Poverty Reduction Strategy Paper (2005) and the Sixth Five Year Plan (2011-2015) also emphasized crop diversification (PC, 2011; IMF, 2005).

Given this backdrop, the present study specifically addresses this critical research gap in knowledge on the farm-level profitability and nature of responsiveness of the mustard farmers to input and output price changes by systematically examining profitability and responsiveness of the mustard producers to market forces using an in-depth farm survey data of 206 farmers from two major mustard growing regions in central Bangladesh (i.e., Tangail and Sirajganj districts). Specifically, the study aims to: (i) Assess financial profitability of producing mustard at the farm level and (ii) Estimate input demand and output supply elasticities of mustard production at the farm level.

The paper is organised as follows. Section 2 presents the analytical framework, the study area and the data. Section 3 presents the results. Section 4 provides conclusions and draws policy implications.

MATERIALS AND METHODS

We apply two main analytical tools to address these two objectives. (a) Cost-Benefit Analysis (CBA) to determine financial profitability of mustard production at the farm level and (b) translog profit function to estimate input demand, output supply and fixed factor elasticities of mustard production at the farm level. The details are as follows.

Profitability analysis of mustard: Profitability or Cost-Benefit Analysis (CBA) includes calculation of detailed financial costs of production and returns from mustard on a per hectare basis. The total cost (TC) is composed of total variable costs (TVC) and total fixed costs (TFC) (Rahman and Rahman, 2014). TVC includes costs of human labour (both family labour and hired labour, wherein the cost of family labour is estimated by imputing market wage rate), mechanical power; seed, manure, chemical fertilizers; pesticides; and irrigation. TFC includes land rent (if owned land is used then the imputed value of market rate of land rent is applied) and interest on operating capital. The gross return (GR) is computed as total mustard output multiplied by the market price of mustard. Profits or gross margin (GM) is defined as GR-TVC, whereas the Net return (NR) is defined as GR-TC. Finally, the Benefit Cost Ratio (BCR) is computed as GR/TC (Rahman and Rahman, 2014).

The profit function approach: A profit function approach is used to examine impacts of prices and fixed factors on farmers' resource allocation decisions. This is because profit function has a duality relationship with the underlying production function. An advantage of a profit function model is that it is specified as a function of prices and fixed factors which are exogenous in nature and, therefore, are free from possible endogeneity problem associated with a production function model (Rahman *et al*., 2012). The basic assumption is that farm management decisions can be described as static profit maximization problem. Specifically, the farm household is assumed to maximize 'restricted' profits from growing specific crops, defined as the gross value of output less variable costs, subject to a given technology and given fixed factor endowments (Rahman and Parkinson, 2007).

A flexible functional form, the translog function was used that approximates most of the underlying true technology. The general form of the translog profit function, denoting the *i*th subscript for the farm, is defined as:

$$\ln \pi' = \alpha_0 + \sum_{j=1}^{4} \alpha_j \ln P'_j + \frac{1}{2}\sum_{j=1}^{4}\sum_{k=1}^{4} \gamma_{jk} \ln P'_j \ln P'_k + \sum_{j=1}^{4}\sum_{l=1}^{4} \delta_{jl} \ln P'_j \ln Z_l + \sum_{l=1}^{4} \beta_l \ln Z_l + \frac{1}{2}\sum_{l=1}^{4}\sum_{m=1}^{4} \theta_{lm} \ln Z_l \ln Z_m + v, \quad (5)$$

where:

π' = restricted profit (total revenue less total cost of variable inputs) normalized by price of output (P_y),

P'_j = price of jth input (P_j) normalized by output price (P_y),

j = 1, fertilizer price,

= 2, labour wage,

= 3, mechanical power price,

= 4, seed price,

Z_l = quantity of fixed input, l,

l = 1, area under mustard,

= 2, experience,
= 3, education,
= 4, land fragmentation,
v = random error,
ln = natural logarithm, and
$\alpha_0, \alpha_j, \gamma_{jk}, \beta_l, \delta_{jl}$, *and* θ_{lt}, are the parameters to be estimated. The corresponding share equations are expressed as,

$$S_j = -\frac{P_j X_j}{\pi} = \frac{\partial \ln \pi'}{\partial \ln P'_j} = \alpha_j + \sum_{k=1}^{4} \gamma_{jk} \ln P'_k + \sum_{l=1}^{4} \theta_{jl} \ln Z_l, \quad (6)$$

$$S_y = \frac{P_y X_y}{\pi} = 1 + \frac{\partial \ln \pi'}{\partial \ln P_y} = 1 + \sum_{j=1}^{4} \alpha_j + \sum_{j=1}^{4} \sum_{k=1}^{4} \gamma_{jk} \ln P'_j + \sum_{j=1}^{4} \sum_{l=1}^{4} \theta_{jl} \ln Z_l, \quad (7)$$

where S_j is the share of *j*th input, S_y is the share of output, X_j denotes the quantity of input *j* and *Y* is the level of output. Since the input and output shares form a singular system of equations (by definition $S_y - \Sigma S_j = 1$), one of the share equations, the output share, is dropped and the profit function and variable input share equations are estimated jointly using SURE procedure using STATA V10 econometric software program (Stata Corp, 2007). The joint estimation of the profit function together with factor demand equations ensures consistent parameter estimates (Sidhu and Baanante, 1981).

Data and the study area: The data to analyse profitability, output supply and input demand of mustard production at the farm level was taken from a recently completed NFPCSP-FAO project. The data was collected during February-May 2012 through an extensive farm survey in 17 districts (or 20 sub-districts) of Bangladesh. A multistage stratified random sampling technique was employed. At the first stage, districts where the specified crops are dominant are selected which includes mustard as one of the crops. At the second stage, sub-districts (upazilla) were selected according to highest concentration of these specified crops in terms of area cultivated based on information from the district offices of the Directorate of Agricultural Extension (DAE). At the third stage, unions were selected using same criteria at the union/block level which was obtained from the upazilla offices of the DAE. Finally, the farmers were selected at random from the villages with the same criteria classified by three standard farm size categories. These are: marginal farms (farm size 50–99 decimals)[1], small farms (100–249 decimals), and medium/large farms (>250 decimals) (Hossain 1989; Hossain *et al*., 1990). Specifically, information on mustard production was collected from two districts where it is dominant. These are Tangail and Sirajganj districts in central region. Although a total of 210 mustard producing households (70 marginal farms, 70 small farms and 70 medium/large farms) were interviewed, full information necessary for this study is available for only 206 farmers which is the final sample size. The questionnaire used was pre-tested in the non-sampled villages from Tangail district prior to finalization. The survey was carried out by trained enumerators who are graduate students at the Sher-e-Bangla Agricultural University, Dhaka and/or Bangladesh Agricultural University, Mymensingh (For details, see Kazal *et al*., 2013).

[1]We have excluded functionally landless households (farm size <0.50 decimal) defined by Hossain (1989) and Hossain *et al.* (1990) in our sampling strategy because the main focus of the study is to explore the prospect of crop diversification amongst the farming households of Bangladesh.

RESULTS AND DISCUSSION

Financial profitability of mustard production: Table 1 presents profitability information of mustard production. It is clear from Table 1 that mustard production is profitable based on the net return and BCR in the central region of Bangladesh. The average yield is estimated at 1.48 t/ha and the net return is estimated at BDT 18,857.41/ha with BCR of 1.34. Although the yield, net return and BCR were higher relatively for the small farms, there is no significant difference amongst of these measures amongst farm sizes as evidenced from the Chi-squared test results (Table 1). The implication is that farm size has no influence on the yield and profitability of mustard production, which is encouraging given that a largely majority of the farmers in Bangladesh is either marginal or small. The estimated mustard yield of 1.48 t/ha is substantially higher than the yield of 0.81 t/ha in Nepal (Dhakal *et al*., 2015) and closely comparable to the experiment station yield levels reported by Azam *et al*. (2013). The computed BCR of 1.34 is lower than mustard production in Nepal estimated at 1.43 (Dhakal *et al*., 2015), maize estimated at 1.63 (Rahman and Rahman, 2014) and wheat at 1.40 (Hasan, 2006) but higher than Boro rice at 1.14 (Baksh, 2003) in Bangladesh. The implication is that mustard production can compete with the major rice crop in Bangladesh.

Output supply, input demand and fixed factor elasticities of mustard production: One main limitation and/or criticism in applying a profit function model in a cross-section of data is the lack of variation in input and output prices (Rahman and Hasan, 2011). The geographical dispersion of the sampled farmers and imperfections in the input markets in Bangladesh ensure adequate variability in prices at any given point in time. However, a valid test is required to confirm this intuition. In our sample, mustard price varied from BDT 32.50-70.00 per kg; fertilizer price (average price of 5 types of fertilizers used) varied from BDT 5.00 to 17.22 per kg; labour wage varied from BDT 175-418.75 per person day; mechanical power price varied from BDT 4.01-42.43 per decimal of land and seed price varied from BDT50.00-120.00 per kg, respectively. A formal

t-test for differences in the prices of mustard, fertilizers, labour wage, mechanical power services and seed between the two districts rejected the null-hypothesis of 'no-difference' at 1% level of significance, thereby confirming that significant price variations exist in our sample, and hence, the application of the profit function model is justified (Table 2).

Table 1 Financial profitability of mustard production by farm size in central region (Tangail and Sirajganj districts)

Region and farm type	Yield (t/ha)	Sale price (BDT/t)	Gross return (BDT/ha)	Variable cost (BDT/ha)	Total cost (BDT/ha)	Gross margin (BDT/ha)	Net return (BDT/ha)	Undiscounted BCR
All	1.48	47,846.19	74,017.62	31,729.49	55,160.22	42,288.13	18,857.41	1.34
Marginal (<0.50 decimals)	1.41	48,560.71	72,291.86	31,268.57	55,017.49	41,023.29	17,274.38	1.31
Small (0.50 – 2.49 decimals)	1.50	47,853.57	74,974.93	30,847.96	53,950.15	44,126.96	21,024.78	1.39
Medium & Large (>2.50 decimals)	1.52	47,124.29	74,786.08	33,071.93	56,513.01	41,714.15	18,273.07	1.32
χ^2	0.11						0.74	

Note: Exchange rate: USD 1.00 = BDT 81.86 in 2012 (BB, 2013)

Table 2 Price variation between districts

Prices	Measurement	Tangail	Sirajganj	t-statistic
Mustard price	BDT/kg	45.57	50.19	-7.41***
Fertilizer price	BDT/kg	11.88	11.44	2.20**
Labour wage	BDT/person/day	333.04	199.76	43.57***
Mechanical power price	BDT/decimal	10.72	6.59	6.83***
Seed price	BDT/kg	68.47	51.14	21.22***

Note: Exchange rate: USD 1.00 = BDT 81.86 in 2012 (BB, 2013)

Table 3 presents the estimates of the profit function estimated jointly with four input demand equations for mustard. Among the regularity properties of the profit function specified in equation (5), homogeneity was automatically imposed because the normalized specification was used (Rahman and Parkinson, 2007). The monotonicity property of a translog profit function model holds if the estimated output share is positive (Wall and Fisher, 1987 cited in Farooq *et al*., 2001) which was found true in present case. The symmetry property was tested by imposing cross-equation restrictions of equality on the corresponding parameters between the profit function and the four factor demand equations. The test failed to reject the restrictions thereby confirming that the symmetry property also holds and the sample farms do maximize profit with respect to normalized prices of the variable inputs (Sidhu and Baanante, 1981). The convexity property was assumed to hold and was not tested.

The parameter estimates of the profit function model are used to estimate the elasticities with respect to variable input demand, output supply and fixed factors (Table 4). All own price elasticities have negative signs consistent with theory, but all of them are in the inelastic range except labour which is in the elastic range. Results of the cross-price elasticities of demand are mixed with some being complements and some being substitutes.

On the whole, changes in market price of inputs and output significantly influence farmers' resource use and productivity (mustard supply) as expected. The output supply response to output price change is positive, consistent with theory. The elasticity value of 0.62 indicates that a one per cent increase in mustard price will increase output supply by 0.62%. The output supply response is higher than for HYV rice estimated at 0.27 (Rahman and Parkinson, 2007) but much lower than HYV wheat estimated at 0.95 (Rahman *et al*., 2012) in Bangladesh. Mustard price is the most dominant driver. For example, the demand for mechanical power, fertilizer and labour will increase by 1.06 per cent, 1.05 per cent and 1.01 per cent, respectively for a one per cent increase in mustard price. The rise in labour demand in response to mustard price increase will lead to a redistribution of gains accrued from mustard production to landless labourers via wages, an argument in favour of widespread diffusion of modern agricultural technology in Bangladesh (Rahman and Hasan, 2011). In fact, labour input alone accounts for a substantial 36.4 per cent of total input costs in mustard production. However, an increase in the demand for pesticide in response to a rise in mustard price is a cause of concern although the influence is lowest (Table 4). However, results also show that a one per cent increase in mustard price will decrease seed demand by 3.96 per cent, because an increase in the output price is likely to be carried on to a corresponding increase in seed price. But this should not be a major cause of concern because farmers use relatively fixed amount of seed in the production process.

The responsiveness of labour demand to wage increase is in the elastic range. This is expected because labour is the main variable input in mustard production as mentioned above. Therefore, the farmers' response to a rise in wage is quite high estimated at -1.01 implying that a one per cent

increase in labour wage will reduced labour demand by 1.01 per cent. Elastic response of labour demand to a rise in wage was also reported for HYV wheat in Bangladesh estimated at -1.11 (Rahman *et al*., 2012) which is very close to our estimate for mustard crop. The own price elasticity of other inputs are in the inelastic range low and similar to those reported for HYV rice (Rahman and Parkinson, 2007) and HYV wheat (Rahman *et al*., 2012).

Table 3 Restricted parameter estimates of the translog profit function and factor share equations

Variables	Parameters	Coefficients	t-ratio
Profit Function			
Constant	α_0	2.6072	1.08
lnP'_F	α_F	-0.0041	-0.03
lnP'_W	α_W	-0.1366	-0.30
lnP'_M	α_M	0.0124	0.17
lnP'_S	α_S	0.0410	1.06
$½(lnP'_F \times lnP'_F)$	γ_{FF}	-0.0671***	-13.68
$½(lnP'_W \times lnP'_W)$	γ_{WW}	-0.2702***	-3.98
$½(lnP'_M \times lnP'_M)$	γ_{MM}	-0.0170***	-4.84
$½(lnP'_S \times lnP'_S)$	γ_{SS}	0.0084	0.52
$lnP'_F \times lnP'_W$	γ_{FW}	-0.1159***	-6.77
$lnP'_F \times lnP'_M$	γ_{FM}	-0.0090**	-2.31
$lnP'_F \times lnP'_S$	γ_{FS}	-0.0044*	-1.70
$lnP'_W \times lnP'_M$	γ_{WM}	-0.0173	-1.46
$lnP'_W \times lnP'_S$	γ_{WS}	-0.0225*	-1.84
$lnP'_M \times lnP'_S$	γ_{MS}	0.0001	0.06
$lnP'_F \times lnZ_A$	δ_{FA}	-0.0220	-0.98
$lnP'_F \times lnZ_I$	δ_{FI}	-0.0095	-0.27
$lnP'_F \times lnZ_L$	δ_{FL}	0.0098	1.41
$lnP'_F \times lnZ_E$	δ_{FE}	-0.0360*	-1.83
$lnP'_W \times lnZ_A$	δ_{WA}	-0.0165	-0.25
$lnP'_W \times lnZ_I$	δ_{WI}	0.0198	0.19
$lnP'_W \times lnZ_L$	δ_{WL}	0.0184	0.91
$lnP'_W \times lnZ_E$	δ_{WE}	-0.1798***	-2.98
$lnP'_M \times lnZ_A$	δ_{MA}	-0.0255***	-2.35
$lnP'_M \times lnZ_I$	δ_{MI}	-0.0003	-0.02
$lnP'_M \times lnZ_L$	δ_{ML}	0.0051	1.51
$lnP'_M \times lnZ_E$	δ_{ME}	0.0108	1.07
$lnP'_S \times lnZ_A$	δ_{SA}	-0.0042	-0.79
$lnP'_S \times lnZ_I$	δ_{SI}	-0.0029	-0.36
$lnP'_S \times lnZ_L$	δ_{SL}	0.0015	0.95
$lnP'_S \times lnZ_E$	δ_{SE}	0.7539***	11.01
lnZ_A	β_A	0.4583	0.74
lnZ_I	β_I	0.0310	0.03
lnZ_L	β_L	-0.2718	-1.27
lnZ_E	β_E	0.4445	0.76
$½(lnZ_A \times lnZ_A)$	θ_{AA}	0.2121	1.56
$½(lnZ_I \times lnZ_I)$	θ_{II}	0.0579	0.21
$½(lnZ_L \times lnZ_L)$	θ_{LL}	0.0283	1.04
$½(lnZ_E \times lnZ_E)$	θ_{EE}	0.2476**	2.00
$lnZ_A \times lnZ_I$	θ_{AI}	-0.0620	-0.52
$lnZ_A \times lnZ_L$	θ_{AL}	0.0228	0.84
$lnZ_A \times lnZ_E$	θ_{AE}	-0.1667	-1.42
$lnZ_I \times lnZ_L$	θ_{IL}	0.0235	0.54
$lnZ_I \times lnZ_E$	θ_{IE}	-0.0234	-0.19
$lnZ_L \times lnZ_E$	θ_{LE}	-0.0088	-0.33
Fertilizer share equation			
Constant	α_F	-0.0041	-0.03
lnP'_F	γ_{FF}	-0.0671***	-13.68
lnP'_W	γ_{FW}	-0.1159***	-6.77
lnP'_M	γ_{FM}	-0.0090**	-2.31
lnP'_S	γ_{FS}	-0.0044*	-1.70

Table 3 (contd....)

Variables	Parameters	Coefficients	t-ratio
lnZ_A	δ_{FA}	-0.0220	-0.98
lnZ_I	δ_{FI}	-0.0095	-0.27
lnZ_L	δ_{FL}	0.0098	1.41
lnZ_E	δ_{FE}	-0.0360*	-1.83
Labor share equation			
Constant	α_W	-0.1366	-0.30
lnP'_F	γ_{FW}	-0.1159***	-6.77
lnP'_W	γ_{WW}	-0.2702***	-3.98
lnP'_M	γ_{WM}	-0.0173	-1.46
lnP'_S	γ_{WS}	-0.0225*	-1.84
lnZ_A	δ_{WA}	-0.0165	-0.25
lnZ_I	δ_{WI}	0.0198	0.19
lnZ_L	δ_{WL}	0.0184	0.91
lnZ_E	δ_{WE}	-0.1798***	-2.98
Mechanical power share equation			
Constant	α_M	0.0124	0.17
lnP'_F	γ_{FM}	-0.0090**	-2.31
lnP'_W	γ_{WM}	-0.0173	-1.46
lnP'_M	γ_{MM}	-0.0170***	-4.84
lnP'_S	γ_{MS}	0.0001	0.06
lnZ_A	δ_{MA}	-0.0255***	-2.35
lnZ_I	δ_{MI}	-0.0003	-0.02
lnZ_L	δ_{ML}	0.0051	1.51
lnZ_E	δ_{ME}	0.0108	1.07
Seed share equation			
Constant	α_S	0.0410	1.06
lnP'_F	γ_{FS}	-0.0044*	-1.70
lnP'_W	γ_{WS}	-0.0225*	-1.84
lnP'_M	γ_{MS}	0.0001	0.06
lnP'_S	γ_{SS}	0.0084	0.52
lnZ_A	δ_{SA}	-0.0042	-0.79
lnZ_I	δ_{SI}	-0.0029	-0.36
lnZ_L	δ_{SL}	0.0015	0.95
lnZ_E	δ_{SE}	-0.0069	-1.34
F-statistic		112.01***	
Observations		206	

Note:*** Significant at 1 % level (p<0.01); ** Significant at 5 % level (p<0.05); * Significant at 10 % level (p<0.10); Variables Pi' = normalised variable input prices, and Zk = fixed inputs; Subscripts F = fertilizer price, W = labour wage, M = mechanical power price, S = seed price, A = land area cultivated, I = experience, L = education, and E = land fragmentation; Based on the estimation of the restricted translog profit function and four variable input share equations with across-equation restrictions (symmetry) and linear homogeneity imposed.

Table 4 Estimated elasticities of translog profit function

	Mustard price	Fertilizer price	Labour wage	Mechanical power price	Seed price	Land area	Experience	Education	Land fragmentation
Mustard supply	0.6244***	-0.1219***	-0.7195***	-0.1278***	-0.1759***	0.5471	0.0743	0.2603	-0.8524
	(16.24)	(-2.68)	(-7.70)	(-5.36)	(-3.05)	(0.88)	(0.07)	(1.21)	(1.44)
Fertilizer demand	1.0536***	-0.9505***	-0.0801**	-0.0184	-0.0046	0.6054	0.1190	-0.3068	0.4839
	(15.30)	(-48.81)	(-2.09)	(-0.65)	(-0.73)	(0.98)	(0.11)	(-1.44)	(0.83)
Labour demand	1.0087***	0.0027**	-1.1039***	-0.0210	0.0235	0.5449	0.0366	-0.3031	0.7094
	(9.67)	(2.01)	(-10.01)	(-1.57)	(0.57)	(0.88)	(0.04)	(-1.40)	(1.14)
Mechanical power demand	1.0583***	-0.0646*	-0.2432*	-0.7245***	-0.0259	1.0096	0.0843	-0.3644	0.1207
	(6.35)	(-1.73)	(-1.70)	(-13.39)	(-0.92)	(1.48)	(0.08)	(-1.60)	(0.22)
Seed demand	-3.9683***	-0.0248	0.5140	-0.0624	-1.4314**	0.7152	0.2168	-0.3395	-36.2729***
	(-2.92)	(-0.73)	(0.55)	(-0.90)	(-2.04)	(1.06)	(0.19)	(-1.40)	(-10.55)

Among the conventional fixed factors, there is no role of land area in influencing productivity and resource use. This may be due to the fact that farmers decide to allocate a fixed amount of land for growing mustard which is mainly for sale and allocate the rest of the land area to produce the main rice crop in order to meet subsistence and other needs. For example, Hossain *et al*. (1990), based on a nationally representative sample survey of 1345 households from the 62 districts of Bangladesh, noted that oilseeds occupied only 2.4 per cent and rice (traditional and modern varieties) occupied a substantial 71.8 per cent of the gross cropped area. Similarly, Rahman (1998), based on a sample of 406 households from 21 villages from three districts of Bangladesh, noted that oilseeds occupied only 3.1 per cent and rice (traditional and modern varieties) occupied 79.2 per cent of the gross cropped area. Although irrigation is important in field crop production such as rice, wheat, maize and/or vegetables, most farmers did not use any supplementary irrigation in mustard production. Hence, irrigation variable is excluded from the analysis. Similarly, experience and land fragmentation do not seem to have any influence on output supply and input demand except a detrimental effect of land fragmentation on seed demand.

The principal aim of this study is to assess financial profitability and responsiveness of mustard farmers to price changes at the farm level. Results revealed that mustard production is profitable at the farm level (BCR = 1.34) with no adverse influence of farm size on yield as well as profitability. The average yield of mustard is 1.48 t/ha and a net return of BDT 18,857.41 per ha. Farmers are responsive to changes in market prices of mustard and inputs although the level of responsiveness is low. The dominant driver of mustard supply and input demand is mustard price. A rise in mustard price will increase output supply by 0.62% and demand for mechanical power, fertilizer and labour inputs by 1.06%, 1.05% and 1.01%, respectively. Experienced farmers exert negative influence on output supply and input demand for mustard production with no influence of land availability on these measures.

The following policy implications can be derived from the results of this study. First, price policy to improve the price of mustard will increase mustard supply as well as demand for inputs including labour use. Second, tenurial reform aimed at improving land fragmentation to consolidate farm sizes through modification of law of inheritance and regulations to prevent land fragmentation (Rahman and Rahman, 2008). And third, policies to facilitate smooth operation of the hired labour market which will in turn enable the landless labourers to reap the benefits of increase mustard production through wages. This is because labour is the major input in mustard production. Effective implementation of these policy measures, although formidable, will boost mustard production.

REFERENCES

Azam M G, Mahmud J A, Ahammad K U, Gulandazi M A and Islam M 2013. Efficiency of different dose of zinc on growth, productivity and economic returns of mustard in AEZ 11 of Bangladesh. *Journal of Environmental Science and Natural Resources*, **6**: 37-40.

Baksh M E 2003. Economic efficiency and sustainability of wheat production in wheat-based cropping systems in north-west Bangladesh. Ph.D. Dissertation, Department of Agricultural Economics, Bangladesh Agricultural University, Mymensingh, Bangladesh.

BB 2013. Economic Trends (monthly publications, December 2013). Bangladesh Bank, Dhaka, Bangladesh. http://www.bangladesh-bank.org/pub/archive.php.

BBS, 2016. *Yearbook of Agricultural Statistics of Bangladesh 2014*. Bangladesh Bureau of Statistics, Dhaka, Bangladesh.

BBS 2014. *Yearbook of Agricultural Statistics of Bangladesh 2012*. Bangladesh Bureau of Statistics, Dhaka, Bangladesh.

Boomiraj K, Chakrabarti B, Aggarwal P K, Choudhary R and Chander S 2010. Assessing the vulnerability of Indian mustard to climate change. *Agriculture, Ecosystems and Environment*, **138**: 265-273.

Dhakal S C, Regmi P P, Thapa R B, Sah S K and Khatri-Chhetri D B 2015. Resource use efficiency of mustard production in Chitwan district of Nepal. *International Journal of Applied Science and Biotechnology*, **3**: 604-608.

Farooq U, Young T, Russell N and Iqbal M 2001. The supply response of Basmati rice growers in Punjab, Pakistan: price and non-price determinants. *Journal of International Development*, **13**: 227-237.

Hasan M K 2006. Yield gap in wheat production: a perspective of farm specific efficiency in Bangladesh. Ph.D. Dissertation, Department of Agricultural Economics, Bangladesh Agricultural University, Mymensingh, Bangladesh.

Hossain M 1989. *Green Revolution in Bangladesh: Impact on Growth and Distribution of Income*. University Press Limited, Dhaka, Bangladesh.

Hossain M, Quasem M A, Akash M M and Jabber M A 1990. *Differential Impact of Modern Rice Technology: The Bangladesh Case.* Bangladesh Institute of Development Studies, Dhaka.

Hossain M M, Haider M R and Hasan A F M F 2013. Variables contributing to farmers' perception on mustard cultivation in between Aman and Boro Rice. *Bangladesh Journal of Extension Education*, **25**: 95-103.

IMF 2005. Bangladesh Poverty Reduction Strategy Paper. *IMF Country Report No. 04/410, 2005,* Washington, DC, USA.

Kazal M M H, Rahman S, Alam M J and Hossain S T 2013. Financial and Economic Profitability of Selected Agricultural Crops in Bangladesh. NFPCSP-FAO Research Grant Report #05/11, Dhaka, Bangladesh, July 2013. http://www.nfpcsp.org/agridrupal/sites/default/files/ToR%205-Final%20Technical%20 Report_MAFI,%20SAU_Dr.Kazal_Submit.pdf.

Mallik M S A 2013. *Quality seed production of oilseed crops: An overview.* Paper presented in the workshop on 'Modern Techniques for Quality Seed Production of Oilseed Crops'. Oilseed Research Centre, Bangladesh Agricultural Research Institute, Gazipur.

Miah M A M, Afroz S, Rashid M A and Shiblee S A M 2015. Factors affecting the adoption of improved varieties of mustard cultivation in some selected sites of Bangladesh. *Bangladesh Journal of Agricultural Research*, **40**: 363-379.

MoA 2008. *Agricultural Handbook of Bangladesh, 2007*. Ministry of Agriculture, Government of Bangladesh, Dhaka.

Mondal N A, Hossain S M A, Bhuiyan S U and Jahiruddin M 2008. Productivity of rainfed mustard in relation to tillage and mulching. *Bangladesh Journal of Agricultural Research*, **33**: 597-606.

PC 1998. *The Fifth Five Year Plan (1997-2002).* Ministry of Planning, Government of Bangladesh, Dhaka, Bangladesh.

PC 2011. *The Sixth Five Year Plan (2011-2015).* Ministry of Planning, Government of Bangladesh, Dhaka, Bangladesh.

Rahman S 1998. Socio-economic and environmental impacts of technological change in Bangladesh agriculture. Ph. D. Dissertation, Asian Institute of Technology, Bangkok, Thailand.

Rahman S 2003. Profit efficiency among Bangladeshi rice farmers. *Food Policy*, **28**: 487-503.

Rahman S and Hasan M K 2011. Environmental constraints and profitability relationships in agriculture: a case study of wheat farming in Bangladesh. *Journal of the Asia Pacific Economy*, **16**: 630-643.

Rahman S and Parkinson R J 2007. Soil fertility and productivity relationships in rice production system. *Bangladesh. Agricultural Systems*, **92**: 318-333.

Rahman S and Rahman M 2008. Impact of land fragmentation and resource ownership on productivity and efficiency: the case of rice producers in Bangladesh. *Land Use Policy*, **26**: 95-103.

Rahman S and Rahman M S 2014. Exploring the potential and performance of maize production in Bangladesh. *International Journal of Agricultural Management*, **3**: 99-106.

Rahman S, Rahman M S and Rahman M H 2012. Joint determination of the choice of growing season and economic efficiency of maize in Bangladesh. *Journal of the Asia Pacific Economy*, **17**: 138-150.

Sidhu S S and Baanante C A 1981. Estimating farm-level input demand and wheat supply in the Indian Punjab using a translog profit function. *American Journal of Agricultural Economics*, **63**: 237-246.

Stata Corp 2007. Stata Statistical Software: Release 10.0. College Station, TX: Stata Corporation.

Combining ability for seed yield and its components in castor (*Ricinus communis* L.)

R H KAVANI, J H VACHHANI, R B MADARIYA, S R JADEJA AND K L DOBARIYA

Main Oilseeds Research Station, Junagadh Agricultural University, Junagadh-362 001, Gujarat

(Received: February 3, 2016; Revised: February 19, 2016; Accepted: February 26, 2016)

ABSTRACT

Thirty two castor hybrids generated in a line x tester (4 lines x 8 testers) mating design were studied along with parents to estimate combining ability for ten characters in castor. The components of GCA and SCA from analysis of combining ability revealed that non-additive gene action was preponderance in the genetic control of all the characters studied except oil content, which controlled by additive gene action, while 100-seed weight indicated negative estimate. Among female parents, JP-96 was good general combiner for plant height, number of effective spikes per plant, 100-seed weight and oil content, while SKP-84 and SKP-106 were found good general combiners for number of nodes up to main spike, number of capsules on primary raceme and number of effective spikes per plant. For earliness, JP-96 and SKP-84 were found to be good general combiners. Among male parents, PCS-124 and SKI-271 were identified as good general combiners for plant height, number of nodes up to main spike, number of capsules on primary raceme and oil content. None of the parents was found as good general combiner for seed yield. Among the hybrids, JP-105 x SKI-271, JP-96 x SKI-294, JP-105 x SKI-291 and JP-96 x PCS-124 had high *sca* effects for seed yield per plot and other yield traits, were also accompanied with high *per se* performance; hence *per se* performance of the hybrids would be a good indicator for predicting *sca* effects. These hybrids could be exploited through heterosis breeding as these are expected to give desirable transgressive segregants in the succeeding segregating generation.

Keywords: Castor, Combining ability, GCA, Gene action, L x T analysis, SCA

Castor (*Ricinus communis* L.) is a principle oilseed crop of India for both internal and export purpose. Selection of suitable parents for hybridization is an important aspect in the crop improvement programme and the performance of hybrids in a trial may give an idea of their relative superiority. Therefore, in any sound breeding programme, the proper choice of parents based on their combining ability is a pre-requisite. As studies indented to determine the combining ability not only provide necessary information regarding the choice of parents but also illustrate the nature and magnitude of gene action involved. Accordingly, the present investigation was undertaken on combining ability for seed yield and its components in castor with a view to identify good general combiners and specific cross combinations which may be used to create a population with favourable genes for seed yield and its component characters of some newly developed male and female lines through line x tester analysis in castor.

MATERIALS AND METHODS

Four diverse pure lines *viz*., JP-96, JP-105, SKP-84 and SKP-106 used as females were crossed with eight male parents *viz*., JI-244, JI-258, JI-368, PCS-124, SKI-215, SKI-271, SKI-291 and SKI-294 to develop 32 F_1 crosses using line x tester mating method during *kharif* season of 2010-11. The experimental material consisting 45 entries including 12 parents (4 lines and 8 testers) and their resultant 32 hybrids along with one standard check hybrid (GCH-7), was evaluated in Randomized Block Design with two replications at Main Oilseeds Research Station, Junagadh Agricultural University, Junagadh, Gujarat. Each genotype was accommodated in two rows plot of 2.4 x 4.8 m with a spacing of 120 x 60 cm. All the recommended agronomic management practices and plant protection measures were adopted timely to raise the healthy crop. The observations on five randomly selected competitive plants were recorded from each entry per replication on ten characters (Table 1) and their mean values were finally subjected to statistical analysis. The days to flowering and days to maturity were recorded on plot basis. The oil content was analyzed by using Nuclear Magnetic Resonance Spectrophotometer. The seed yield per plot was recorded picking wise and cumulated as total seed yield and expressed in g/plot. The analysis of variance to test the variation among the parents and crosses was done as per Cochran and Cox (1957). The combining ability analysis was performed according to the method suggested by Kempthorne (1957).

RESULTS AND DISCUSSION

The analysis of variance for combining ability revealed the existence of significant differences among the hybrids for

E-mail: jhvachhani@jau.in

all the characters (Table 1). The mean sum of squares attributed to the male and female parents of the hybrids which provide a measure of their general combining ability and the interaction between male and female parents as a measure of specific combining ability. The mean sum of squares due to males and females were significant for all the traits barring total seed weight per plot in lines while, days to 50% flowering of primary spike and total seed weight per plot in testers when tested against error mean squares. Mean sum of squares due to lines were significant for all the traits except total seed weight per plot when tested against lines x testers interaction, whereas tester variances for number of nodes up to main spike, days to 50% flowering of primary spike, days to maturity of primary spike, number of effective spikes per plant and total seed weight per plot were non significant when tested against lines x testers interaction. This indicated the involvement of both additive and non-additive types of gene actions in the inheritance of these characters. These findings are in accordance with those obtained by Sridhar *et al.* (2010) and Patel and Chauhan (2013), who reported the role of additive and non-additive gene effects in the expression of yield and its components, while Mehta *et al.* (2000) and Madariya *et al.* (2008) reported the importance of additive gene effects for the inheritance of yield and its components. However, Chandra Mohan *et al.* (2006) and Madariya *et al.* (2008) also observed the role of non-additive gene effects in the inheritance of yield and its components. The variance component due to specific combining ability (σ^2SCA) was greater in magnitude than that of general combining ability (σ^2GCA) for all the characters and the ratio of σ^2GCA/σ^2SCA, which was found less than unity for all the characters except oil content indicating preponderance of non-additive type of gene action for all these characters while oil content governed by additive gene effect, which is in agreement with the results of Chandra Mohan *et al.* (2006) and Madariya *et al.* (2008).

Table 1 Analysis of variance for combining ability for ten characters in castor

Source of variance	d. f.	Mean sum of squares									
		Pant height (cm)	Effective length of main spike (cm)	No. of nodes up to main spike	No. of capsules on primary raceme	Days to 50% flowering of primary spike	Days to maturity of primary spike	No. of effective spikes per plant	100-seed weight (g)	Oil content (%)	Total seed weight (g/plot)
		1	2	3	4	5	6	7	8	9	10
Replications	1	23.77	21.39	1.27*	2.25	45.56	0.06	0.25	7.38	10.04**++	400056
Hybrids	31	275.39**	39.61**	2.60**	211.97**	169.22**	57.56**	2.90**	19.38**++	2.48**+	543639**
Lines (L)	3	412.89**+	69.14**+	8.77**++	680.29** ++	337.06**+	134.85**++	10.13** ++	79.74**++	12.20**++	260218
Testers (T)	7	539.52* *++	65.94**+	2.96**	327.68**+	163.35	36.06*	2.71**	39.19**++	2.75*+	282085
L x T	21	167.70**	26.62**	1.60**	106.49**	147.21	53.69**	1.92**	4.16	1.00*	671312**
Error	31	9.31	7.58	0.17	2.44	79.21	9.48	0.51	4.23	0.49	160918
σ^2 l	-	25.22	3.85	0.54**	42.37**	16.12	7.84	0.60**	4.72**	0.73**	6206
σ^2 t	-	66.27*	7.30	0.35	40.65*	10.52	3.32	0.28	4.37**	0.28*	15146
σ^2 GCA	-	38.91**	4.99**	0.48**	41.80**	14.25*	6.33*	0.49**	4.60**	0.58**	9186
σ^2 SCA	-	79.80**	9.52**	0.72**	52.03**	34.00	22.10**	0.71**	@	0.26*	255197**
σ^2 GCA/σ^2 SCA	-	0.49	0.52	0.67	0.80	0.42	0.29	0.69	@	2.23	0.04

*, ** significant 5% and 1% levels of probability, respectively against error mean squares.
+, ++ significant 5% and 1% levels of probability, respectively against L x T interaction mean squares. @ Estimates negative.

A perusal of *gca* effects of 12 parents (4 lines and 8 testers) for 10 traits revealed that none of the parents was found good general combiners simultaneously for all the traits studied (Table 2). Among the lines, line JP-96 was good general combiner for number nodes up to main spike, early flowering and early maturity by exhibiting significant *gca* effects in negative direction and is also good general combiner for tall plants, number of effective spikes per plant, 100-seed weight and oil content by exhibiting significant *gca* effects in positive direction. The line JP-105 was found to be good general combiner for effective length of main spike, number of capsules on primary raceme, late maturity, large seed size and high oil content by recording *gca* effects in the positive direction, it is also suitable parent for dwarf plant due to showing high negative *gca* effects for plant height. The line SKP-84 was identified as good general combiner for number of nodes up to main spike, number of capsules on primary raceme and number of effective spikes per plant by expressing significant positive *gca* effects, while it was good general combiner for dwarfness and earliness by showing significant negative *gca* effects. However SKP-84 and JP-105 were poor combiners for total seed weight per plot and oil content. The line SKP-106 was found to be a good general combiner for number of nodes up to main spike, number of capsules on primary raceme and number of effective spikes per plant by recorded significant

gca effects in positive direction, while it was found early maturing due to its negative significant *gca* effects for days to maturity.

Among the testers, JL-258 and JL-368 were good general combiner for majority of the traits i.e., dwarfiness, number of nodes up to main spike, early flowering, early maturity and number of effective spikes per plant showing significant *gca* effects in favourable direction. For economic traits like number of capsules on primary raceme, number of effective spikes per plant and oil content, the tester SKI-215 was found to possess favourable alleles by showing significant *gca* effects.

Table 2 Estimate of general combining ability (*gca*) effects of the parents for ten characters in castor

Parents	Plant height (cm)	Effective length of main spike (cm)	No. of nodes up to main spike	No. of capsules on primary raceme	Days to 50% flowering of primary spike	Days to maturity of primary spike	No. of effective spikes per plant	100-seed weight (g)	Oil content (%)	Total seed weight (g/plot)
LINES										
JP-96	6.23 **	-2.20 **	-0.33 **	-9.56 **	-3.34 **	-1.28 **	0.31 **	1.12 *	0.23 **	170.94
JP-105	-5.83 **	2.67 *	-0.89 **	3.50 **	4.78	4.22 *	-1.19 **	2.41 **	0.97 **	-86.88 **
SKP-84	-1.70 **	0.42	0.61 **	4.69 **	-4.47 **	-2.34 **	0.50 **	-0.84 **	-1.13 **	-107.19 **
SKP-106	1.30	-0.89 **	0.61 **	1.38 **	3.03	-0.59 **	0.38 **	-2.69 **	-0.08 **	23.13
S.E. (gi)±	**0.76**	**0.69**	**0.10**	**0.39**	**2.23**	**0.77**	**0.18**	**0.51**	**0.17**	**100.29**
TESTERS										
JI-244	0.61	-2.14 **	-0.70 **	2.38 **	-0.66 **	0.66	-0.06 **	2.36 *	0.63 **	-28.75 **
JI-258	-0.91 **	-3.02 **	-0.70 **	-5.75 **	-1.28 **	-2.59 **	0.56 **	0.95	-0.69 **	-122.50 **
JI-368	-9.64 **	-4.14 **	-0.45 **	-7.88 **	-2.78 **	-0.59 **	0.81 **	0.85	0.13	-113.75 **
PCS-124	5.98 *	2.36	0.17 **	1.88 *	0.47	-1.59 **	-0.44 **	-4.45 **	0.34 *	368.13
SKI-215	15.61 **	2.48	1.05 **	2.14 *	-6.53 **	-0.72 **	0.31 *	-0.41 **	0.68 **	-166.88 **
SKI-271	-0.14 **	3.48	0.30 **	12.63 **	9.09	3.78	-0.94 **	0.47	-0.93 **	-146.25 **
SKI-291	-1.77 **	-0.64 **	-0.08 **	-1.25 **	-0.91 **	-1.22 **	0.19	-1.74 **	0.08	30.00
SKI-294	-9.77 **	1.61	0.42 **	-4.13 **	2.59	2.28	-0.44 **	1.97	-0.25 **	180.00
S.E. (gj) ±	**1.08**	**0.97**	**0.15**	**0.55**	**3.15**	**1.09**	**0.25**	**0.73**	**0.25**	**141.83**

*, ** significant 5% and 1% levels of probability, respectively against error mean squares.

Table 3 Estimates of specific combining ability (*sca*) effects of the hybrids for ten characters in castor

Crosses	Plant height (cm)	Effective length of main spike (cm)	No. of nodes up to main spike	No. of capsules on primary raceme	Days to 50% flowering of primary spike	Days to maturity of primary spike	No. of effective spikes per plant	100-seed weight (g)	Oil content (%)	Total seed weight (g/plot)
JP-96 x JI-244	6.39**	-6.92 **	-0.30	-5.44 **	-2.28	-0.72	0.94	1.75	-0.02	-186.56
JP-96 x JI-258	9.89**	0.45	-0.80 *	-8.81 **	-7.66	1.53	-0.69	1.75	0.00	252.19
JP-96 x JI-368	11.64**	-0.42	0.45	8.81 **	-5.66	-2.97	0.56	-0.92	0.07	-794.06**
JP-96 x PCS-124	0.52	0.58	0.33	-5.44 **	-0.91	0.53	-0.69	-1.44	0.27	646.56 *
JP-96 x SKI-215	-9.11**	-2.55	-0.55	0.81	9.59	2.66	0.56	-2.70	0.35	151.56
JP-96 x SKI-271	-15.36**	0.45	0.20	-0.19	-1.53	-2.34	0.81	-1.20	0.81	-76.56
JP-96 x SKI-291	-6.73**	1.08	-0.42	0.19	9.97	2.16	0.19	0.82	-1.21 *	-822.81**
JP-96 x SKI-294	2.77	7.33 **	1.08 **	10.06 **	-1.53	-0.84	-1.69 **	1.94	-0.26	829.69**
JP-105 x JI-244	0.95	3.20	0.77 *	-5.00 **	-1.91	-6.22 **	-0.56	-1.09	0.53	61.25
JP-105 x JI-258	-3.55	-0.42	1.27 **	2.63 *	8.72	4.53 *	-0.19	-1.43	0.24	-97.50
JP-105 x JI-368	-12.80**	-1.80	-0.98 **	-0.25	-0.78	-1.97	-1.44 **	0.78	0.50	218.75
JP-105 x PCS-124	-5.42 *	0.20	-1.11 **	8.00 **	-6.03	-0.97	0.81	0.53	-0.50	-973.13**
JP-105 x SKI-215	-1.55	5.08 *	-0.48	-0.75	11.47	-1.34	0.56	1.30	-1.00	-115.63
JP-105 x SKI-271	13.70**	-1.42	0.77 *	9.75 **	-8.66	-3.84	0.31	1.64	-0.84	973.75**
JP-105 x SKI-291	7.83**	0.70	0.14	-1.38	-5.16	1.66	-0.31	-1.11	1.04 *	695.00 *
JP-105 x SKI-294	0.83	-5.55 **	-0.36	-13.00 **	2.34	8.16 **	0.81	-0.62	0.04	-762.50 *
SKP-84 x JI-244	-16.67**	-1.55	-0.73 *	4.31 **	9.34	10.84 **	0.25	0.13	0.43	-185.94
SKP-84 x JI-258	-1.67	-3.17	-0.23	-0.56	4.97	0.59	1.63 **	1.25	0.39	-294.69
SKP-84 x JI-368	-0.92	-0.55	0.02	-4.94 **	2.47	-3.91	0.38	0.72	-0.34	321.56
SKP-84 x PCS-124	-1.05	0.45	-0.61 *	-3.69 **	0.72	2.09	-0.88	0.05	0.45	174.69
SKP-84 x SKI-215	10.83**	0.83	1.52 **	-5.94 **	-21.78 **	-2.78	-0.63	0.41	0.27	-232.81
SKP-84 x SKI-271	6.58**	2.83	0.27	3.06 **	10.09	0.72	-1.38 *	-1.28	-0.85	-485.94
SKP-84 x SKI-291	3.20	-0.05	0.64 *	1.94	0.09	-0.28	-0.50	-0.11	0.14	285.31
SKP-84 x SKI-294	-0.30	1.20	-0.86 **	5.81 **	-5.91	-7.28 **	1.13 *	-1.16	-0.49	417.81
SKP-106 x JI-244	9.33**	5.27 *	0.27	6.13 **	-5.16	-3.91	-0.63	-0.79	-0.94	311.25
SKP-106 x JI-258	-4.67 *	3.14	-0.23	6.75 **	-6.03	-6.66 **	-0.75	-1.57	-0.63	140.00
SKP-106 x JI-368	2.08	2.77	0.52	-3.63 **	3.97	8.84 **	0.50	-0.58	-0.23	253.75
SKP-106 x PCS-124	5.95**	-1.23	1.39 **	1.13	6.22	-1.66	0.75	0.86	-0.21	151.88
SKP-106 x SKI-215	-0.17	-3.36	-0.48	5.88 **	0.72	1.47	-0.50	1.00	0.38	196.87
SKP-106 x SKI-271	-4.92 *	-1.86	-1.23 **	-12.63 **	0.09	5.47 *	0.25	0.83	0.88	-411.25
SKP-106 x SKI-291	-4.30	-1.73	-0.36	-0.75	-4.91	-3.53	0.63	0.41	0.03	-157.50
SKP-106 x SKI-294	-3.30	-2.98	0.14	-2.88 *	5.09	-0.03	-0.25	-0.16	0.71	-485.00
S.E. (sij) ±	**2.16**	**1.95**	**0.29**	**1.11**	**6.29**	**2.18**	**0.50**	**1.45**	**0.49**	**283.65**

*, ** significant 5% and 1% levels of probability, respectively against error mean squares

From the foregoing discussion it would be concluded that the lines, JP-96 and JP-105 gave high total seed weight per plot in combination with different testers indicating that these lines could be utilized for yield improvement in future breeding programme. The *sca* effects showed that no single cross showed maximum *sca* effects for all the characters. The crosses JP-105 x SKI-271, JP-96 x SKI-294, JP-105 x SKI-291 and JP-96 x PCS-124 exhibited maximum *sca* effects for the seed yield per plot as well as dwarf plant, number of nodes up to main spike and number of capsules on primary raceme (Table 3).

The best four crosses showing high *sca* effects for seed yield coupled with *per se* performance and status of *gca* parents are present in Table 4. All the crosses were classified as low x low, low x medium and medium x medium combiners on the basis of their *gca* effects for seed yield, it may be due to the presence of genetic diversity among the parents and there could be some complementation indicating importance of non-additive gene effects.

Table 4 Top ranking four specific combiners for seed yield per plant and their *per se* performance and its *gca* status of parents in castor

Crosses	*sca* effects	*Per se* performance($\bar{x}$)	*gca* status	
			Female	Male
JP-105 x SKI-271	973.75 **	2923	L	L
JP-96 x SKI-294	829.69 **	2263	M	M
JP-105 x SKI-291	695.00 *	2820	L	M
JP-96 x PCS-124	646.56 *	3368	M	M

*, ** significant 5% and 1% levels of probability, respectively, against error mean squares.
H=Desired significant *gca* (high combiner)
M=Desired non-significant *gca* (medium combiner)
L=Non-desired significant *gca* (low combiner)

For exploitation of dominance and epistatic effects, it appears worthwhile to inter-mate the selected progenies in early segregating generations, which would be resulted in the accumulation of favourable genes for the characters. Hence, biparental mating or few cycles of recurrent selection followed by pedigree selection may give fruitful results.

REFERENCES

Chandra Mohan Y, Vishnuvardhan Reddy A and Nageshwar Rao 2006. Inheritance of bloom nature in castor, *Ricinus communis* L. *Journal of Oilseeds Research*, **23**(2):184-186.

Cochran W G and Cox G M 1957. *Experimental Designs.* John Willey & Sons, New York. pp. 107-108.

Kempthorne O 1957. *An Introduction to Genetic Statistics.* John Wiley & Sons, New York, 545 pp.

Madariya R B, Vaddoria M A, Mehta D R and Kavani R H 2008. Combining ability analysis over environment for seed yield and its components in castor (*Ricinus communis* L.). *Crop Improvement*, **35**(2): 163-166.

Mehta D R 2000. Combining ability analysis for yield and its component characters in castor (*Ricinus communis* L.). *Indian Journal of Agricultural Research*, **34**(3): 200-202.

Patel M S and Chauhan R M 2013. Study on gene action, heterosis and inbreeding depression for yield and quality traits in castor (*Ricinus communis* L.). *Journal of Oilseeds Research*, **30**(2): 138-143.

Sridhar V, Dangi K S, Reddy A V, Sudhakar R and Sankar A S 2010. Combining ability studies for the related to earliness in castor (*Ricinus communis* L.). *Research on Crops*, **11**(2): 479-482.

Impact of intercropping of canola oilseed rape (*Brassica napus*) and Ethiopian mustard (*Brassica carinata*) with Indian rape (*Brassica rapa* var. *toria*) on productivity, economics and competitive indices

MANDEEP KAUR, VIRENDER SARDANA AND PUSHP SHARMA

Punjab Agricultural University, Ludhiana-141 004, Punjab

(Received: January 4, 2016; Revised: February 27, 2016; Accepted: March 8, 2016)

ABSTRACT

In the absence of additional land available for cultivation of oilseeds, the widening gap between demand and availability of edible oils in India *vis-à-vis* increasing dependence on import of vegetable oils can be bridged through improvement in productivity per unit area and time. The present investigation was conducted during *rabi* 2014-15 to study the compatibility, production potential and optimum row proportion of component crops and economics of intercropping systems of oilseed rape (*Brassica napus*), Ethiopian mustard (*Brassica carinata*) and Indian rape (*Brassica rapa* var. *toria*). The experiment comprising 14 treatments was conducted in randomized complete block design with three replications. Treatments comprised intercropping of Indian rape with oilseed rape (canola and non canola) and Ethiopian mustard in different row proportions and row spacings and sole crops. Crops were sown simultaneously in mid September and harvested at different times. Canola/non canola oilseed rape based ICS resulted in higher oilseed rape equivalent seed yields (1806-1958 kg/ha for canola and 2272 kg/ha for non canola), gross income (₹ 64645-68194/ha for canola and ₹ 79212/ha for non canola) and net returns (₹ 37527-38126/ha for canola and ₹ 49144/ha for non canola) than sole crops (1630 kg, ₹ 60135 and ₹ 34625 per ha, respectively for canola and 1849 kg, ₹ 70188 and ₹ 44678 per ha, respectively for non canola). Yields, gross and net returns, B:C ratio, monetary advantage index, land equivalent ratio and area time equivalent ratio of intercropping of non canola oilseed rape (2272 kg/ha, ₹ 79212/ha, ₹ 49144/ha, 1.63, ₹ 13990/ha, 1.40 and 1.10, respectively) with Indian rape were higher than that from canola oilseed rape based ICS (1806-1958 kg/ha, ₹ 64645-68194/ha, ₹ 37527-38126, 1.26-1.38, ₹ 5379-8709/ha, 1.17-1.29 and 0.97-1.02, respectively). On the other hand, sole crop of Ethiopian mustard (30 cm row spacing) produced higher equivalent seed yield (2245 kg/ha) and resulted in higher gross income (₹ 79376/ha), net returns (₹ 52660/ha) and B:C (1.97) than its intercropping with Indian rape (2176-2216kg/ha, ₹ 77339-77760/ha, ₹ 50220-50642/ha and 1.85-1.87, respectively). Non-canola oilseed rape was more compatible with Indian rape than canola oilseed rape and Ethiopian mustard.

Keywords: Competitive indices, Intercropping systems, Mustard

The production of oilseeds in India during the last decade has increased only by about 2 per cent in comparison to the compound annual growth rate in demand/consumption of edible oils of 5.6 per cent. The current annual production of edible oils (9.86 million tonnes) in the country can meet only about 48 per cent of the domestic requirements leading to import of about 11.06 m.t. of edible oil worth ₹ 56,907 crores (Kumar, 2015). India accounts for 10 per cent of total edible oil consumption and is the second largest importer of edible oils in the world. The current per capita edible oils consumption of 14.3 kg per annum in India is lower than the global average *per capita* consumption of 24 kg per year (Anonymous, 2014). The demand for vegetable oils at the global level is also expected to increase faster than the cereals in future due to diversion of vegetable oils for energy uses for substituting fossil fuel to meet the guidelines of Inter Governmental Panel on Climate Change and for non food uses. This will make import of edible oils more difficult and expensive. The situation demands concerted efforts to increase production and productivity of oilseeds in the country to bridge the demand-supply gap and reduce import of edible oils and outflow of massive foreign exchange. Rapeseed-mustard which comprises Indian mustard (*Brassica juncea*), canola oilseed rape (*Brassica napus*), Ethiopian mustard (*Brassica carinata*), Indian rape (*Brassica rapa* var. *toria*), brown sarson, (*Brassica rapa* var. *brown sarson*), yellow sarson (*Brassica rapa* var. *yellow sarson*), black mustard (*Brassica nigra*) and taramira (*Eruca sativa*), is an important group of edible oilseed crops in India. The country ranks second in area (6.70 mha) of rapeseed-mustard after China and third in its production (7.88 m.t.) after Canada and China with a contribution of about 12.5 per cent in the total rapeseed-mustard production of the world. In India, this group of crops is next only to soybean among different oilseed crops with a share of 22.2 per cent in total area under oilseeds and 22.6 per cent in total oilseeds production (Kumar *et al.,* 2012). Rapeseed-mustard group of crops is the third most important source of edible oil in the world after soybean and oil palm and with a share of 26 per cent is the largest consumed oil in the country amongst domestically produced edible oils (Meena *et al*., 2014).

Traditional cultivars of rapeseed-mustard contain high levels of erucic acid in oil and glucosinolates in de-oiled seed meal which restrict the use of oil for humans and seed meal for livestock. Canola (double zero) cultivars of rapeseed mustard which are free from erucic acid (<2 per cent) and possess higher oleic acid (>60 per cent) content in oil and low concentration of glucosinolates in seed meal (<30 µmoles per gram defatted seed meal) are nutritionally superior to conventional non canola cultivars. The present investigation was planned and executed to study the compatibility of Indian rape (*Brassica rapa* var. *Toria*), canola oilseed rape (*Brassica napus*) and Ethiopian mustard (*Brassica carinata*) in intercropping systems and production potential as well as economic viability of such intercropping systems (ICS).

MATERIALS AND METHODS

The field experiment was conducted with fourteen treatments at the research farm of Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana during *rabi* 2014-15. It comprised of 14 treatments as detailed below.

T_1: Canola oilseed rape (22.5 cm) + Indian rape (22.5 cm) in 1:1 ratio
T_2: Canola oilseed rape (22.5 cm) + Indian rape (22.5 cm) in 2:1 ratio
T_3: Canola oilseed rape (30 cm) + Indian rape (30 cm) in 2:1 ratio
T_4: Ethiopian mustard (22.5 cm) + Indian rape (22.5 cm) in 1:1 ratio
T_5: Ethiopian mustard (30 cm) + Indian rape (30 cm) in 1:1 ratio
T_6: Ethiopian mustard (22.5 cm) + Indian rape (22.5 cm) in 2:1 ratio
T_7: Ethiopian mustard (30 cm) + Indian rape (30 cm) in 2:1 ratio
T_8: Ethiopian mustard (22.5 cm) + Indian rape (22.5 cm) in 1:2 ratio
T_9: Non canola oilseed rape (22.5 cm) + Indian rape (22.5 cm) in 1:1 ratio
T_{10}: Canola oilseed rape at 45 cm
T_{11}: Ethiopian mustard at 30 cm
T_{12}: Ethiopian mustard at 45 cm
T_{13}: Non canola oilseed rape at 45 cm
T_{14}: Indian rape at 30 cm

The experiment was conducted in a randomized complete block design in three replications. The soil of experimental field was loamy sand in texture, neutral in pH, low in organic carbon content (0.28, 0.16%), low in available nitrogen (188, 97 kg/ha), rich in available phosphorus (28, 25 kg/ha) and medium in available potassium (148, 196 kg/ha) at 0-15 cm and 15-30 cm soil depths.

The test cultivars TL 17 of Indian rape, GSC 7 of canola oilseed rape, GSL 1 of non canola oilseed rape and BJC13-4 of Ethiopian mustard were sown as per treatments on 18 September, 2014. Recommended agronomic practices were followed except for treatments. Plant to plant spacing of 10 cm was maintained for all treatments. The gross plot size was 18.0 m^2 (5.0m x 3.6m) whereas the net plot size was 11.88 m^2 (4.4m x 2.7m). The dose of nutrients applied was 62.5 kg N and 20 kg P_2O_5/ha to sole crop of Indian rape and 100 kg N, 30 kg P_2O_5 and 15 kg K_2O/ha to each of oilseed rape and Ethiopian mustard grown as sole crops. In case of ICS, nutrients to each component crop were applied on area basis. Urea, single super phosphate and muriate of potash comprised the sources of N, P and K, respectively. Indian rape was harvested in second fortnight of December, while oilseed rape and Ethiopian mustard were harvested in second fortnight of March.

Income (gross and net income, benefit cost ratio and monetary advantage) as well as various competition indices (land equivalent ratio, area time equivalent ratio, competitive ratio, aggressivity, relative crowding coefficient) were calculated. Gross income includes income earned from sale of produce i.e., seed and stover. Minimum support price of seed fixed for the crop year 2014-15 (₹ 31 per kg for oilseed rape and Ethiopian mustard and ₹ 30.20 per kg for Indian rape) and market price of stover (Rupee one per kg irrespective of crop) were used to calculate gross income. Net income, B:C ratio and Monetary Advantage Index (MAI) were calculated for different treatments. The MAI represents the economic advantage of growing crops in intercropping system (Ghosh, 2004). It was calculated as:

$$MAI = (\text{Value of combined intercrops}) \times \frac{(\text{Land equivalent ratio} - 1)}{\text{Land equivalent ratio}}$$

Land equivalent ratio (LER), which indicates the relative land area required by component crops when grown as sole crops to produce the same yields as produced by these crops in the ICS was calculated as:

$$LER = LER_a + LER_b \quad \text{Where, } LER_a = \frac{Y_{ab}}{Y_{aa}}, \text{ and } LER_b = \frac{Y_{ba}}{Y_{bb}}$$

LER_a and LER_b are the partial LER of crops 'a' and 'b', respectively. Y_{ab} is yield of crop 'a' when grown in association (intercropping) with crop 'b' and Y_{ba} is yield of crop 'b' when grown in association with crop 'a'; Y_{aa} and Y_{bb} are the yields per unit area of crops 'a' and 'b', respectively when grown as sole crops under same conditions.

Area time equivalent ratio (ATER) takes into account the duration of crops i.e. the time taken by crops from sowing to maturity. It also permits the evaluation of crops on yield per day basis (Hiebsh and McCollum, 1987). It is a modification of LER and expressed as below:

$$ATER = \frac{\{(L_a \times D_a) + (L_b \times D_b)\}}{T}$$

Where L_a and L_b are the partial LER of component crops 'a' and 'b'; D_a and D_b indicates the duration of component crops and T is the total duration of the intercropping system.

Aggressivity (A) shows the degree of dominance of one crop over the other when sown together and is often used to indicate how much the relative yield increase in crop 'a' is greater than that for crop 'b' and *vice-versa* when the crops are grown in an intercropping system (McGilchrist, 1965). Aggressivity of crop 'a' with 'b' and of crop 'b' with 'a' is calculated as:

$$A_{ab} = \frac{Y_{ab}}{Y_{aa} \times Z_{ab}} - \frac{Y_{ba}}{Y_{bb} \times Z_{ba}}$$

$$A_{ba} = \frac{Y_{ba}}{Y_{bb} \times Z_{ba}} - \frac{Y_{ab}}{Y_{aa} \times Z_{ab}}$$

Where, A_{ab} and A_{ba} are the aggressivity of crops 'a' and 'b' intercropped with crop 'b' and 'a', respectively. 'Z_{ab}' and 'Z_{ba}' are the relative proportion of the component crops in the intercropping system.

Competitive ratio (CR) measures the competitive ability of the crops and takes into account the proportion of the crops in which they are initially sown (Willey and Rao, 1980). The competitive ratio is calculated as:

$$CR_a = \frac{LER_a}{LER_b} \times \frac{Z_{ba}}{Z_{ab}}$$

$$CR_b = \frac{LER_b}{LERa} \times \frac{Z_{ab}}{Z_{ba}}$$

Where, LER_a and LER_b are the partial land equivalent ratio of crop 'a' and 'b', respectively. Z_{ab} and Z_{ba} are the proportion of intercropped area initially allocated to crop 'a' and 'b', respectively.

The relative crowding coefficient (K) is the measure of the relative dominance of one crop/species over the other in an intercropping or mixed cropping system (De Wit, 1960). It indicates whether a species or crop grown in mixed population, has produced more or less yield than expected in pure stand. The coefficient is given as:

$$K_{ab} = \frac{Y_{ab}}{Y_{aa} - Y_{ab}} \times \frac{Z_{ba}}{Z_{ab}}$$

$$K_{ba} = \frac{Y_{ba}}{Y_{bb} - Y_{ba}} \times \frac{Z_{ab}}{Z_{ba}}$$

Where, K_{ab} and K_{ba} are the relative crowding coefficient of crop 'a' and 'b' intercropped with crop 'b' and 'a' respectively, Y_{ab} and Y_{ba} are the yield per unit area of crop 'a' and 'b' intercropped with crop 'b' and 'a' (expressed over the area occupied by both crops), Y_{aa} and Y_{bb} are the yield per unit area of the sole crop 'a' and 'b', Z_{ab} and Z_{ba} are the proportion of intercropped area initially allocated to crop 'a' and 'b', respectively.

RESULTS AND DISCUSSION

Effect of treatments on equivalent yield and economics: As a component crop in the ICS, Indian rape produced highest seed yield (1162 kg/ha) in Ethiopian mustard + Indian rape in 1:2 row ratio at 22.5 cm apart rows which was 10.2 and 15.5 per cent higher than Ethiopian mustard + Indian rape (1:1) sown at 22.5 and 30 cm row spacing, respectively and 67.6 and 79.5 per cent higher than Ethiopian mustard + Indian rape (2:1) sown at 22.5 and 30 cm row spacing, respectively but 24.2 per cent lower than sole crop of Indian rape (1444 kg/ha). Thus, Indian rape significantly out yielded all the other treatments with regard to seed yield. Similarly, seed yield of Indian rape obtained from intercropping of canola oilseed rape + Indian rape (1:1) at 22.5 cm apart rows (1081 kg/ha) was 11.9 per cent higher than its yield in 2:1 row proportion at 22.5 cm row spacing and 75.1 per cent higher than its yield in 2:1 row proportion at 30 cm row spacing of component crops but 33.6 per cent lower than sole crop of Indian rape. Thus, seed yield of Indian rape in canola oilseed rape/Ethiopian mustard + Indian rape in 1:1 row proportion was significantly higher than 2:1 row proportion. These differences in seed yield of Indian rape in the ICS were caused mainly by variation in plant population due to varied row ratios and also by competition from oilseed rape and Ethiopian mustard.

Sole crop of non-canola oilseed rape (1849 kg/ha) produced significantly higher (13.4%) seed yield than sole crop of canola oilseed rape but 45.7 per cent lower yield when intercropped with Indian rape (Table 1). Similarly, seed yield of sole crop of canola oilseed rape (1630 kg/ha) was 91.0, 60.2 and 35.3 per cent higher than its intercropping with Indian rape at 22.5 cm row spacing in 1:1 and 2:1 row proportion and 30 cm row spacing in 2:1 row proportion, respectively. Both canola and non canola oilseed rape differed in their growth pattern and non canola oilseed rape with slow initial growth seems more compatible for intercropping with Indian rape. Gupta *et al.* (1989) reported similar results for non canola oilseed rape + Indian rape ICS at Gurdaspur, Punjab.

The seed yields of Ethiopian mustard obtained with row spacing of 30 cm (2245 kg/ha) and 45 cm (2149 kg/ha) were at par but significantly higher (41.5-128.8%) than its yield under different ICS with Indian rape (Table 1). Seed yield of Ethiopian mustard (1586 kg/ha) when intercropped with Indian rape in 2:1 row proportion at 30 cm row spacing was 18.5, 45.3, 32.6 and 61.7 per cent higher than its yield from

2:1 row proportion at 22.5 cm row spacing, 1:1 row proportion at 22.5 and 30 cm row spacing and 1:2 row proportion at 22.5 cm row spacing, respectively.

Intercropping of non canola oilseed rape with Indian rape in alternate rows (1:1) at 22.5 cm row spacing resulted in highest oilseed rape seed equivalent yield (2272 kg/ha) which was at par with sole crop of Ethiopian mustard sown at 30 or 45 cm row spacing, intercropping of Ethiopian mustard with Indian rape in 1:1 row proportion at 22.5 or 30 cm row spacing, in 2:1 row ratio at 30 cm row spacing or in 1:2 row ratio at 22.5 cm row spacing. In case of canola oilseed rape, equivalent seed yield of canola oilseed rape + Indian rape sown at 22.5 cm row spacing in 1:1 or 2:1 row proportion was 16.9 and 20.1 per cent (significantly) higher than sole crop of canola oilseed rape (1630 kg/ha). Similarly, non canola oilseed rape + Indian rape (1:1) at 22.5 cm row spacing resulted in 22.9 per cent (significantly) higher oilseed rape equivalent seed yield than sole crop of non canola oilseed rape (1849 kg/ha).

The highest gross (₹ 79,376/ha) and net returns (₹52,660/ha) were obtained from Ethiopian mustard sown as sole crop at 30 cm row spacing (Table 1). Ethiopian mustard sown as sole crop at 45 cm row spacing resulted in highest B:C ratio (1.99) closely followed by its sowing at 30 cm row spacing (1.97). Intercropping of non canola oilseed rape + Indian rape in 1:1 row ratio at 22.5 cm row spacing resulted in higher gross income (₹ 79,212/ha), net returns (₹ 49,144/ha) but lower B:C ratio (1.63) to the tune of ₹ 9024/ha, ₹ 4466/ha and -0.12, respectively, over sole crop of non canola oilseed rape. Intercropping of non canola oilseed rape + Indian rape resulted in highest MAI (₹ 13990/ha) among all ICS. Among canola oilseed rape based ICS, canola oilseed rape + Indian rape in 2:1 row ratio at 22.5 cm row spacing and canola oilseed rape + Indian rape in 1:1 row ratio at 22.5 cm row spacing resulted in similar but higher gross income (₹ 8059 and 7925/ha) and net returns (3501, 3367/ha) but lower B:C ratio (-0.09, 0.10) over sole crop of canola oilseed rape (₹ 60135/ha, 34625/ha, 1.36). Intercropping of canola oilseed rape + Indian rape in 2:1 row proportion resulted in ₹ 698/ha higher MAI than that obtained from crop sown in 1:1 row proportion. Sole crop of Indian rape resulted in lowest gross income, net returns and B:C ratio (Table 1). Several workers have reported higher income from different Brassica based ICS than sole crops (Srivastava *et al*., 2007; Kumar *et al*., 2008; Kumar *et al*., 2009; Abraham *et al*., 2010; Sharma and Kushwaha, 2012; Singh *et al*., 2012; Yadav *et al*., 2013; Singh *et al*., 2014; Choudhury and Jana, 2015). Similar higher B:C ratio from ICS comprising different *Brassica* species than sole crops have been reported from several locations (Kumar *et al*., 2009; Sharma and Kushwaha, 2012; Yadav *et al*., 2013; Choudhury and Jana, 2015). The positive values of monetary advantage index (MAI) reveal a definite economic advantage of intercropping in all intercropping combinations compared with sole cropping (Table 1).

Table 1 Effect of different intercropping systems on yields of component crops, equivalent yield and economics of intercropping systems

Treatments	Seed yield (kg/ha)			Oilseed rape equivalent yield (kg/ha)	Gross income (₹/ha)	Net returns (₹/ha)	B:C ratio	MAI* (₹/ha)
	*IR	*OR	*EM					
T_1: Canola oilseed rape (22.5 cm) + Indian rape (22.5 cm) in 1:1 ratio	1081	853	-	1906	68060	37992	1.26	8010
T_2: Canola oilseed rape (22.5 cm) + Indian rape (22.5 cm) in 2:1 ratio	966	1018	-	1958	68194	38126	1.27	8708
T_3: Canola oilseed rape (30 cm) + Indian rape (30 cm) in 2:1 ratio	617	1204	-	1806	64645	37527	1.38	5379
T_4: Ethiopian mustard (22.5 cm) + Indian rape (22.5 cm) in 1:1 ratio	1054	-	1091	2118	73696	43628	1.45	7789
T_5: Ethiopian mustard (30 cm) + Indian rape (30 cm) in 1:1 ratio	1007	-	1196	2176	77339	50220	1.85	9361
T_6: Ethiopian mustard (22.5 cm) + Indian rape (22.5 cm) in 2:1 ratio	694	-	1338	2013	70485	40417	1.34	2834
T_7: Ethiopian mustard (30 cm) + Indian rape (30 cm) in 2:1 ratio	648	-	1586	2216	77760	50642	1.87	6756
T_8: Ethiopian mustard (22.5 cm) + Indian rape (22.5 cm) in 1:2 ratio	1162	-	981	2113	75526	45458	1.51	8502
T_9: Non canola oilseed rape (22.5 cm) + Indian rape (22.5 cm) in 1:1 ratio	1030	1269	-	2272	79212	49144	1.63	13990
T_{10}: Canola oilseed rape at 45 cm	-	1630	-	1630	60135	34625	1.36	-
T_{11}: Ethiopian mustard at 30 cm	-	-	2245	2245	79376	52660	1.97	-
T_{12}: Ethiopian mustard at 45 cm	-	-	2149	2149	76181	50671	1.99	-
T_{13}: Non canola oilseed rape at 45 cm	-	1849	-	1849	70188	44678	1.75	-
T_{14}: Indian rape at 30 cm	1444	-	-	1407	47761	24568	1.06	-
CD (P=0.05)	157	122	173	211	5587	5587	0.20	-

*IR = Indian rape, OR = Oilseed rape, EM = Ethiopian mustard, * Monetary Advantage Index

Effect of treatments on competitive indices

Land equivalent ratio: All treatments of intercropping of Indian rape resulted in LER of greater than unity (>1.0) indicating advantage of intercropping over sole crops and such differences were significant over sole crops except for Ethiopian mustard + Indian rape in 2:1 row ratio at 22.5 cm row spacing (Table 2). The highest LER for ICS was observed for non canola oilseed rape + Indian rape in 1:1 row ratio at 22.5 cm row spacing (1.40) followed by canola oilseed rape + Indian rape in 2:1 row ratio at 22.5 cm row spacing (1.29), canola oilseed rape + Indian rape in 1:1 row ratio at 22.5 cm row spacing (1.27) and Ethiopian mustard + Indian rape in 1:2 row ratio at 22.5 cm row spacing (1.25). Non canola oilseed rape intercropped with Indian rape did not-significantly affect growth of Indian rape throughout the crop season. Yield advantage of intercropping of non canola oilseed rape with Indian rape in 1:1 row ratio at 22.5 cm spacing has been reported earlier as these two component crops differ greater in their growth pattern/peak period of growth (Gutpa *et al*., 1989). It might also be due to complementary relationship, leading to better use of growth resources. Singh *et al*. (2014) obtained higher LER (1.26 to 1.45) by intercropping of 1-3 rows of oat for fodder between two rows of non canola or canola oilseed rape sown in different row proportion (45, 60, 75 or 90 cm). Choudhury and Jana (2015) also registered higher LER (1.63) from potato + Indian mustard intercropping in 2:1 row ratio.

Area time land equivalent ratio (ATER): The ATER of non canola oilseed rape intercropped with Indian rape (1:1) and canola oilseed rape intercropped with Indian rape (2:1) at 22.5 cm row spacing showed advantage of intercropping (Table 2). It was less than unity for rest of the treatments, lowest being for Ethiopian mustard + Indian rape (2:1, 22.5 cm row spacing). The ATER takes into account the duration of crops and allows evaluation of crops on yield per day basis. The ATER of less than unity indicates that there was no advantage of intercropping. In contrast to non canola oilseed rape which differ greatly in growth pattern and in which flowering and reproductive growth occurred after harvesting of Indian rape, flowering and seed setting of canola oilseed rape and Ethiopian mustard coincided with reproductive phase of Indian rape which might have resulted in severe competition between component crops.

Aggressivity: The aggressivity index indicates the relative dominance of component crops in the ICS. The study reveals that Indian rape dominated over non canola/canola oilseed rape (Table 3) and canola oilseed rape in canola oilseed rape + Indian rape (2:1, 22.5 cm row spacing) suffered maximum competition (1.12) whereas non canola oilseed rape in case of non canola oilseed rape + Indian rape (1:1, 22.5) cm row spacing remained almost unaffected by Indian rape (0.05). The study further indicates that Indian rape was more competitive to canola oilseed rape in the narrow row spacing and with greater proportion of Indian rape. Lack of competition between Indian rape and non canola oilseed rape was due to differences in their peak period of growth. In Ethiopian mustard based ICS, Indian rape was more competitive to Ethiopian mustard in 1:1 than in 2:1 row ratio of Ethiopian mustard + Indian rape (Table 3). Bora (1999) reported varying competitive behavior of different proportions of wheat and rapeseed in the ICS.

Table 2 Effect of different intercropping systems on land equivalent ratio and area time equivalent ratio

Treatments	Land Equivalent Ratio (LER)				ATER*
	LER_{IR}	LER_{OR}	LER_{EM}	LER_{ICS}	
T_1: Canola oilseed rape (22.5 cm) + Indian rape (22.5 cm) in 1:1 ratio	0.75	0.52	-	1.27	0.97
T_2: Canola oilseed rape (22.5 cm) + Indian rape (22.5 cm) in 2:1 ratio	0.67	0.62	-	1.29	1.02
T_3: Canola oilseed rape (30 cm) + Indian rape (30 cm) in 2:1 ratio	0.43	0.74	-	1.17	0.99
T_4: Ethiopian mustard (22.5 cm) + Indian rape (22.5 cm) in 1:1 ratio	0.73	-	0.49	1.22	0.95
T_5: Ethiopian mustard (30 cm) + Indian rape (30 cm) in 1:1 ratio	0.70	-	0.53	1.23	0.97
T_6: Ethiopian mustard (22.5 cm) + Indian rape (22.5 cm) in 2:1 ratio	0.48	-	0.60	1.07	0.90
T_7: Ethiopian mustard (30 cm) + Indian rape (30 cm) in 2:1 ratio	0.45	-	0.70	1.16	0.99
T_8: Ethiopian mustard (22.5 cm) + Indian rape (22.5 cm) in 1:2 ratio	0.81	-	0.44	1.25	0.95
T_9: Non canola oilseed rape (22.5 cm) + Indian rape (22.5 cm) in 1:1 ratio	0.71	0.68	-	1.40	1.10
T_{10}: Canola oilseed rape at 45 cm	-	1.00		1.00	1.00
T_{11}: Ethiopian mustard at 30 cm	-	-	1.00	1.00	1.00
T_{12}: Ethiopian mustard at 45 cm	-	-	1.00	1.00	1.00
T_{13}: Non canola oilseed rape at 45 cm	-	1.00	-	1.00	1.00
T_{14}: Indian rape at 30 cm	1.00	-	-	1.00	1.00
CD (P=0.05)	0.11	0.07	0.07	0.13	NS

* = Area time equivalent ratio LER: Land equivalent ratio

Table 3 Effect of different intercropping systems on aggressivity, competitive ratio and relative crowding coefficient

Treatments	Aggressivity (A)			Competitive Ratio (CR)			Relative Crowding Coefficient (RCC)			
	A_{IR}	A_{OR}	A_{EM}	CR_{IR}	CR_{OR}	CR_{EM}	RCC_{IR}	RCC_{OR}	RCC_{EM}	RCC_{ICS}
T_1: Canola oilseed rape (22.5 cm) + Indian rape (22.5 cm) in 1:1 ratio	0.45	-0.45	-	1.43	0.70	-	3.48	1.11	-	4.0
T_2: Canola oilseed rape (22.5 cm) + Indian rape (22.5 cm) in 2:1 ratio	1.12	-1.12	-	2.19	1.39	-	4.10	0.86	-	3.55
T_3: Canola oilseed rape (30 cm) + Indian rape (30 cm) in 2:1 ratio	0.21	-0.21	-	1.18	1.98	-	1.52	0.58	-	0.88
T_4: Ethiopian mustard (22.5 cm) + Indian rape (22.5 cm) in 1:1 ratio	0.48	-	-0.48	1.51	-	0.67	2.79	-	0.97	2.82
T_5: Ethiopian mustard (30 cm) + Indian rape (30 cm) in 1:1 ratio	0.33	-	-0.33	1.31	-	0.76	2.36	-	1.26	2.97
T_6: Ethiopian mustard (22.5 cm) + Indian rape (22.5 cm) in 2:1 ratio	0.44	-	-0.44	0.40	-	2.55	1.89	-	0.74	1.40
T_7: Ethiopian mustard (30 cm) + Indian rape (30 cm) in 2:1 ratio	0.15	-	-0.15	0.32	-	3.21	1.68	-	1.44	2.43
T_8: Ethiopian mustard (22.5 cm) + Indian rape (22.5 cm) in 1:2 ratio	0.12	-	-0.12	3.75	-	0.27	3.36	-	1.59	5.63
T_9: Non canola oilseed rape (22.5 cm) + Indian rape (22.5 cm) in 1:1 ratio	0.05	-0.05	-	1.04	0.96	-	2.49	2.19	-	5.45
CD (P=0.05)	0.25	0.16	0.28	0.43	0.15	0.42	NS	0.23	0.41	2.57

Competitive ratio (CR): In case of oilseed rape based ICS, the highest (2.19) and lowest CR (1.04) for Indian rape was registered in canola oilseed rape + Indian rape (2:1, 22.5 cm row spacing) and non canola oilseed rape + Indian rape (1:1, 22.5 cm row spacing), respectively (Table 3). For Ethiopian mustard based ICS, the CR index for Indian rape was highest in Ethiopian mustard + Indian rape in 1:2 row ratio at 22.5 cm row spacing (3.75) and lowest in Ethiopian mustard + Indian rape in 2:1 row ratio at 30 cm row spacing (0.32). Intercropping systems comprising canola oilseed rape + Indian rape in 2:1 row ratio at 30 cm row spacing and canola oilseed rape + Indian rape in 1:1 row ratio at 22.5 cm row spacing offered the highest (1.98) and lowest (0.70) CR index, respectively of oilseed rape indicating dominant nature of oilseed rape in the former than later ICS. In case of Ethiopian mustard based ICS, Ethiopian mustard + Indian rape in 2:1 row ratio at 30 cm row spacing and Ethiopian mustard + Indian rape in 1:2 row ratio at 22.5 cm row spacing registered highest (3.21) and lowest (0.27) values of CR index for Ethiopian mustard. The study reveals that Ethiopian mustard offered more competition than oilseed rape to Indian rape in the 2:1 row proportion whereas in 1:1 row proportion, both component crops were equally competitive to Indian rape. The CR is a measure of competition ability and represents the partial LER of component crops. Higher plant population and consequently higher yields of oilseed rape and Ethiopian mustard in 2:1 row proportion resulted in higher LER and higher CR index than narrow row proportion.

Relative crowding coefficient (RCC): Canola oilseed rape + Indian rape (2:1 at 22.5 cm row spacing) resulted in highest (4.10) whereas the same ICS at 30 cm row spacing resulted in lowest (1.52) RCC of Indian rape (Table 3). However intercropping (1:1, 22.5 cm row spacing) of non canola oilseed rape with Indian rape registered higher RCC (2.19) of non canola oilseed rape than canola oilseed rape (1.11). In Ethiopian mustard + Indian rape ICS, Ethiopian mustard registered RCC value of 1.59 in 1:2 row ratio at 22.5 cm row spacing, 1.44 in 2:1 row ratio at 30 cm row spacing and 1.26 in 1:1 row ratio at 30 cm row spacing.

The RCC indicates the relative dominance of one crop over the other in ICS. The RCC values of greater than unity indicate advantage of intercropping. Higher RCC values of Indian rape indicate its dominance over oilseed rape and Ethiopian mustard. Overall, Ethiopian mustard + Indian rape in 1:2 row ratio at 22.5 cm row spacing (RCC 5.63), oilseed rape + Indian rape in 1:1 row ratio at 22.5 cm row spacing (RCC 5.45), canola oilseed rape + Indian rape in 1:1 row ratio at 22.5 cm row spacing (RCC 4.0) and canola oilseed rape + Indian rape in 2:1 row ratio at 22.5 cm row spacing (RCC 3.55) were more promising than other ICS (Table 3). Banik *et al.* (2000) obtained higher RCC value from 1:1 than 2:1 row replacement series in case of Indian mustard + lentil but in Indian mustard + pea ICS, RCC value was higher in 2:1 than 1:1 row replacement series. Choudhury and Jana (2015) reported higher RCC in potato + Indian mustard intercropping in 2:1 than other row proportions. Rafey and Prasad (1991) reported higher RCC values from intercropping of safflower with *Brassica napus* than with *Brassica rapa* at different row spacing of safflower. Srivastava *et al.* (2007) reported similar results from wheat + Indian mustard ICS and Tuti *et al.* (2012) from wheat + Indian rape/lentil ICS.

REFERENCES

Abraham T, Thenua O V S and Shivakumar B G 2010. Impact of levels of irrigation and fertility gradients on dry matter production, nutrient uptake and yield of chickpea (*Cicer arietinum*) intercropping system. *Legume Research,* **33**: 10-16.

Ali Z, Malik M A and Cheema M A 2000. Studies on determining a suitable canola-wheat intercropping pattern. *International Journal of Agricultural Biology*, **2**(1-2): 42-44.

Anonymous 2014. *India's Import of Agricultural Products.* Director General of Commercial Intelligence and Statistics. Ministry of Commerce, Kolkata. www.agricoop.nic.in.

Bora P C 1999 Competition studies in intercropping of wheat (*Triticum aestivum*), rapeseed (*Brassica juncea*) and pea (*Pisum sativum*). *Indian Journal of Agronomy*, **44**: 509-513.

Choudhury P and Jana J C 2015. Growth, yield, quality and economic impacts of intercropping in potato. *Agricultural Biology Science Journal*, **1**: 6-9.

De Wit C T 1960. *On Competition.* Verslag Landbouw-Kundige Onderzoek, 66: 1-28.

Ghosh P K 2004. Growth, yield, competition and economics of groundnut/cereal fodder intercropping systems in the semi-arid tropics of India. *Field Crops Research*, **88**: 227-237.

Gupta T R, Saini J S and Labana K S 1989. Intercropping of Indian mustard (*Brassica napus* var. *napus*) and gobhi sarson (*Brassica napus* subsp. *olifera* var. *annua*) with different planting patterns. *Indian Journal of Agricultural Sciences*, **59**: 349-353.

Kumar A 2015. Stakeholders Access to Oilseed Technologies towards Self Sufficiency. Rao M V lecture delivered during third National *Brassica* Conference at ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur.

Kumar A, Yadava D K and Rana D S 2012 Rapeseed-mustard in India: Present scenario, future projections and R & D issues. *Indian Farming*, **62**(8): 14-21.

Kumar B R M, Mansur C P, Salimath P M, Alagundagi S C and Sarawad I M 2009. Influence of different row proportions on yield components and yield of *rabi* crops under different intercropping systems. *Karnataka Journal of Agricultural Sciences*, **22**: 1087-1089.

Kumar N, Prakash V, Mina B L, Gopinath K A and Srivastva A K 2008. Evaluation of *toria* (*Brassica campestris*) and lentil (*Lens culinaris*) varieties in intercropping system with wheat (*Triticum aestivum*) under rainfed conditions. *Indian Journal of Agronomy*, **53**: 47-50.

McGilchrist CA 1965. Analysis of competition experiments. *Biometrics*, **21**: 975-985.

Meena C P, Chauhan J S, Singh M., Singh K H, Rathore S S and Meena M L. 2014. Genetic parameters and correlations for seed yield and morphological characters in Indian mustard [*Brassica juncea* (L.) Czern. & Coss.]. *Journal of Oilseeds Research*, **31**(2): 114-117.

Rafey A and Prasad N K 1991. Biological potential and economic feasibility of intercropping oilseeds and pulses with safflower (*Carthamus tinctorius*) in drylands. *Indian Journal of Agricultural Sciences*, **61**: 893-897.

Sharma C S and Kushwaha B L 2012. Effect of intercropping and weed management on yield and quality of mustard (*Brassica juncea*). *Bhartiya Krishi Anushandhan Patrika*, **27**: 9-12.

Singh J, Patel B S, Patel G N and Ali S 2012. Studies on inter/mixed cropping systems of mustard [*Brassica juncea* (L.) Czern. & Coss.] + lucerne (*Madicago sativa*) under different agro-climatic conditions of Northern Gujarat. *Journal of Oilseeds Research*, **29**(1): 106-108.

Singh A K, Singh R K and Singh U 2014. Production potential and competitive indices of Indian mustard (*Brassica juncea*) based intercropping with wheat (*Triticum aestivum*) and lentil (*Lens culinaris*) under different row ratios of eastern Uttar Pradesh. *Archives of Agronomy and Soil Science*, **60**: 225-237.

Srivastava R K, Bohra J S and Singh R K 2007. Yield advantage and reciprocity functions of wheat (*Triticum aestivum*) + Indian mustard (*Brassica juncea*) intercropping under varying row ratio, variety and fertility level. *Indian Journal of Agricultural Sciences*, **77**: 139-144.

Tuti M D, Mahanta D, Mina B L, Bhattacharya R, Bisht J K and Bhatt J C 2012. Performance of lentil (*Lens culinaris*) and toria (*Brassica campestris*) intercropping with wheat (*Triticum aestivum*) under rainfed conditions of north-west Himalaya. *Indian Journal of Agricultural Sciences*, **82**: 841-844.

Willey R W and Rao M R A 1980. Competitive ratio for quantifying competition between intercrops. *Experimental Agriculture*, **16**: 117-125.

Yadav P K, Ram V, Dohere A P S and Ruchi R 2013. Effect of row ratio and phosphorus fertilizer in chickpea (*Cicer arietinum*) and mustard (*Brassica juncea*) intercropping system. *Indian Journal of Agronomy*, **58**(2): 198-202.

Studies on integrated nutrient management on growth and productivity of Indian mustard (*Brassica juncea*) in high altitude range of Himalaya

DHIMAN MUKHERJEE

Regional Research Station, Uttar Banga Krishi Viswavidyalaya, Darjeeling-734301, West Bengal

(Received: May 3, 2015; Revised: February 15, 2016; Accepted: February 23, 2016)

ABSTRACT

Field investigations were carried out during the winter season of 2010-11 and 2011-12 at Lava (1850 m asl), under the aegis of Uttar Banga Krishi Viswavidayalaya, to evaluate the effect of different FYM and phosphorous levels on growth, yield and economics of Indian mustard [*Brassica juncea* (L.) Czern & Coss.] at high altitude. The field experiment consisted of four FYM levels (0, 10, 20 and 30 t/ha) in main plot and four phosphorous levels (0, 20, 40 and 60 kg P_2O_5/ha) in subplot. Higher plant height and other growth parameters were registered with FYM @ 20t/ha, and was followed by FYM @10 t/ha. Amongst different levels of phosphorus, application of 60 kg P_2O_5/ha registered significantly higher growth parameters and was at par with 40 kg/ha at 60 DAS and statically superior to other levels of P application. All the yield attributing characters were statistically influenced by different treatment combinations. Significantly higher seed yield was obtained with FYM @ 20t/ha (2.0 and 1.9 t/ha) and was statistically at par with FYM @ 10t/ha (1.8 and 1.9 t/ha) during 2010-11 and 2011-12, respectively. Amongst various subplot treatment highest seed yield during the first year was associated with the application of P_2O_5 @ 40 kg/ha (2.1 t/ha) and significantly better to other level of phosphorous. However during the second year higher seed yield was registered with 40 kg P_2O_5/ha (1.9 t/ha), and was statistically similar with 60 kg P_2O_5/ha (1.8 t/ha) and 20 kg/ha (1.7 t/ha). Application of P_2O_5 @ 40 kg/ha resulted in 140.7% higher seed yield over no phosphorous application. Incorporation of FYM @ 20 t/ha registered 74.0% more stover yield compared to no FYM application. With various phosphorous doses, higher yield was registered with the application of 40 kg P_2O_5/ha which was at par with 60 kg P_2O_5/ha during both the year of experimentation. Application of FYM @ 20 t/ha gave maximum gross returns (₹ 19380/ha) and higher benefit: cost ratio (1.9). Higher benefit: cost ratio (1.90) was recorded with the application of P_2O_5 @ 60 kg/ha with net return of ₹ 18470/ha.

Keywords: Economics, Farm Yard Manure, Mustard, Phosphorous

Rapeseed and mustard are important oilseed crops and India is second in mustard production next to China and first in area. Mustard is one of the most important crops adopted by the farmers in the north-eastern hill region of India. This is a potential crop in winter (*rabi*) season due to its wider adaptability and suitability to exploit residual moisture. Cropping sequence with mustard in the mid hill areas without proper nutrient management has led to fast depletion of soil fertility and crop productivity. With the current practices of crop cultivation under sub-optimal management, especially without nutrient application, significant soil nutrient mining is occurring. The cultivation of oilseeds in the rainfed area (72%) in varying agro-climatic regions, with uncertain returns on investment, are the major factors for low productivity (Paroda, 2013; Singh and Chauhan, 2013). In Darjeeling, this is a major oilseed crop but its productivity in the state (906 kg/ha) is much lower than its realizable yield potential of 2200 to 2400 kg/ha. The role of organic materials in maintaining and increasing soil fertility is well established to sustain reasonable productivity. The fertility status of soils of high altitude region of West Bengal is low and whatever amount of organic matter is present is lost very fast due to heavy rain. The soils of this region are sandy in texture and besides the major nutrients, deficient in several micronutrients. Thus, the use of organic manure (FYM) and supplementation of soil phosphorous is essential not only to harvest higher yields of crops but to maintain the soil fertility also.

Availability of nutrients (N, S, Zn & Fe) increased significantly with increasing levels of FYM (Gajandand *et al*., 2012). Organic source alone or in combination with inorganic sources proved vital in attaining economical harvests that emphasize the need to adopt integrated nutrient management (Yadav *et al*., 2010). This will result into increasing farmer's premiums as well as maintain soil nutrition. Moreover, this practice would have an environmental friendly strategy. The potential of FYM to supply nutrients and enhance beneficial microbes for faster decomposition is being recognized widely under hill condition. Use of organics alone does not result in spectacular increase in crop yields due to their low nutrient status. Use of FYM helps to build up soil humus and beneficial microbes, besides improvement of soil physical properties. Thus judicious combination of organics and chemical fertilizers helps to maintain soil productivity. Most of the soils in Darjeeling hill are poor in phosphorus due to phosphate fixation in acidic soils. Phosphorus is a critical nutrient for plant growth, since it is involved in cellular

energy transfer, respiration, and photosynthesis. Hill soils are mostly deficient in phosphorous status. There may be a number of factors responsible for low yield of mustard in high altitude of Himalaya due to poor soil fertility status and phosphorous in particular (fixation problem). Further, sub optimal use of fertilizer nutrients, particularly, nitrogen and phosphorus appears to be most important (Premi and Kumar, 2004). As we know phosphorous play a vital role as a structural component of cell constituent and metabolically active compounds i.e., chloroplasts, mitochondria, phytin, nucleic acid, protein, flavin nucleotides and several enzymes. Therefore, the present study was carried out with objective to study the effect of FYM and phosphorous levels on growth, economics and nutrient uptake of mustard in high altitude range of Darjeeling, Himalaya.

MATERIALS AND METHODS

An experiment was conducted during *rabi* season of 2010-11 and 2011-12, with a view to find out the influence of FYM and phosphorous levels on yield and economics of Indian mustard at Lava (1850 m asl) at Regional Research Station (Hill Zone), Uttar Banga Krishi Viswavidyalaya. The soil was sandy loam in texture, high in organic carbon (0.93%), available N (254.15 kg/ha), P_2O_5 (16.11 kg/ha) and K_2O (166.10 kg/ha) content with pH 4.8. The total rainfall recorded during crop growth period was 21.3 and 18.5 mm, minimum temperature ranged from 1.1 to 8.3 and 2.3 to 10.1, and maximum temperature ranged from 15.3 to 26.1 and 11.3 to 24.9°C during winter 2011-12 and 2012-13, respectively. The field experiment was conducted with split plot design with three replication, having sixteen treatments combinations including four FYM levels (0, 10, 20 and 30 t/ha) in main plot and four subplot treatment consisting of four P_2O_5 levels (0, 20, 40, 60 kg /ha). The recommended dose of nitrogen and potassium 60:40 kg N, and K_2O /ha, respectively were applied. Source of major nutrients were through urea, single superphosphate and muriate of potash. Mustard cultivar Varuna (T 59) was sown on 22th October 2011 and 28th October 2012, respectively. FYM was applied two weeks before sowing of mustard cultivar during both the years of experimentation. Full amount of phosphorus and potash and half amount of nitrogen applied at the time of sowing, while the remaining dose of nitrogen was top dressed at the pre-flowering stage. The irrigation was given and other recommended packages of practice were adopted during the crop growth period in both the years. Five randomly selected plants from each plot were uprooted and later cleaned and observation like plant height, leaf area and dry weigh leaf and stem at peak growth stage i.e., 60 days after sowing (DAS) were recorded and averaged. The branches of five randomly selected plants were counted and reported as number of branches/plant. The yield attributes were recorded at harvest to assess the contribution to yield. Similarly, the total siliqua of five sample plants were counted and expressed as number of siliqua/plant. The 1000-seed weight were counted from the lot, weighed and expressed as 1000 seed weight. The seed and stover yield was computed from the harvest of net plot and expressed in tonne/ha (t/ha). Plant and soil sample were analyzed for uptake of nitrogen, phosphorus and potash as per standard laboratory procedures (Jackson, 1973). Available phosphorous was determined by Olsen's method as outlined by Jackson (1973) using spectrophotometer (660 nm wave length). Available potassium was extracted with neutral normal ammonium acetate and the content of K in the solution was estimated by flame photometer (Jackson, 1973). The experimental data were analyzed statistically by applying the technique of analysis of variance (ANOVA) prescribed for the design to test the significance of overall difference among treatments by the F test and conclusions were drawn at 5% probability level. Benefit: cost ratio (B: C) was obtained by dividing the gross income with cost of cultivation. The effect of treatments was evaluated on pooled analysis basis on growth, yield attributes and yields. For working out the economics, prevailing market prices for mustard seeds (₹38.85/kg), urea (₹10.95/kg), SSP (₹14.80/kg), MOP (₹8.90/kg) and cost of labour (₹183.50 /day) were considered.

RESULTS AND DISCUSSION

Growth characters: The plant height was significant with application of FYM levels (Table 1). Higher plant height was observed with 30 t/ha during first year and in second year this was with FYM @ 20 t/ha and was at par with all other levels. Amongst different levels of phosphorus, application of 60 kg P_2O_5/ha registered significantly more plant height at 60 DAS and statically better to other levels of phosphorus application during the first year. During second year, use of 40 kg P_2O_5/ha recorded higher plant height and significantly better to other levels. A slight increase in plant height with addition of phosphorous was probably due to increased efficiency of metabolism by P and formation of structural carbohydrates (Ghosh and Gulati, 2001). Further, leaf area index was not significantly influenced during both the year of experimentation. Higher LAI was registered with the incorporation of FYM @ 30 t/ha and was followed by FYM @ 20 t/ha. These two treatments were significantly superior to other set of FYM application. This might be due to additional availability of micro and macro nutrients to plant which help to increase the plant height and leaf area (Kumar, 2006). More number of branches was registered with the application of FYM @ 30 t/ha and was statistically similar with other levels (i.e., 20 and 10 t/ha) and significantly better to no application of FYM. Number of primary branches were higher with the application of 60 kg P_2O_5/ha, and was at par with the 40 kg P_2O_5/ha, and statistically superior to other levels (Table 1). Application of 40-60 kg P_2O_5/ha, notably

better response towards higher secondary branches, and was statistically similar to each other. Application of FYM @ 10 t/ha during first year, 20 t/ha during second year produced more leaf biomas. Higher dose of phosphorus helped in increasing the leaf area, shoot dry weight, shoot P and leads to vigorous growth of plant. Total dry matter accumulation significantly varied with application of FYM and P_2O_5 levels. Maximum dry matter was recorded with the application of FYM @ 20 t/ha during both the years, and significantly better to other levels. Application of 40 kg P_2O_5/ha during first year and 60 kg P_2O_5/ha during second year recorded high dry matter accumulation and statistically at par with each other and better to other levels of phosphorous use.

Yield attributes: All yield attributing characters were statistically influenced by different treatment combinations (Table 2). Number of siliqua/plant and seed/siliqua was more with use of FYM @ 20 t/ha and was closely followed by incorporation of FYM @ 10 t/ha, and statistically similar to each other. However, during second year highest number of siliqua/plant was recorded with the FYM @ 10 t/ha and significantly superior to rest of the treatments under the main plots. More number of siliqua/plant and seed/siliqua found with the phosphorous @ 60 kg/ha during both the years and was at par with other treatments except no phosphorous in first year and 20 kg/ha phosphorous in the second year. This corroborate with the finding of Premi and Kumar (2004). Overall observation revealed that, more phosphorous application under high altitude range help to enhance higher number of siliqua/plant. This might be due to more phosphorus uptake leads to increased net CO_2 fixation with increased rate of photosynthesis and thereby more photosynthates to develop more number of siliqua per plant (Badsra and Chaudhary, 2001).

Table 1 Effect of FYM and phosphorus levels on different growth parameters of mustard

Treatment	Plant height (cm)		LAI		Number of primary branches/plant		Number of secondary branches/plant		Total dry matter of plant (g/plant)	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
FYM (t/ha)										
0	58.0	67.3	0.4	0.4	2.4	1.9	9.1	8.1	21.3	22.8
10	71.1	70.4	0.5	0.5	3.0	3.4	10.1	10.3	21.4	25.6
20	72.0	73.2	0.5	0.5	3.3	3.4	10.5	11.0	28.7	28.0
30	73.2	70.3	0.6	0.5	3.3	3.9	10.1	10.9	25.1	27.2
SEm (±)	0.8	1.3	0.1	0.1	0.1	0.1	0.2	0.2	0.4	0.3
CD (P = 0.05)	2.1	3.6	0.2	NS	0.2	0.2	0.5	0.6	1.2	1.1
Phosphorus level (kg/ha)										
0	55.0	60.1	0.5	0.4	2.8	2.7	8.0	9.01	27.9	20.5
20	61.8	65.3	0.5	0.5	2.9	2.8	10.1	9.8	24.6	26.3
40	71.1	78.9	0.5	0.5	3.9	3.9	11.5	10.8	28.7	27.8
60	74.2	69.3	0.5	0.5	3.9	3.9	10.8	11.0	27.0	29.1
SEm (±)	1.5	1.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.6
CD (P = 0.05)	4.3	3.9	NS	NS	0.2	0.3	0.3	0.5	1.0	1.5

NS = Non significant

Table 2. Effect of FYM and phosphorus levels on yield attributing characters and nutrient uptake by mustard

Treatment	Yield attributing parameters						Uptake by crop (kg/ha)					
	No. of siliqua/plant		Seeds /siliqua		1000-seed weight (g)		N		P		K	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
FYM (t/ha)												
0	64.9	54.3	8.0	9.3	2.8	2.9	79.1	58.0	13.2	15.1	60.1	53.3
10	92.6	90.4	11.9	10.8	3.6	3.4	111.6	102.3	27.0	23.6	99.7	73.9
20	96.3	83.2	11.3	10.9	3.0	3.7	137.1	113.1	30.3	27.1	108.0	98.6
30	84.3	70.1	10.0	9.2	2.9	3.6	94.3	83.4	21.4	16.9	84.0	60.9
SEm (±)	1.5	1.9	0.3	0.2	1.0	0.8	3.7	2.4	1.0	2.0	2.3	2.6
CD (P = 0.05)	5.1	5.2	1.0	0.6	NS	NS	10.3	7.6	3.4	5.1	5.6	7.5
Phosphorus level (kg/ha)												
0	52.0	44.3	9.4	7.4	2.9	3.1	71.2	60.4	14.0	10.4	55.3	49.3
20	83.6	74.9	10.4	9.9	3.0	3.1	93.0	89.1	23.9	25.0	99.3	87.4
40	84.3	74.9	11.9	10.9	3.5	3.0	111.7	104.0	27.1	23.9	103.2	95.3
60	87.1	80.7	12.5	13.4	3.7	3.2	132.1	111.1	29.9	28.3	129.2	103.0
SEm (±)	1.3	2.2	0.2	0.3	0.5	0.3	2.4	1.5	1.0	0.9	3.7	2.5
CD (P = 0.05)	4.8	6.8	0.6	0.8	NS	NS	7.5	4.5	3.3	3.0	8.3	7.3

NS = Non significant

More number of seeds/siliqua produced mainly because of application of phosphorus lead to synthesis and deposition of seed reserves (starch, lipid, protein and phytin) that ultimately produce higher number of seeds per siliqua (Jat *et al.,* 2000). The higher value of yield attributes is the result of higher levels of FYM and phosphorous levels resulted in to better growth and more translocation of photosynthates from source to sink (Tripathi *et al.,* 2005; Rana *et al.,* 2005).

Nutrient uptake: Uptake of nitrogen was more registered with FYM @ 20 t/ha, and was statistically superior to rest of the main plot treatments (Table 2). This was followed by incorporation of FYM @ 10 t/ha. With different phosphorous levels, highest uptake of nitrogen was recorded with 60 kg P_2O_5/ha, and was statistically superior to all other levels of application. As far uptake pattern of phosphorus is concerned, more was observed with the FYM @ 20 t/ha and statistically similar with the incorporation of FYM @ 10 t/ha, significantly better to other doses of manure application. This was followed by treatment with FYM @ 30 t/ha and zero level claim of FYM. However, with respect to phosphorous levels, highest uptake of phosphorous was recorded with the claim of 60 kg P_2O_5/ha, during both the years, and was at par with 40 kg P_2O_5/ha during the first year only and significantly better to rest of the application rate.

Further, observation revealed that uptake of potassium was more with the FYM @ 20 t/ha and was statistically superior to other main plot treatments (Table 2). Amongst various phosphorous levels, maximum uptake was registered with the 60 kg P_2O_5/ha, and was significantly better to other treatments. This was followed by phosphorous 60 and 10 kg/ha. Observation of table 2 revealed that more nutrient uptake in case of organic sources particularly FYM application. More primary nutrient uptake by this treatment might be because of soil and rhizosphere bacteria and microrganism can affect the mineral nutrition of plants by changing root-uptake characteristics, due to a modification of root morphology or alteration of uptake mechanism, relative growth rate or internal composition of mustard plant (Amanullah *et al.,* 2010)

Yield parameters: Significantly maximum seed yield of was obtained under FYM @ 20 t/ha (2.0 and 1.9 t/ha) and was statistically at par with FYM @ 10 t/ha (1.8 and 1.9 t/ha) during both the years (Table 3). Mean seed yield was highest with FYM @ 20 t/ha and was followed by FYM @ 10 t/ha. Treatment with FYM @ 20 t/ha produced 166.0% more seed yield compared to the no FYM application. The improvement in crop growth increased the yield attributes and thereby the seed yield of mustard. This could further be supported by the positive and significant correlation between yields attributes and yield (Rao *et al.,* 2006).

Table 3 Effect of FYM and phosphorus levels on seed, stover yield and economics of mustard

Treatment	Seed yield (t/ha)			Stover yield (t/ha)			Harvest index (%)		Net returns (x 10^3 ₹ /ha)			B:C ratio		
	2010	2011	Mean	2010	2011	Mean	2010	2011	2010	2011	Mean	2010	2011	Mean
FYM (t/ha)														
0	0.8	0.7	0.7	2.1	2.8	2.4	27.7	20.3	7.3	6.9	7.1	1.2	0.9	1.1
10	1.9	1.9	1.8	4.0	4.3	4.2	31.8	30.5	18.2	15.6	16.4	1.7	1.5	1.6
20	2.0	1.9	2.0	4.4	4.1	4.2	31.7	32.6	19.9	18.8	19.4	1.9	1.8	1.9
30	1.8	1.6	1.7	3.8	3.4	3.6	32.4	32.5	15.1	14.2	14.5	1.2	1.1	1.1
SEm (±)	0.1	0.1		0.3	0.3		0.2	0.4						
CD (P = 0.05)	0.3	0.2		0.9	0.9		0.8	0.9						
Phosphorus level (kg/ha)														
0	0.8	0.8	0.8	2.5	2.3	2.4	24.4	26.2	7.9	8.1	7.9	0.9	1.0	0.9
20	1.8	1.7	1.7	3.8	3.1	3.4	31.8	35.8	17.4	17.1	17.2	1.5	1.2	1.3
40	2.1	1.9	1.9	4.5	4.2	4.3	32.0	30.8	20.2	19.1	19.6	1.8	1.1	1.4
60	1.8	1.8	1.8	4.3	4.0	4.2	29.8	30.9	18.9	18.0	18.5	2.0	1.9	1.9
SEm (±)	0.1	0.1		0.3	0.3		0.4	0.3						
CD (P = 0.05)	0.2	0.2		0.6	0.6		0.9	0.9						

Among various subplot treatments, highest seed yield during the first year was associated with the application of 40 kg P_2O_5/ha (2.1 t/ha), and significantly better to other levels of phosphorous. However during the second year maximum yield was registered with the use of 40 P_2O_5 kg/ha (1.9 t/ha) and was statistically similar with 60 P_2O_5 kg/ha (1.8 t/ha) and 20 kg/ha (1.73 t/ha). Application of 40 kg P_2O_5/ha gave 140.7% more seed yield over no phosphorous application. Stover yield was significantly more with FYM @ 20 t/ha (4.4 t/ha) during the first year and was at par all levels of FYM except no FYM. Incorporation of FYM @ 20 t/ha registered 74.1% more stover yield compared to no FYM. Further table revealed that field treated with various phosphorous doses, maximum yield was registered with the application of 40 kg P_2O_5/ha and was at par with 60 kg P_2O_5/ha during both the years of inspection. Application of 40 kg P_2O_5/ha registered 80.5% more stover capitulate compared to no application of phosphorous level. Mean stover yield was highest with 40 kg P_2O_5/ha and was followed by 60 kg P_2O_5/ha. The better stover yield at higher

phosphorous was attributed to increased plant height and leaf area and finally more accumulation of dry matter per plant and this was also concluded by Kumar (2006). Harvest index was highest registered with the combination of FYM @ 30 t/ha and showed parity with FYM @ 20 t/ha during both the years and only with FYM @ 10 t/ha in second year. As per the subplot treatments assimilation of 40 kg P_2O_5/ha produced more harvest index and was at par with 20 kg P_2O_5/ha. Moreover in second year more harvest index registered with 20 kg P_2O_5/ha and significantly better to rest of the subplot combination.

Economics: Economics revealed that application of FYM @ 20 t/ha gave maximum gross return (₹19380/ha) and higher benefit : cost ratio (1.9). This was followed by FYM @ 10 t/ha gave good return (₹16400) and highest benefit: cost ratio (1.6). Further with subplot treatment, highest net return (₹19640) was observed with the application of 40 kg P_2O_5 /ha with B:C ratio of 1.4. However maximum benefit: cost ratio (1.9) was recorded with the application of 60 kg P_2O_5/ha with net returns of ₹ 18470/ha (Table 3). From the table 3, the best performance was revealed by application of FYM @ 20 t/ha coupled with 60 P_2O_5 kg/ha.

REFERENCES

Amanullah M A, Sekhar S and Muthukrishnan P 2010. Prospect and potential of chicken manure. *Asian Journal of Plant Sciences*, **34**(1): 1-11.

Badsra S R and Chaudhary L 2001. Association of yield and its components in Indian mustard. *Agriculture Science Digest*, **21**(2): 83-86.

Gajandand J, Sharma K K and Jat N K 2012. Effect of FYM and mineral nutrients on physico-chemical properties of soil under mustard in western arid zone of India. *Annals of Plant and Soil Research*, **14**(2): 167-166.

Ghosh S K and Gulati S C 2001. Genetic variability and association of yield component in Indian mustard (*Brassica juncea* L.). *Crop Research*, **21**(3): 345-349.

Jackson M L 1973. *Soil Chemical Analysis,* Prentice Hall of India Pvt. Ltd., New Delhi.

Jat R S, Kanhangarot S S and Rathore S S 2000. Effect of different fertility levels on growth and yield of mustard (*Brassica juncea* L. Czern and Coss). *Annals of Agriculture Research*, **21**(3): 421-423.

Khajanchi L and Dravid M S 1990. Phosphate sulphate silicate and FYM interaction on P utilization by mustard. *Journal of Nuclear Agriculture and Biology*, **19**(4): 232-235.

Kumar N 2006. Integrated nutrient management practices in mustard (*Brassica juncea* L.) and its effect on the productivity of succeeding rice crop. Ph.D. Thesis, Chaudhary Charan Singh University, Meerut.

Paroda R S 2013. The Indian oilseeds scenario: challenges and opportunities. *Journal of Oilseeds Research*, **30**(2): 111-126.

Premi O P and Kumar M 2004. Response of Indian mustard (*Brassica juncea* L.) to different levels of nitrogen and phosphorus under irrigated condition. *Indian Journal of Agriculture Research*, **38**(2): 151-153.

Rana K S, Rana D S and Gautam R C 2005. Influence of phosphorus, sulphur and boron on growth, yield and nutrient uptake and economics of Indian mustard [*Brassica juncea* (L.)] under rainfed condition. *Indian Journal of Agronomy*, **50**(4): 314-316.

Rao K T, Naidu G J and Subbaiah G 2006. Effect of foliar application of micronutrient on yield and yield attributes on Indian mustard (*Brassica juncea* L.). *Agriculture Science Digest*, **26**(2): 144-146.

Singh M and Chauhan J S 2013. Genetic variation and correlations for some physiological characters and seed yield in Indian mustard (*Brassica juncea* L.) under rainfed conditions. *Journal of Oilseeds Research*, **30**(2): 167-170.

Tripathi M K, Chaturvedi S, Shukla D K and Mahapatra B S. 2010. Yield performance and quality in Indian mustard [*Brassica juncea* (L.)] as affected by integrated nutrient management. *Indian Journal of Agronomy*, **55**(2): 138-142.

Yadav R P, Tripathi M L and Trivedi S K 2010. Yield and quality of Indian mustard (*Brassica juncea*) as influenced by irrigation and nutrient levels. *Indian Journal of Agronomy*, **55**(1): 56-59.

Response of sesame (*Sesamum indicum* L.) to irrigation scheduling based on climatological approach and N fertigation levels

SREEDHAR CHAUHAN, V PRAVEEN RAO, A PRATAP KUMAR REDDY,
G JAYASREE AND S NARENDER REDDY

College of Agriculture, Prof. Jayashankar Telangana State Agricultural University, Hyderabad-500 030, Telangana State

(Received: April 25, 2015; Revised: February 22, 2016; Accepted: February 29, 2016)

ABSTRACT

A field experiment was conducted on sesame during summer season of 2010-11 and 2011-12 on red sandy loam soil of Northern Telangana zone of Telangana, India to find out the combined effect of irrigation and N levels through fertigation on growth, yield attributes, yield and quality of sesame with Swetha til variety. The treatments consisted 15 possible combinations of 5 levels of irrigation as main plot and 2 levels of N in sub-plot in split-plot design. The results revealed that drip irrigation scheduled at 100% Epan and application of 50% recommended dose of nitrogen (RDN) through fertigation to sesame recorded significantly higher number of effective branches/plant, length of capsule, number of capsules/plant, number of seeds/capsule, seed and stover yields, Harvest index (HI), 1000-seed weight, oil content, oil yield and NPK uptake compared to surface irrigation scheduled at 1.0 IW/CPE ratio and 0% N application applied through fertigation. Maximum WUE was also recorded with 100% Epan irrigation and application of 50% RDN. Interaction effect was found significant with plant height, LAI, dry matter production, seed yield/plant; seed, stover and oil yield, HI and total NPK uptake.

Keywords: Irrigation schedules, Fertigation, Sesame, Water use efficiency

Sesame (*Sesamum indicum* L.) is one of the most important ancient oilseed crops and is cultivated almost throughout India for its high quality oil and has tremendous potential of export. Sesame is mainly grown during summer season in North Telangana zone of Telangana state in considerable area. This crop is generally grown as a sequence crop after turmeric or cotton or redgram or in rice fallows being short duration in nature. However, with the limited availability of irrigation water and farm power supply, the area under cultivation of crop is increasing year after year due to more productivity, higher market price and net monetary returns (Chandra Mohan *et al*., 2012). To achieve higher productivity potential, irrigation scheduling and balanced fertilization are the key factors (Ranganatha *et al*., 2012). Narang and Gill (1998) reported that seed yield of summer sesame increased with increase in the number of irrigations. Keeping in view, fast ever diminishing water resources and increasing competition from and within agriculture for water, its economical and efficient utilization becomes quite imperative. Under limited water supply, higher seed yield can only be obtained by proper scheduling of irrigation either based on irrigation at critical crop growth stages or based on climatological approach. It is well established fact that there is a positive correlation between nutrient application and productivity. In general, this crop is not supplied with proper quantity of nutrients particularly nitrogen because of preceding crop like turmeric which is highly fertilized either with organic manures or tank silt during *kharif* and assuming its residual effect on sesame. Very little work has so for been carried out on irrigation scheduling and nutritional requirement of summer sesame under Telangana region. Hence, the present investigation was undertaken to study the effect of scheduling and fertility levels (particularly with nitrogen) on growth, yield and quality of summer sesame under red sandy loam soils of Northern Telangana zone of Telangana state.

MATERIALS AND METHODS

A field experiment was conducted during summer season of 2010-11 and 2011-12 at Regional Agricultural Research Station, Jagtial, PJTSAU, Karimnagar, Telangana state on sandy loam soil having 7.8 pH, 0.36 dS/m EC with 175:86:222 kg/ha available N:P_2O_5:K_2O, respectively. The experiment was laid out in a split plot design with 3 replications in 15 treatment combinations consisting of five irrigation schedules based on climatological approach *viz.,* I_1 - Drip irrigation at 100% Epan, I_2 - Drip irrigation at 80% Epan, I_3 - Drip irrigation at 60% Epan, I_4 - Drip irrigation at 40% Epan and I_5 - Surface irrigation at IW/CPE ratio 1.0 as main plot treatments, three nitrogen fertigation levels *viz.,* N_1- 50% recommended dose of nitrogen (RDN), N_2- 25% RDN and N_3- 0% RDN as sub-plot treatments. Sesame variety Swetha til (JCS 96) was sown in rows at 60 cm apart and 10 cm between plants on 12th March of 2011 and 14th March of 2012, respectively and harvested on 7th and 17th June of 2010-11 and 2011-12, respectively. The drip system laterals of 16 mm diameter were laid 1.2 m apart with 0.4 m spacing between two in line emitters with discharge rate of 2.0 liters per hour (LPH). A common irrigation was given

immediately after sowing the crop for satisfactory seed germination and proper establishment of crop. After that, irrigation schedules in drip irrigated treatments were based on pre determined (40-100%) of daily pan evaporation rates from USWB class A pan evaporimeter, which are expressed in mm of water evaporated over a given time period, usually a day. Further, in surface irrigation, the irrigation of 50 mm depth was given by taking the cumulative account of evaporation data recorded from the meteorological observatory. The recommended fertilizer dose was 30:60:40 kg N, P_2O_5 and K_2O/ha. Nitrogen was applied as per the treatments in six equal splits at weekly intervals up to 50 DAS in the form of urea through fertigation. Full dose of phosphorous was applied at the time of sowing to soil as basal dose in the form of single super phosphate and the recommended potassium was applied in two equal splits as basal and at 30 DAS along with nitrogen through fertigation in the form of sulphate of potash. Other agronomical operations were followed as per the recommendations made by the University. Randomly five plants were selected from each net plot and were harvested separately for post-harvest study. Mean of these five observation plants were used for calculating sampling values of growth parameters, yield attributes and quality parameters. Oil content, NPK content and uptake were estimated by standard methods. Statistical analysis of the data was carried out using standard analysis of variance.

RESULTS AND DISCUSSION

Effect of irrigation on growth, yield attributes and yield: Significantly maximum plant height, more number of branches/plant, capsules/plant, length of capsule, seed capsule, higher seed yield/plant, 1000-seed weight, seed yield (1372 kg/ha), stover yields (3088 kg/ha), harvest index as well as oil yield (712 kg/ha) were recorded with drip irrigation scheduled at 100% Epan (I_1) compared to irrigation scheduled at 40% Epan (I_4) (Tables 7 and 8). The mean seed yield increased under I_1, I_2, I_3 and I_5 over I_4 were to the tune of 81.5, 64.6, 24.1 and 39.0%, respectively. The per cent increase in stover yield in I_1, I_2, I_3 and I_5 over I_4 were to the tune of 55.4, 43.7, 20.7 and 19.9%, accordingly. Increase in yield under I_1 might be due to the fact that crop might have received sufficient quantity of irrigation water throughout the crop growth period in accordance with amount of water that was lost through the evapotranspiration. Hence, the soil moisture content remained optimum in the surrounding root zone area which finally resulted in improvement in number of branches/plant, capsule length, capsules/plant, seeds/capsule and seed yield as well as higher uptake of nutrients by plant might have increased plant height and LAI resulting in more efficient partitioning of dry matter to the yield attributing parts of plant. The findings are in close agreement with the results obtained by Patra (2001). The influence of different irrigation schedules on oil content of sesame was not significant during both the years of study (Table 1).

Table 1 Effect of irrigation schedules and N fertigation levels on growth, yield attributes, seed yield, oil yield and WUE of summer sesame (pooled data of two years)

Treatments	Number of effective branches/plant	Number of capsules/plant	Capsule length (cm)	Number of seeds/capsule	1000-seed weight (g)	Oil content (%)	Oil yield (kg/ha)	WUE (kg/ha-mm)
Irrigation schedules								
I_1- DI at 100% Epan	6.85	97.5	3.68	60.9	3.70	51.9	712	3.83
I_2- DI at 80% Epan	6.26	93.3	3.27	56.3	3.97	51.5	640	3.76
I_3- DI at 60% Epan	5.04	76.7	3.07	44.8	3.50	51.9	488	3.17
I_4- DI at 40% Epan	3.81	66.1	1.81	38.2	3.75	50.3	382	3.11
I_5- Surface irrigation at IW/CPE ratio at 1.0	5.20	80.9	2.78	49.4	4.03	51.4	540	2.58
SEm (±)	0.13	1.52	0.14	1.05	0.11	0.7	29.2	-
CD (P=0.05)	0.44	4.95	0.45	3.41	0.34	NS	95.1	-
CV (%)	17.4	15.5	14.4	16.2	8.34	4.2	15.8	-
N fertigation levels								
N_1-50% RDN	6.04	93.4	3.03	55.2	3.83	51.2	655	3.67
N_2-25% RDN	5.40	82.6	2.94	49.6	3.74	51.8	555	3.56
N_3-0% RDN	4.86	72.7	2.80	44.9	3.81	51.2	448	2.88
SEm (±)	0.07	0.97	0.04	0.42	0.07	0.5	6.1	-
CD (P=0.05)	0.19	2.85	0.12	1.25	NS	NS	17.9	-
CV (%)	14.7	14.5	15.4	13.3	7.3	3.5	4.3	-
I x N interaction	NS	NS	NS	NS	NS	NS	Sig.	-

Significantly maximum NPK uptake of 48.89, 7.15 and 40.0 kg/ha, respectively was recorded with irrigation scheduled at 100% Epan (I_1) (Table 3). This uptake of nutrients under I_1 irrigation schedule might be due to the cumulative effect of higher N, P and K content in seed and stover; and higher seed as well as stover yields. Absorption of nutrients by the plant root is influenced by the concentration gradient of available nutrients in soil solution. Potential of soil to replenish the nutrient pool adjacent to the roots and ability of plant roots to absorb and translocate nutrients. The increase in solubility of nutrients with increase in water content in soil with higher water replenishment with shorter interval might be responsible for higher uptake of nutrients. Results of nutrient uptake confirm the findings of Dutta *et al.* (2000) and Kundu and Singh (2006).

Effect of nitrogen fertigation on growth, yield attributes and yield: Application of 50% RDN (N_1) recorded significantly higher values of all the growth and yield attributes as well as seed (1273 kg/ha), stover yield (2861 kg/ha) and oil yield (655 kg/ha). The per cent increase in seed, stover and oil yields under N_1, N_2 over N_3 were to the tune of 45.8, 22.6, 46.2 and 29.2, 15.2, 23.9 per cent, respectively (Table 1 and 2). Increase in growth and yield attributes with higher level of nitrogen might be due to the fact that balanced nutrient supply increase the adsorptive power of soil for cation and anion, created a situation favourable for higher uptake of NPK by plant. These absorbed ions are released slowly for the entire growth period resulted in better nutrient availability at active growth of the crop and increases observed in growth parameters. The findings are in close vicinity with the results obtained by Patra (2001). The overall improvement in vegetative growth of the plant due to application of higher dose of N fertilizer through fertigation which favourably effected yield attributing characters *viz.,* number of branches/plant, number of capsules/plant, length of capsule, number of seeds/capsule. These increase in seed and stover yields of sesame with the higher level of N fertigation evidently resulted from overall improvement in growth and yield attributing characters. Higher seed and stover yields with higher N fertigation were also probably a consequence of greater amount of nutrient uptake by the seed and stover. The increase in yield with increased N-fertilizer level is in close conformity with the findings of Thanki *et al.* (2014). Oil content in sesame was not significantly influenced with application of N through fertigation (Table 2).

Table 2 Effect of irrigation schedules and N fertigation levels on total NPK uptake of summer sesame (pooled data of two years)

Treatments	Nutrient uptake (kg/ha)		
	N	P	K
Irrigation schedules			
I_1- DI at 100% Epan	63.3	9.5	49.9
I_2- DI at 80% Epan	59.0	9.9	46.5
I_3- DI at 60% Epan	41.4	5.7	35.0
I_4- DI at 40% Epan	33.2	4.19	29.4
I_5- Surface irrigation at IW/CPE ratio at 1.0	47.4	6.5	39.4
SEm (±)	1.59	0.32	0.96
CD (P=0.05)	5.17	1.06	3.15
CV (%)	9.7	13.6	7.23
N fertigation levels			
N_1-50% RDN	59.4	9.2	47.8
N_2-25% RDN	48.8	7.0	40.0
N_3-0% RDN	38.5	5.2	32.3
SEm (±)	0.43	0.16	0.39
CD (P=0.05)	1.27	0.47	1.15
CV (%)	3.4	8.5	3.76
I x N interaction	Sig.	Sig.	Sig.

Table 3 Effect of irrigation schedules and nitrogen fertigation levels on sesame plant height (cm) (Pooled data of two years)

N fertigation levels	Irrigation schedules					
	I_1-DI at 100% Epan	I_2-DI at 80% Epan	I_3-DI at 60% Epan	I_4-DI at 40% Epan	I_5-SI at IW/CPE ratio 1.0	Mean
N_1-50% RDN	170.0	160.1	136.1	124.2	146.5	147.4
N_2-25% RDN	157.6	151.5	127.7	114.2	134.3	137.1
N_3-0% RDN	143.5	139.6	118.1	107.5	119.2	125.6
Mean	157.1	150.4	127.3	115.3	133.2	
			Interactions			
	Irrigation schedules	N fertigation levels	N fertigation at same level of irrigation schedules		Irrigation at same or different levels of N fertigation	
SEm (±)	1.59	0.72	1.61		2.43	
CD (P=0.05)	5.2	2.1	4.8		7.6	

Application of higher dose of N through fertigation to summer sesame resulted in significantly higher NPK uptake of 59.40, 9.25 and 47.79 of NPK/ha, respectively (Table 3). The increase in uptake of nutrients by sesame crop appears due to the cumulative effects of increased seed and stover yields thereby total drymatter. The application of N, P and K might have increased their availability and uptake by plant. The results are substantiating the findings of Mondal *et al.* (1997), Patra (2001) and Thanki *et al.* (2014).

Interaction effect of irrigation and fertility levels: Data of two years revealed significant interaction between irrigation and fertility levels (I x F). Significantly higher plant height, LAI, dry matter production; seed, stover and oil yields, harvesting index were recorded with drip irrigation scheduled at 100% Epan along with application of 50% RDN through fertigation (I_1 x N_1) than rest of the combinations (Tables 3-9). Due to application of sufficient amount of water along with optimum amount of nutrients might have increased physiological processes like cell division and cell expansion which resulted favourable growth conditions. These results are in close agreement of the results obtained by Khade *et al.* (1996) and Ravinder *et al.* (1996). Similarly, higher N P and K uptake was realised with drip irrigation scheduled at 100% Epan along with application of 50% RDN through fertigation (I_1 x N_1) (Tables 10-12).

Water use efficiency: Significantly higher water use efficiency of 3.83 kg/ha mm was recorded with drip irrigation scheduled at 100% Epan (I_1). The lowest water use efficiency (2.58 kg/ha mm) was observed with surface irrigation scheduled at IW/CPE ratio (I_5) and comparable with drip irrigation scheduled at 40% Epan (Table 2). These findings indicate that the impact of irrigation during summer season is more pronounced on yield and contributed to higher WUE. Under sufficient soil moisture i.e., drip irrigation scheduled at 100% Epan (I_1), sesame crop recorded higher vegetative growth and development resulted in increased yield attributes, finally seed and stover yields. This might be due to higher water use and ultimately prone to higher water use efficiency. These results completely collaborate with the findings of Mitra and Pal (1999). In case of N fertigation levels, higher water use efficiency of 3.67 kg/ha mm was found when crop was fertilized with 50% RDN (N_1) compared to other lower levels of N fertigation.

Table 4 Effect of irrigation schedules and nitrogen fertigation levels on sesame LAI at 60 DAS (Pooled data of two years)

N fertigation levels	Irrigation schedules					
	I_1-DI at 100% Epan	I_2-DI at 80% Epan	I_3-DI at 60% Epan	I_4-DI at 40% Epan	I_5-SI at IW/CPE ratio 1.0	Mean
N_1-50% RDN	3.17	2.79	2.23	1.76	2.30	2.45
N_2-25% RDN	2.25	2.38	1.88	1.40	1.86	1.96
N_3-0% RDN	2.12	1.82	1.34	0.96	1.38	1.52
Mean	2.52	2.33	1.82	1.37	1.85	
			Interactions			
	Irrigation schedules	N fertigation levels	N fertigation at same level of irrigation schedules		Irrigation at same or different levels of N fertigation	
SEm (±)	0.07	0.040	0.08		0.11	
CD (P=0.05)	0.21	0.11	0.24		0.30	

Table 5 Effect of irrigation schedules and nitrogen fertigation levels on dry matter production at harvest of sesame (Pooled data of two years)

N fertigation levels	Irrigation schedules					
	I_1-DI at 100% Epan	I_2-DI at 80% Epan	I_3-DI at 60% Epan	I_4-DI at 40% Epan	I_5-SI at IW/CPE ratio 1.0	Mean
N_1-50% RDN	5260	4625	3815	3176	3796	4135
N_2-25% RDN	4446	4132	3379	2732	3415	3621
N_3-0% RDN	3674	3541	2816	2322	3087	3088
Mean	4460	4099	3337	2743	3433	
			Interactions			
	Irrigation schedules	N fertigation levels	N fertigation at same level of irrigation schedules		Irrigation at same or different levels of N fertigation	
SEm (±)	65.7	21.9	48.9		97.2	
CD (P=0.05)	214.5	64.6	144.4		308.9	

Table 6 Effect of irrigation schedules and nitrogen fertigation levels on seed yield/plant (g) of sesame (Pooled data of two years)

N fertigation levels	Irrigation schedules					
	I_1-DI at 100% Epan	I_2-DI at 80% Epan	I_3-DI at 60% Epan	I_4-DI at 40% Epan	I_5-SI at IW/CPE ratio 1.0	Mean
N_1-50% RDN	7.41	6.41	6.72	5.58	6.76	6.58
N_2-25% RDN	6.76	5.79	5.12	4.90	5.21	5.56
N_3-0% RDN	5.77	4.93	4.69	4.17	4.58	4.83
Mean	6.65	5.71	5.51	4.88	5.52	
			Interactions			
	Irrigation schedules	N fertigation levels	N fertigation at same level of irrigation schedules		Irrigation at same or different levels of N fertigation	
SEm (±)	0.07	0.06	0.14		0.13	
CD (P=0.05)	0.22	0.19	0.43		0.38	

Table 7 Effect of irrigation schedules and nitrogen fertigation levels on seed yield (kg/ha) of sesame (Pooled data of two years)

N fertigation levels	Irrigation schedules					
	I_1-DI at 100% Epan	I_2-DI at 80% Epan	I_3-DI at 60% Epan	I_4-DI at 40% Epan	I_5-SI at IW/CPE ratio 1.0	Mean
N_1-50% RDN	1671	1414	1098	953	1231	1273
N_2-25% RDN	1394	1280	933	703	1041	1070
N_3-0% RDN	1051	1039	782	612	882	873
Mean	1372	1244	938	756	1051	
			Interactions			
	Irrigation schedules	N fertigation levels	N fertigation at same level of irrigation schedules		Irrigation at same or different levels of N fertigation	
SEm (±)	44.0	7.86	17.5		63.0	
CD (P=0.05)	143.5	23.2	51.8		193.8	

Table 8 Effect of irrigation schedules and nitrogen fertigation levels on stalk yield (kg/ha) of sesame (Pooled data of two years)

N fertigation levels	Irrigation schedules					
	I_1-DI at 100% Epan	I_2-DI at 80% Epan	I_3-DI at 60% Epan	I_4-DI at 40% Epan	I_5-SI at IW/CPE ratio 1.0	Mean
N_1-50% RDN	3589	3211	2717	2223	2565	2861
N_2-25% RDN	3052	2852	2446	2029	2374	2551
N_3-0% RDN	2623	2502	2034	1710	2206	2215
Mean	3088	2855	2399	1987	2382	
			Interactions			
	Irrigation schedules	N fertigation levels	N fertigation at same level of irrigation schedules		Irrigation at same or different levels of N fertigation	
SEm (±)	45.6	21.5	48.0		70.2	
CD (P=0.05)	148.6	63.4	141.7		219.5	

Table 9 Effect of irrigation schedules and nitrogen fertigation levels on harvest index (%) of sesame (Pooled data of two years)

N fertigation levels	Irrigation schedules					
	I_1-DI at 100% Epan	I_2-DI at 80% Epan	I_3-DI at 60% Epan	I_4-DI at 40% Epan	I_5-SI at IW/CPE ratio 1.0	Mean
N_1-50% RDN	31.7	30.5	28.9	29.4	32.4	30.6
N_2-25% RDN	31.3	30.9	27.5	25.6	30.4	29.1
N_3-0% RDN	28.5	29.2	27.4	26.4	28.4	28.0
Mean	30.5	30.2	27.9	27.1	30.4	
			Interactions			
	Irrigation schedules	N fertigation levels	N fertigation at same level of irrigation schedules		Irrigation at same or different levels of N fertigation	
SEm (±)	1.00	0.23	0.52		1.45	
CD (P=0.05)	NS	0.71	1.53		4.70	

Table 10 Effect of irrigation schedules and nitrogen fertigation levels on total N uptake (kg/ha) by sesame (Pooled data of two years)

N fertigation levels	Irrigation schedules					
	I_1-DI at 100% Epan	I_2-DI at 80% Epan	I_3-DI at 60% Epan	I_4-DI at 40% Epan	I_5-SI at IW/CPE ratio 1.0	Mean
N_1-50% RDN	81.12	71.67	49.42	38.34	56.48	59.40
N_2-25% RDN	61.80	60.53	41.74	32.90	46.90	48.77
N_3-0% RDN	47.13	44.82	33.17	28.46	38.95	38.51
Mean	63.35	59.01	41.44	33.23	47.44	
			Interactions			
	Irrigation schedules	N fertigation levels	N fertigation at same level of irrigation schedules		Irrigation at same or different levels of N fertigation	
SEm (±)	1.59	0.43	0.96		2.31	
CD (P=0.05)	5.17	1.27	2.84		7.39	

Table 11 Effect of irrigation schedules and nitrogen fertigation levels on total P uptake (kg/ha) by sesame (Pooled data of two years)

N fertigation levels	Irrigation schedules					
	I_1-DI at 100% Epan	I_2-DI at 80% Epan	I_3-DI at 60% Epan	I_4-DI at 40% Epan	I_5-SI at IW/CPE ratio 1.0	Mean
N_1-50% RDN	13.05	12.08	7.52	5.31	8.31	9.25
N_2-25% RDN	9.25	9.66	5.59	4.11	6.41	7.00
N_3-0% RDN	6.20	7.88	3.96	3.15	4.77	5.19
Mean	9.50	9.87	5.69	4.19	6.49	
			Interactions			
	Irrigation schedules	N fertigation levels	N fertigation at same level of irrigation schedules		Irrigation at same or different levels of N fertigation	
SEm (±)	0.32	0.16	0.35		0.50	
CD (P=0.05)	1.06	0.47	1.04		1.57	

Table 12 Effect of irrigation schedules and nitrogen fertigation levels on total K uptake (kg/ha) by sesame (Pooled data of two years)

N fertigation levels	Irrigation schedules					
	I_1-DI at 100% Epan	I_2-DI at 80% Epan	I_3-DI at 60% Epan	I_4-DI at 40% Epan	I_5-SI at IW/CPE ratio 1.0	Mean
N_1-50% RDN	63.15	55.45	41.38	33.42	45.54	47.79
N_2-25% RDN	48.48	46.86	35.25	29.86	39.51	39.99
N_3-0% RDN	38.15	37.08	28.45	24.97	33.10	32.35
Mean	49.93	46.47	35.03	29.42	39.38	
			Interactions			
	Irrigation schedules	N fertigation levels	N fertigation at same level of irrigation schedules		Irrigation at same or different levels of N fertigation	
SEm (±)	0.96	0.39	0.87		1.45	
CD (P=0.05)	3.15	1.15	2.56		4.58	

REFERENCES

Chandra Mohan Y, Rao V T and Bharathi D 2012. Variability and genetic divergence in sesame (*Sesamum indicum* L.). *Journal of Oilseeds Research*, **29**(2): 139-141.

Dutta D, Jana P K, Bandyopadhyay P and Maity D 2000. Response of summer sesame (*Sesamum indicum* L.) to irrigation. *Indian Journal of Agronomy*, **45**(3): 613-616.

Khade V N, Jadhav S N and Khanvilkar S A 1996. Studies on scheduling of irrigation and phosphate fertilization to sesamum. *Journal of Maharashtra Agricultural Universities*, **21**(3): 410-411.

Kundu D K and Singh R 2006. Effect of irrigation on yield and nutrient uptake of summer sesame (*Sesamum indicum* L.) in coastal Orissa. *Indian Journal of Agricultural Sciences*, **76**(9): 531-534.

Mitra S and Pal A K 1999. Water use and productivity of summer sesame as influenced by irrigation and nitrogen. *Journal of Indian Society of Soil Science*, **47**(3): 400-404.

Mondal D K, Sounda G, Panda P K, Ghosh P, Mitra S and Roy D K 1997. Effect of different irrigation levels and nitrogen doses on growth and yield of sesame (*Sesamum indicum* L.). *Indian Agriculturist*, **41**(1): 15-21.

Narang R S and Gill M S 1998. Irrigation scheduling for higher WUE in oilseeds and pulses. *Fertlizer News*, **43**(3): 57-67.

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

Ranganatha A R G, Lokesha R, Tripathi A, Tabassum A, Paroha S and Shrivastava M K. 2012. Sesame improvement: present status and future strategies. *Journal of Oilseeds Research*, **29**(1): 1-26.

Ravinder N, Satyanarayana V, Rao V P, Latchanna A and Varaprasad P V 1996. Influence of irrigation and fertilization on seed yield, nutrient uptake and fertilizer use efficiencies in summer sesame (*Sesamum indicum* L.). *Indian Journal of Agricultural Sciences*, **75**(3): 143-147.

Thanki R B, Solanki R M, Modhavadia J M, Gohil B S and Prajapati P J 2014. Effect of irrigation scheduling at critical growth stages and fertility levels on growth, yield and quality of summer sesame (*Sesamum indicum* L.). *Journal of Oilseeds Research*, **31**(1): 41-45.

Maximum entropy modelling for predicting the potential distribution of wild sesame, *Sesamum alatum* Thonn. in India

B SARATH BABU, NILAMANI DIKSHIT[1], K RAMEASH AND N SIVARAJ

ICAR-National Bureau of Plant Genetic Resources, Regional Station, Hyderabad-500 030, Telangana State

(Received: March 9, 2016; Revised: March 16, 2016; Accepted: March 28, 2016)

ABSTRACT

Ecological niche modelling or predictive habitat distribution framework for wild sesame, *Sesamum alatum* Thonn., an important wild taxa occurring in India has been analyzed using Maximum Entropy method. The model indicated that parts of Kanyakumari, Thoothukudi, Sivaganga, Pudukottai, Coimbatore, Thiruvalluvar districts of Tamil Nadu and Chittoor, Kadapa, Nellore, Prakasam, Guntur, Krishna, West Godavari, East Godavari, Visakhapatnam districts of Andhra Pradesh are falling under high probability regions for climate suitability of *S. alatum* species where the *in-situ* conservation and other genetic resources activity could be taken up in the changed climatic regime. Mean temperature of coldest quarter (30.4%), annual mean temperature (26.0%) and mean diurnal range (17.7%) are major bioclimatic variables contributing to the climatic model of the wild sesame.

Keywords: GIS, Ecological niche modelling, Maxent, *Sesamum alatum*

The genus *Sesamum* is of great economic importance as an oilseed crop in the hotter and drier parts of the Mediterranean region, Africa, India and the Far East. About 35 species are reported in the world, while the origin of the plant is not known with certainty (Ranganatha *et al.,* 2012; Kumaraswamy *et al.,* 2015). The presence of a large number of wild relatives suggests Africa as its possible primary centre and India as its secondary centre, while the genus may be Asiatic (Hooker, 1885). Six species are reported from India of which *S. indicum* is cultivated. *Sesamum alatum* is one of the wild relatives of cultivated sesame and it is widely distributed in tropical Africa, occurring in dry regions from Senegal to South Africa. In Madagascar, India and occasionally elsewhere it has been introduced. It could be distinguished from cultivated sesame (*S. indicum*) by its palmate basal leaves and winged seeds.

S. alatum is an erect annual herb up to 1.5 m tall, with simple or sparsely branched stem, glabrous but with mucilage glands. Leaves opposite, lower ones palmately divided or lobed, upper ones simple; stipules absent; petiole 1-7 cm long; leaflets or lobes of lower leaves lanceolate, central one longest, up to 8 cm × 2 cm, often with undulate margin. Flowers solitary in leaf axils, bisexual, zygomorphic; fruit a narrowly obconical capsule up to 5 cm × 0.7 cm, base gradually narrowed, apex with beak up to 12 mm long, 4-grooved, dehiscing longitudinally, many-seeded. Seeds obconical, c. 2.5 mm × 1.5 mm, with a large, 2-3 mm long wing at apex and 2 shorter wings at base, testa with honeycomb-like structure, pale to dark brown.

[1]ICAR-National Bureau of Plant Genetic Resources, Regional Station, Akola-444 104, Maharashtra

In India, it is mostly occurring as a weedy species, however in African countries, the leaves and young shoots of *S. alatum* are collected from the wild and used as a cooked vegetable, sometimes flavoured with its pounded seeds. The seeds are occasionally cooked separately as a relish or boiled with pumpkin leaves and served with a staple food. The seed produces edible oil, and is used as an aphrodisiac and to cure diarrhoea and other intestinal disorders. Considering its importance, an attempt has been made to predict the potential regions for the distribution of this valuable species and to map the climate suitability for managing the wild sesame genetic resources in India.

MATERIALS AND METHODS

The potential regions of distribution of *S. alatum* was analysed using the Maximum Entropy (Maxent) niche modelling method. The geographical coordinates recorded for *S. alatum* using Global Positioning System (GPS, Garmin 12) during the multi-crop exploration missions carried out by ICAR-National Bureau of Plant Genetic Resources (NBPGR), Regional Station, Hyderabad and Akola formed the source data for the crop presence information which is used in CSV (comma delimited) format using MS-Excel. Characterization of *S. alatum* was carried out at NBPGR Regional Station, Akola using standard descriptors. Bioclimatic variables (BC) are often used in ecological niche modelling and they represent annual trends, seasonality and extreme or limiting environmental factors. Bioclimatic variables are generally selected based on species ecology (Roura-Pascual *et al.,* 2009). For the current climate (baseline) of India we used monthly data from the

WorldClim (WC) database sourced from global weather stations. The variables, including annual mean temperature, mean diurnal range, maximum temperature of warmest month, minimum temperature of coldest month, annual precipitation, and precipitation of the wettest and driest months were downloaded from the WorldClim dataset (freely available at http://www.worldclim.org). The WorldClim data provides interpolated global climate surfaces using latitude, longitude and elevation as independent variables and represents long term (1950-2000) monthly means of maximum, minimum, mean temperatures and total rainfall as generic 2.5 arc-min grids. Environmental layers used (all continuous): bio1 (Annual mean temperature); bio2 (Mean diurnal range); bio3 (Isothermality); bio4 (Temperature seasonality); bio5 (Max temperature of warmest month); bio6 (Min temperature of coldest month); bio7 (Temperature annual range); bio8 (Mean temperature of wettest quarter); bio9 (Mean temperature of driest quarter); bio10 (Mean temperature of warmest quarter); bio11 (Mean temperature of coldest quarter); bio12 (Annual precipitation); bio13 (Precipitation of wettest month); bio14 (Precipitation of driest month); bio15 (Precipitation seasonality); bio16 (Precipitation of wettest quarter); bio17 (Precipitation of driest quarter); bio18 (Precipitation of warmest quarter); bio19 (Precipitation of coldest quarter).

RESULTS AND DISCUSSION

Maximum Entropy (Maxent) is a niche modelling approach that has been developed linking species distribution information built only on identified presences and is a general-purpose method for making predictions or inferences from incomplete information. Maxent can take the environmental conditions at occurrence locations and produce a probability distribution that can then be used to assess every other location for its likely occurrence/cultivation. The result is a map of the probability of conditions being favourable to occurrence/cultivation. The basis for this model is the general notion that knowledge about environmental conditions at locations where *S. alatum* is distributed should provide a basis for summarizing species growth parameters throughout the region. We have used Maxent niche modelling method for predicting potential pockets for managing sustainable wild sesame genetic resources in India. *S. alatum* characterization data is presented in Table 1.

Fig.1 is a representation of the Maxent model for *S. alatum.* Warmer colours show areas with better predicted conditions (high probability value of 0.72-1.0). These regions are highly suitable climatic sites for the cultivation of this unique wild species of sesame. The model indicates that parts of Tamil Nadu (Kanyakumari, Thoothukudi, Sivaganga, Pudukottai, Coimbatore, Thiruvalluvar districts) and Andhra Pradesh (Chittoor, Kadapa, Nellore, Prakasam, Guntur, Krishna, West Godavari, East Godavari, Visakhapatnam) are the high probability pockets where this wild species has climate suitable regions for the distribution of *S. alatum* with high probability value of 0.79-1.0. In these parts of South India *in-situ* conservation and other genetic resources management of *S. alatum* could be taken up in future in the light of climate change.

Table 1 Characterization of *Sesamum alatum* at Akola, India

Traits	Mean
Plant height (cm)	167.8
No. of ramifications	5.0
Length of lower leaves (cm)	4.15
Width of lower leaves (cm)	0.35
Length of upper leaves (cm)	5.45
Width of upper leaves (cm)	0.3
Root length (cm)	19.4
Root shoot ratio	0.12
Corolla length (cm)	3.14
Corolla width (cm)	1.12
Petiole length of lower leaves (cm)	2.1
First internode length (cm)	7.6
Second internode length (cm)	6.35
No. of capsules/plant	52.5
Capsule length (cm)	3.74
No. of seeds/capsule	85.0
Capsule width (cm)	0.52
100-seed weight (g)	0.11

Fig.2 displays the omission rate and predicted area as a function of the cumulative threshold. The omission rate is calculated both on the training presence records, and (if test data are used) on the test records. The omission rate should be close to the predicted omission, because of the definition of the cumulative threshold. The receiver operating characteristic (ROC) curve for the same data generated for *S. alatum.* This implies that the maximum achievable AUC is less than 1. If test data is drawn from the Maxent distribution itself, then the maximum possible test AUC would be 0.988 rather than 1; in practice the test AUC may exceed this bound. Some common thresholds and corresponding omission rates are provided in Table 1. If test data are available, binomial probabilities are calculated exactly if the number of test samples is at most 25, otherwise using a normal approximation to the binomial. These are 1-sided p-values for the null hypothesis that test points are predicted no better than by a random prediction with the same fractional predicted area. The "Balance" threshold minimizes 6 * training omission rate + .04 * cumulative threshold + 1.6 * fractional predicted area.

Table 2 gives estimates of relative contributions of the environmental variables to the Maxent model. Mean temperature of coldest quarter (30.4%); annual mean temperature (26.0%); mean diurnal range (17.7%) are major bioclimatic variables contributing to the climatic models. To

determine the first estimate, in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda is negative. For the second estimate, for each environmental variable in turn, the values of that variable on training presence and background data are randomly permuted. The model is revaluated on the permuted data, and the resulting drop in training AUC is shown in the table, normalized to percentages. As with the variable jackknife, variable contributions should be interpreted with caution when the predictor variables are correlated.

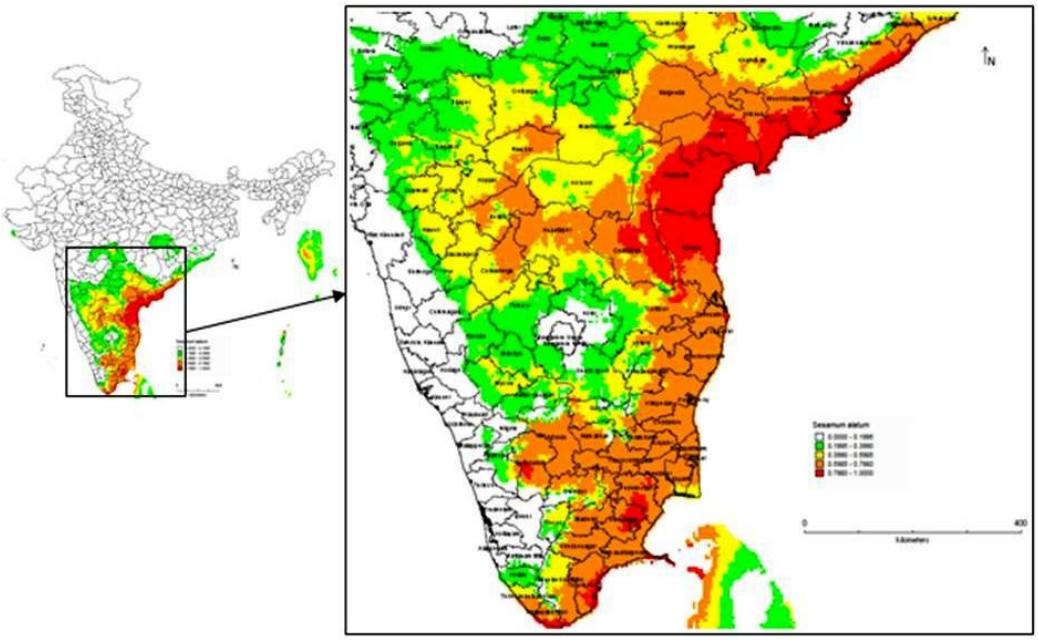

Fig.1. Maxent model generated for the wild sesame, *Sesamum alatum* showing the potential regions of distribution in peninsular India

Fig. 3 shows the results of the jackknife test of variable importance. The environmental variable with highest gain when used in isolation is bio11, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is bio2, which therefore appears to have the most information that isn't present in the other variables. The jackknife approach (Yost *et al.,* 2008; Phillips *et al.,* 2012) was used to assess variable importance. This approach excludes one variable at a time when running the model, by training with each environmental variable first omitted and then used singly. In so doing, it provides information on the performance of each variable in the model in terms of how important each variable is at explaining the species distribution and how much unique information each variable provides. This notion is borne out by the popularity of the general purpose machine learning technique called Maximum Entropy Modelling (Maxent). It has found strong support in the ecology domain as a means for predicting the spatial distribution of species from a limited set of occurrence or presence-only records. The Maxent technique estimates an unknown probability distribution that "satisfies any constraints on the unknown distribution that we are aware of, and that subject to those constraints, the distribution should have maximum entropy (Phillips *et al.,* 2004). In information theory, entropy is randomness or unpredictability, meaning that the portion that is not explained by the probability distribution has no remaining information with respect to the distribution of the prior data. Thus the result of a maximum entropy model is the best possible "description" of the distribution of the prior data. The benefit of Maxent is that we need not specify the determining conditions completely. In the case of this study, the result is a probability distribution of *S. alatum* that reflects the environmental constraints that have been observed to be associated with the locations of existing sesame wild species. The model works well with little sample sites of occurrence data and with both continuous and categorical environmental variables. Similar to logistic regression, ranges from 0 to 1. The information available about the target distribution often presents itself as a set of real-valued variables, called 'features', and the constraints are that the expected value of each feature should match its empirical average (Phillips *et al.,* 2006). Each feature, the

environmental variables, gets weighted according to how much complexity it adds to the model. The program starts with a uniform probability distribution and works in cycles adjusting the probabilities to maximum entropy. It iteratively alters one weight at a time to maximize the likelihood of reaching the optimum probability distribution. Maxent is considered as the most accurate model performing extremely well in predicting occurrences in relation to other common approaches (Elith *et al.,* 2006; Hijmans and Graham, 2006), especially with incomplete information.

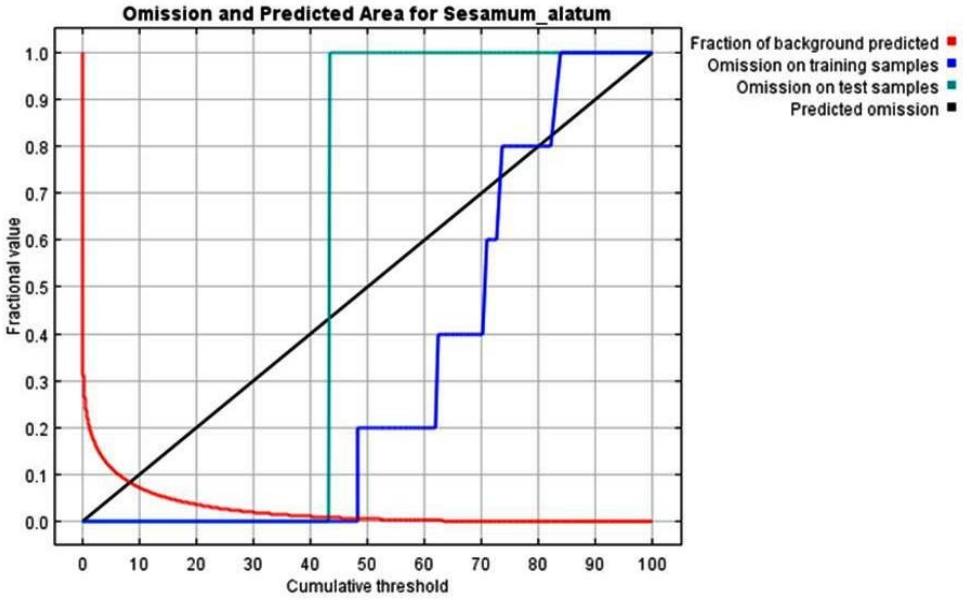

Fig. 2. Omission and predicted area for *Sesamum alatum* in the Maxent model

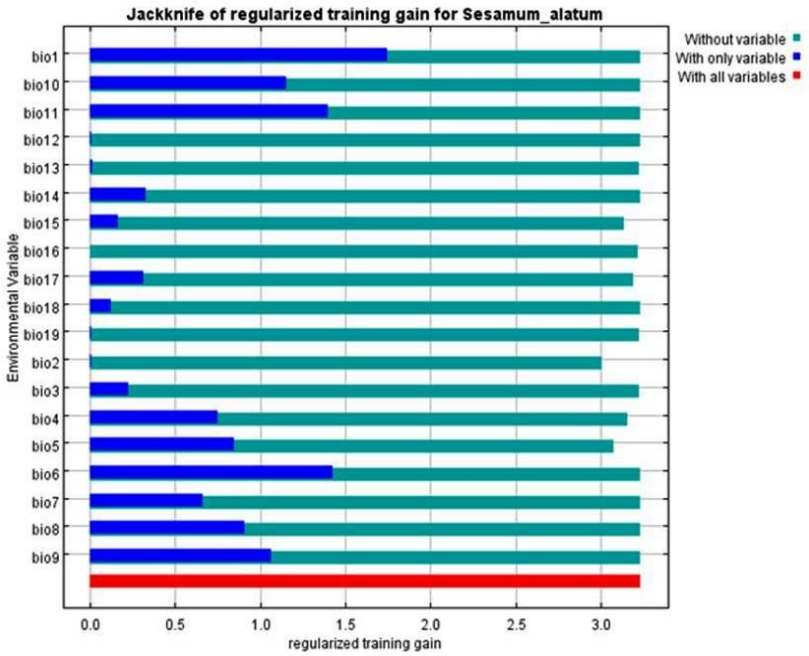

Fig.3. Jacknife test of regularized training gain for *Sesamum alatum*

Table 2 Estimates of relative contributions of environmental variables to the Maxent model on *Sesamum alatum*

Code	Variable	Per cent contribution	Permutation importance
Bio11	Mean temperature of coldest quarter	30.4	0.0
Bio1	Annual mean temperature	26.0	0.0
Bio2	Mean diurnal range	17.7	18.3
Bio12	Annual precipitation	8.8	0.0
Bio17	Precipitation of driest quarter	6.7	1.8
Bio5	Max temperature of warmest month	4.8	56.4
Bio15	Precipitation seasonality	2.8	1.0
Bio4	Temperature seasonality	1.1	15.1
Bio18	Precipitation of warmest quarter	1.0	0.1
Bio16	Precipitation of wettest quarter	0.3	6.5
Bio3	Isothermality	0.1	0.1
Bio13	Precipitation of wettest month	0.1	0.8
Bio8	Mean temperature of wettest quarter	0.0	0.0
Bio19	Precipitation of coldest quarter	0.0	0.1
Bio14	Precipitation of wettest month	0.0	0.0
Bio6	Min temperature of coldest month	0.0	0.0
Bio9	Mean temperature of driest quarter	0.0	0.0
Bio10	Mean temperature of warmest quarter	0.0	0.0
Bio7	Temperature annual range	0.0	0.0

The maximum entropy modelling technique has been successfully used to model potential plant and insect distributions for purposes such as monitoring invasive species and disease vectors and their likely spread due to climate change by many researchers in the recent past (Chamaille *et al.,* 2010; David *et al.,* 2012; Fourcade *et al.,* 2014; Gormley *et al.,* 2011; Khoury *et al.,* 2015; Petersen, 2013; Reddy *et al.,* 2015a, 2015b; Solhjouy-Fard *et al.,* 2013; Villordon *et al.,* 2006; Zimmermann *et al.,* 2015). It executes well on small sample sizes (Pearson *et al.,* 2009), which indicates that the multiplicative methods used in Maxent give better predictions than the discriminative methods employed by other techniques (Elith *et al.,* 2006; Phillips and Dudik, 2008). However, this is the first attempt to predict possible distribution locations of wild sesame (*S. alatum*) in the changed climatic regime.

ACKNOWLEDGEMENTS

The authors are highly thankful to Director, ICAR-National Bureau of Plant Genetic Resources, New Delhi and to the Head, Division of Plant Quarantine, ICAR-NBPGR, New Delhi, for providing necessary facilities.

REFERENCES

Chamaille L, Tran A, Meunier A, Bourdoiseau G, Ready P and Dedet J P 2010. Environmental risk mapping of *Canine leishmaniasis* in France. *Parasites and Vectors*, **3**: 3-31.

David A K, Keith L, Mc Dougall, Christopher C S and Jillian L W 2012. Spatial analysis of risks posed by root rot pathogen, *Phytophthora cinnamomi:* Implications for disease management. *Proceedings of the Linnean Society of New South Wales,* **134**: 147-180.

Elith J, Graham C H, Anderson R P, Dudík M, Ferrier S, Guisan A, Hijmans R J, Huettmann F, Leathwick R, Lehmann A, Li J, Lohmann, L G, Loiselle B A, Manion G, Moritz C, Nakamura M, Nakazawa Y, Overton J, Peterson A T, Phillips J, Richardson K, Scachetti-Pereira R, Schapire E, Soberon J, Williams S, Wisz M and Zimmermann E 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, **29**: 129-151.

Fourcade Y, Engler J O, Rodder D and Secondi J 2014. Mapping species distributions with MAXENT using a geographically biased sample of presence data: a performance assessment of methods for correcting sampling bias. *PLoS One*, **9**(5): e97122. doi:10.1371/journal.pone.0097122.

Gormley A M, Forsyth D M, Griffioen P, Lindeman M, Ramsey D S L, Scroggie M P and Woodford L 2011. Using presence-only and presence-absence data to estimate the current and potential distributions of established invasive species. *Journal of Applied Ecology*, **48**: 25-34.

Hijmans R J and Graham C 2006. The ability of climate envelope models to predict the effect of climate change on species distributions. *Global Change Biology*, **12**: 2272-2281.

Hooker J D 1885. *The Flora of British India,* Vol. IV, Reeve & Co. Ltd, The East House Brook, Kent, England, Reprint edition, BSI, India, pp. 386-387.

Khoury C K, Heide B, Castañeda-Álvarez N P, Achicanoy H A, Sosa C, Miller R E, Scotland R W, Wood J R I, Rossel G, Eserman L A, Jarret R L, Yencho G C, Bernau V, Juarez H, Sotelo S, de Haan S and Struik P C 2015. Distributions, *ex-situ* conservation priorities, and genetic resource potential of crop wild relatives of sweet potato [*Ipomoea batatas* (L.) Lam., I. series Batatas]. *Frontiers in Plant Science*, **6**: 251.

Kumaraswamy H H, Jawaharlal J, Ranganatha A R G and Chander Rao S. 2015. Safe sesame (*Sesamum indicum* L.) production: Perspectives, practices and challenges. *Journal of Oilseeds Research*, **29**(1): 1-24.

Pearson R G, Raxworthy C J, Nakamura M and Peterson A T 2009. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. *Journal of Biogeography*, **34**: 102-117.

Petersen M J 2013. Evidence of a climatic niche shift following North American introductions of two crane flies (Diptera; genus tipula). *Biological Invasions*, **15**: 885-897.

Phillips S J, Anderson R P and Schapire R E 2006. Maximum entropy modelling of species geographic distributions. *Ecological Modelling*, **190**: 231-259.

Phillips S J, Dudik M and Schapire R E 2004. A Maximum Entropy Approach to Species Distribution Modelling. *In: Proceedings of the Twenty-First International Conference* on Machine Learning, Banff, Canada, pp. 655-662.

Phillips S J and Dudik M 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography*, **31**: 161-175.

Ranganatha A R G, Lokesha R, Tripathi A, Tabassum A, Paroha S and Shrivastava M K. 2012. Sesame improvement: present status and future strategies. *Journal of Oilseeds Research*, **29**(1): 1-26.

Reddy M T, Hameedunnisa Begum, Neelam Sunil, Someswara Rao Pandravada, Natarajan Sivaraj 2015. Assessing climate suitability for sustainable vegetable Roselle (*Hibiscus sabdariffa* var. *sabdariffa* L.) cultivation in India using Maxent Model. *Agricultural and Biological Sciences Journal*, **1**(2): 62-70.

Reddy M T, Begum H, Sunil N, Pandravada S R, Sivaraj N and Kumar S 2015. Mapping the climate suitability using Maxent modeling approach for *Ceylon spinach* (*Basellaalba* L.) cultivation in India. *The Journal of Agricultural Sciences*, **10**(2): 87-97.

Roura-Pascual N, Brotons L, Peterson A T and Thuiller W 2009. Consensual predictions of potential distributional areas for invasive species: a case study of Argentine ants in the Iberian *Peninsula. Biological Invasions*, **11**: 1017-1031.

Solhjouy-Fard S, Sarafrazi A, Moeini M M and Ahadiyat A 2013. Predicting habitat distribution of five heteropteran pest species in Iran. *Journal of Insect Science*, **13**: 116.

Tittensor D P, Baco A R, Brewin P E, Clark M R, Consalvey M, Hall-Spencer J, Rowden A A, Schlacher T, Stocks K I and Rogers AD 2009. Predicting global habitat suitability for stony corals on seamounts. *Journal of Biogeography*, **36**: 1111-1128.

Villordon A, Njugana W, Simon G, Philip N, Heneriko K, Simon C J, Don L B, Bernard Y, Phinehas T and Robert O M M 2006. Using GIS based tools and distribution modelling to determine sweet potato exploration and documentation priorities in Sub-Saharan Africa. *Horticultural Science*, **41**(6): 1377-1381.

Yost A C, Petersen S L, Gregg M and Miller R 2008. Predictive modeling and mapping sage grouse (*Centrocercus urophasianus*) nesting habitat using maximum entropy and a long-term dataset from Southern Oregon. *Ecological Informatics*, **3**: 375-386.

Zimmermann H, Loos J, Wehrden H and Fischer J 2015. Aliens in Transylvania: risk maps of invasive alien plant species in Central Romania. *Neo Biota*, **24**: 55-65.

Changes in antioxidant content in selected cultivars of safflower (*Carthamus tinctorius* L.) leaves during different stages of maturity

E SUNEEL KUMAR, APARNA KUNA, P PADMAVATHI[1], CH V DURGA RANI, SUPTA SARKAR[1] AND M SOWMYA

Prof. Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad-500 030, Telangana State

(Received: November 23, 2015; Revised: March 12, 2016; Accepted: March 23, 2016)

ABSTRACT

The antioxidant content in the safflower (*Carthamus tinctorius* L.) leaves was estimated during 30, 50, 70 and 90 days in selected spiny (Manjira, TSF-1 and Annigeri-1) and non-spiny (NARI-6) cultivars. The total carotenoid content was highest during the 30th day in all the four cultivars ranging from 7122.56 - 14892.80µg/100g, while it was lowest during 70th day ranging from 1476.00 - 4066.40µg/100g. Ascorbic acid content was highest during 50th day in Annigeri-1 and Manjira, whereas it was highest on 70th day in NARI-6 variety. The results also indicate that TSF-1 is a poor source of ascorbic acid when compared to Annigeri-1, Manjira and NARI-6. The DPPH (1, 1-dipheny l- 2-picryl-hydrazil) scavenging activity and total flavonoids of safflower leaves were higher at 30th day while superoxide anion activity and total phenolics were higher at later stages. Stage of maturity has a remarkable influence on the antioxidant content of safflower leaves. However, consumption of the safflower leaves at any stage of maturity provides antioxidants in the diet through various mechanisms.

Keywords: Antioxidant, Cultivars, Leaves, Safflower

Green leafy vegetables (GLV) are a rich source of natural antioxidants such as vitamin C, phenolics and β-carotene which contribute to their free radical or scavenging effects and form a major category of vegetable groups that have been designated as "natures anti-aging wonders" (Gupta *et al.,* 2005). Antioxidants are compounds that inhibit or slow down the oxidation of lipids and other molecules through the neutralization of free radicals (Zheng and Wang, 2001). Amongst these, phenolics serve as powerful antioxidants by virtue of the hydrogen-donating properties of their phenolic hydroxyl groups, as well as by donating electrons, stop free radical chain reactions emerging from oxidative stress (John and Shahidi, 2010). Phenolic compounds are important because they can retard the development of coronary and cardiovascular diseases, cancer, and intestinal inflammatory diseases (Arbos *et al.,* 2010).

Under utilized GLV offer a cheap but rich source of a number of micronutrients and other phytochemicals having antioxidant properties (Gupta and Prakash, 2011). In India, various types of underutilized foods are available seasonally but are not utilized to the extent they should be despite their high nutritive value. Safflower (*Carthamus tinctorius* L.), a multipurpose crop, has been grown for centuries in India for the orange-red dye (carthamin) extracted from its brilliantly coloured flowers and for its quality oil rich in polyunsaturated fatty acids (78% linoleic acid) (Singh *et al.,* 2013). The tender leaves, shoots and thinnings of safflower are used as pot herb, green leafy vegetable and salad. They are rich in vitamin A, iron, phosphorus, and calcium. Bundles of young plants are commonly sold as a green vegetable in markets in India and some neighboring countries (Nimbkar, 2002). As the crop matures, the bottom leaves are also consumed during various stages till the completion of flowering stage. Suneel Kumar *et al.* (2015) reported that the use of safflower leaves and leaf powder incorporated products like roti, karam podi (spicy masala powder) at various growth stages have very good sensory acceptability. Changes in chemical composition of fruits and vegetables have reported at different stages of development (Connor *et al.,* 2005; Polyana *et al.,* 2014; Leite *et al.,* 2011; Boroski *et al.,* 2011; Peiretti *et al.,* 2013). However, there are no studies reported on the antioxidant content during different stages of development of safflower leaves. Most research on safflower has been concentrated on seeds and petals, while the leaves of safflower have to a large extent been ignored. Leaves are reportedly inexpensive, easy to cook and are potential sources of minerals, vitamins and antioxidants. The antioxidant potential of safflower leaves has not been widely exploited. Hence, the study was taken up to estimate the changes in antioxidant content in selected cultivars of safflower leaves during different stages of maturity.

MATERIALS AND METHODS

Four different safflower cultivars from spiny (Manjira, TSF-1 and Annigeri-1) and non-spiny (NARI-6) varieties which are commonly grown in Telangana State of India were

[1]ICAR-Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad-500 030, Telangana State
E-mail: aparnakuna@gmail.com

selected for the study. Safflower plants were harvested on 30th day for both spiny and non-spiny varieties. The leaves were harvested on 50th day and 70th day for spiny varieties; 50th, 70th and 90th days for non-spiny varieties between October 2014 and March 2015 from the experimental farms of ICRISAT, Pantancheru, Hyderabad and Regional Agricultural Research Station, Tandur, Ranga Reddy district, Telangana State.

Preparation of extract: Fresh leaves were cleaned and used for preparation of the extract. Extraction was conducted following the method described by Conner *et al.* (2005). 0.5g ground sample was mixed vigorously with 3 ml of methanol (80%) and centrifuged for 15 minutes at 3000 rpm. Supernatant was collected in a 10 ml volumetric flask. The residue was treated again twice with 3 ml methanol (80%) and centrifuged for 15 minutes. Supernatants were collected and standardized to a final volume of 10 ml and kept in screw cap bottles at -20 ºC until further analysis. The extract was used for analysis of scavenging DPPH radicals, superoxide anion radical scavenging activity, total phenolic compounds and total flavonoid content.

Scavenging DPPH radicals: The free radical scavenging capacity of the extracts was determined using 1, 1- dipheny l- 2-picryl-hydrazil (DPPH) (Dorman *et al.,* 2004). 2ml of methanol solution of DPPH radical in the concentration of 0.05mg/ml and 1ml of extract were placed in cuvettes. The mixture was shaken vigorously and allowed to stand at room temperature for 30 minutes and then the absorbance was measured at 517nm against methanol as blank in spectrophotometer. The DPPH free radical concentration was calculated using the following equation:

DPPH scavenging effect (%) = $(A_0 - A_1 / A_0) \times 100$

Where, A_0 was the absorbance of the negative control and A_1 was the absorbance of reaction mixture.

Superoxide anion radical scavenging activity: 0.1ml of extract was mixed with 1ml nitro blue tetrazolium (NBT) solution (156µM in 0.1 M phosphate buffer, pH 7.4) and 1ml NADH solution (468µM in 0.1M phosphate buffer, pH 7.4). The reaction was started by adding 100µl of phenazine methosulphate (PMS) solution (60µM in 0.1M phosphate buffer, pH 7.4). The mixture was incubated at room temperature for 5 minutes and the absorbance was measured at 560nm in spectrophotometer against blank samples (Nishimiki *et al*., 1972). The following formula was used to calculate the percentage inhibition of superoxide anion generation.

Superoxide anion scavenging activity (%)=$(A_0-A_1/A_0) \times 100$

Where A_0 is the absorbance of the negative control consisting of all the reaction agents except the extract and A_1 is the absorbance of reaction mixture.

Total phenolic compounds: 1ml of the extract was diluted with 46 ml of distilled water. Then, one ml of Folin Ciocalteu reagent was added and the mixture was stirred vigorously. 3ml of Na_2CO_3 (2%) was added after 3 minutes and then was allowed to stand for 2hr with intermittent shaking. After that, absorbance was measured at 760 nm in spectrophotometer against blank consisting of all the reaction agents except the extract (Slinkard and Slingleton, 1997). The total phenol content in extract was determined as microgram of pyrocatechol equivalent (PE) according to equation that obtained from standard pyrocatechol graph as:

Absorbance =
0.0021×total phenols [µg pyrocatechol equivalent] - 0.0092

Total flavonoid content: 2 ml of the extract solution was mixed with 2 ml of 2% aluminium trichloride ($AlCl_3$) in methanol. The mixture was incubated for 10 minutes at room temperature and the absorbance was measured at 415 nm in spectrophotometer against blank samples (Meda *et al.,* 2005). The total concentration of flavonoids in the extracts was determined as microgram of rutin equivalent (RE) according to the formula that was obtained from standard rutin graph as

Absorbance =
0.0144×total flavonoid [µg rutin equivalent] + 0.0556

Estimation of total carotenoids and ascorbic acid (vitamin C) was carried out using standard AOAC (2005) methods. Both total carotenoids and ascorbic acid were analyzed on a fresh basis immediately after harvest of plants and leaves. All experiments were performed in three replicates.

Statistical analysis: Analysis of variance (ANOVA) was used to test the difference between means (stages of maturity and difference in cultivars), which were analyzed by the Tukey test at 95% ($p \leq 0.05$) level of significance using the STATISTIC software version 7.0.

RESULTS AND DISCUSSION

The results of total carotenoids and ascorbic acid during various stages of maturity are given in Table 1. The total carotenoid content was highest during the 30th day in all the four cultivars ranging from 9558 to 14893 µg/100g, while it was lowest during 70th day ranging from 1476.00 to 4066.40 µg/100g indicating that the stage of maturity does have a remarkable influence on the total carotenoid content. The results showed that as the stage of maturity increased, there was a significant decrease in the total carotenoid content of safflower leaves. Shiraghinge *et al.* (2010) stated that fruits receiving more light have higher levels of carotenoid. Several factors including cultivar, row spacing and different stages of maturity can influence ascorbic acid, soluble solids, β-carotene and lycopene contents in tomato fruits (Atefeh *et al*., 2013).

The ascorbic acid content among different cultivars (Annigeri-1, Manjira, TSF - 1 and NARI-6) ranged between 6.84 to 9.00mg/100g on 30th day; 8.64 to 12.96 on 50th day; 5.92 to 13.02 on 70th day. Ascorbic acid content was highest during 50th day in Annigeri-1 and Manjira, whereas it was highest on 70th day in NARI-6 variety. The results also indicate that TSF-1 is a poor source of ascorbic acid when compared to Annigeri-1, Manjira and NARI-6. A common observation in all the cultivars was that the ascorbic acid content was low on 30th day as compared to 50th and 70th day in all the cultivars except TSF-1. Atefeh *et al*. (2013) and Purseglove *et al.* (1986) reported that although the cultivar has a dominant influence on the quality determinant properties, the environment in which it grows also has a significant impact on quality characters. The reduction in ascorbic acid with maturity may be due to oxidative destruction by enzymes mainly ascorbic acid oxidase or due to conversion of acid to sugar (Rahman and Rahman, 2010.)

The results of scavenging DPPH activity, super oxide anion activity, total phenolics and total flavonoids during various stages of maturity are summarized in Table 2. From the results of DPPH assay, there was no significant difference in the scavenging activity among the three cultivars Annigeri-1, Manjira and TSF-1 whereas, NARI-6 had significantly lower scavenging activity when compared with the other three cultivars on 30th day. On 50th day, the scavenging activity was similar between Annigeri-1 and Manjira, but significantly lower than TSF-1 and NARI-6 varieties. The DPPH scavenging activity was found to be similar between Manjira, TSF-1 and NARI-6 varieties, which was significantly higher than Annigeri-1 on 70th day.

Table 1 Total carotenoid and ascorbic acid content in various cultivars of safflower leaves during different stages of maturity

Parameters	Days of maturity	Annigeri-1	Manjira	TSF-1	NARI-6	SE values
	30th day	10824±273^{a2}	14893±140^{a1}	9558±110^{a4}	10435±46^{a3}	
Total carotenoids	50th day	3436±11^{b4}	4663±132^{b3}	4946±10^{b2}	5877±163^{c1}	
(µg)	70th day	3590±75^{b2}	1476±27^{c4}	4066±32^{b1}	3203±97^{d3}	118.808
	90th day				8145±27^{b}	
SE value	551.684					
	30th day	6.84±0.09^{b2}	8.20±0.36^{c1}	9.00±0.17^{a1}	8.60±0.10^{c1}	
Ascorbic acid	50th day	11.44±0.34^{a1}	12.96±0.41^{a1}	8.64±0.20^{a2}	11.76±0.31^{b1}	
(mg)	70th day	6.40±0.002^{b2}	10.65±0.34^{b1}	5.92±0.34^{b2}	13.02±0.17^{a1}	0.311
	90th day				7.46±0.97^{c}	
SE value	0.270					

Note: Values are expressed as mean ± standard deviation of three determinations.
Mean values with similar superscripts within a column (alphabets) and row (numerical) do not differ significantly (P=0.05).

Table 2 Antioxidant activity in selected cultivars of safflower leaves during different stages of maturity

Parameters	Days of maturity	Annigeri-1	Manjira	TSF-1	NARI-6	SE Values
	30th day	214.40±0.03^{a1}	214.06±0.11^{a1}	213.70±0.03^{a1}	211.46±0.46^{a2}	
DPPH (%)	50th day	208.56±0.12^{b2}	208.83±0.29^{c2}	212.86±0.09^{a1}	212.17±0.37^{a1}	
	70th day	209.14±1.36^{b2}	212.36±0.21^{b1}	212.06±0.28^{a1}	211.00±0.63^{a1}	0.568
	90th day				209.23±0.50^{b}	
SE value	0.492					
	30th day	81.97±0.77^{a1}	75.96±3.56^{a2}	84.35±1.16^{a1}	77.63±1.19^{a2}	
Superoxide anion (%)	50th day	66.43±0.67^{b1}	70.45±0.51^{b1}	65.23±0.51^{b1}	67.44±0.10^{b1}	
	70th day	59.97±0.70^{c1}	55.49±2.26^{c1}	29.73±0.45^{c3}	39.11±1.85^{c2}	1.706
	90th day				21.77±1.48^{d}	
SE value	1.478					
	30th day	71.20±0.08^{c4}	153.90±0.14^{b3}	188.18±0.28^{a2}	260.72±0.88^{a1}	
Total phenolics	50th day	119.30±0.35^{b4}	137.23±0.14^{c2}	140.88±0.08^{c1}	128.66±0.41^{d3}	
(µg pyrocatechol)	70th day	156.28±0.14^{a3}	162.47±0.14^{a2}	159.77±0.21^{b2}	177.87±0.08^{c1}	0.378
	90th day				199.13±0.47^{b}	
SE value	0.327					
	30th day	173.84±0.12^{a4}	176.99±0.06^{a3}	177.40±0.06^{a2}	179.46±0.22^{a1}	
Total flavonoids	50th day	166.39±0.13^{b1}	166.20±0.38^{b1}	164.81±0.07^{c3}	165.11±0.26^{c2}	
(µg rutin)	70th day	166.28±1.26^{b2}	167.45±0.20^{b2}	169.89±0.32^{b1}	168.47±0.09^{b1}	0.227
	90th day				167.38±0.12^{b}	
SE value	0.197					

Note: Values are expressed as mean ± standard deviation of three determinations.
Mean values with similar superscripts within a column (alphabets) and row (numerical) do not differ significantly (P=0.05).

The superoxide anion activity among the cultivars showed that the antioxidant activity in Annigeri-1 (81.97) and TSF-1 (84.35) varieties was significantly higher than Manjira (75.96%) and NARI-6 (77.63%) varieties on 30th day. The superoxide anion activity was similar in all the four cultivars on 50th day (65.23 to 70.45%). On 70th day, Annigeri-1 (59.97) and Manjira (55.49) varieties had significantly (P=0.05) higher superoxide anion activity followed by NARI-6 (39.11%) followed by TSF-1 (29.73%) variety. There was a gradual and significant (P=0.05) decrease in the superoxide anion activity in Annigeri-1, Manjira, TSF-1 and NARI-6 varieties from 30th day to 50th day to 70th day to 90th day (in NARI-6) indicating gradual reduction in antioxidant activity as the plant matures.

Phenolic compounds are a large group of the secondary metabolites widespread in plant kingdom. They are categorized into classes depending on their structure and subcategorized within each class according to the number and position of hydroxyl group and the presence of other substituents (Aherne and O'Brien, 2002; Anna, 2007; Verma *et al*., 2012). Phenolics are able to scavenge reactive oxygen species due to their electron donating properties. Their antioxidant effectiveness depends on the stability in different systems as well as number and location of hydroxyl groups. The result of estimation of total phenolics is given in Table 2. NARI-6 variety had highest phenolics content (260.72µgPE and 177.87 µgPE) and Annigeri-1 had the least amount of total phenolics (71.20 µgPE and 156.28 µgPE) on 30th and 70th day. On 50th day, TSF-1 had highest amount (140.88 µgPE) where as Annigeri-1 variety had the least amount (119.30 µgPE) of total phenolics. The results indicate that NARI-6 is a better variety for highest amount of polyphenol content during different stages of maturity (128.66 to 260.72 µgPE), whereas Annigeri-1 was a poor source of the ploypheno1s (71.20 to 156.28 µgPE) when compared with other varieties studied.

The results of total flavonoid content among the cultivars at different stages of maturity indicates that the flavonoid content ranged between 173.84 to 179.46 µgRE on 30th day; 164.81 to 166.39 µgRE on 50th day and 166.28 to 169.89 µgRE on 70th day among the four cultivars of safflower leaves. The results showed that Annigeri-1 variety had the least amount of total flavonoids during 30th and 70th day whereas Manjira variety had the least amount of flavonoids on 50th day. TSF-1 and NARI-6 varieties were found to be significantly better sources of flavonoids content among all the four cultivars.

In many *in vitro* studies, phenolic compounds demonstrated higher antioxidant activity than antioxidant vitamins and carotenoids (Srinivasahan and Brindha, 2014). Phenolic compounds acting as antioxidants may function as terminators of free radical chains and as chelators of redox-active metal ions that are capable of catalyzing lipid peroxidation (Aminah and Anna, 2011; Schroeter *et al.,* 2002). The results indicate that safflower leaves are good sources of phenolic compounds especially NARI-6 variety. Our results are similar to findings of study done by Aminah and Anna (2011) on bitter gourd at various ripening stages of maturity. The DPPH scavenging activity and superoxide anion activity in safflower leaves could be due to the presence of polyphenols and other yet to be discovered antioxidant compounds.

The antioxidant content in the safflower plants and leaves changed during the various stages of maturity. The results showed that as the stage of maturity increased, there was a significant decrease in the total carotenoid content of safflower leaves. Ascorbic acid content was low on 30th day as compared to 50th and 70th day in all the cultivars. DPPH scavenging activity and total flavonoids of safflower leaves were higher at 30th day while superoxide anion activity and total phenolics were higher at later stages (70th day and 90th day in NARI-6 variety). This shows that the safflower leaves exhibit antioxidant activity at various stages through different mechanisms such as acting as weak oxidant, scavenging singlet oxygen molecules (superoxide anion activity and total flavonoids) when consumed at earlier stages and scavenging hydrogen peroxide radicals when consumed at matured stages (DPPH activity and total phenols) which shows that consumption of the safflower leaves at any stage provides antioxidants to the diet. This suggests that harvesting safflower leaves for use as GLV at 30 days or 50 days or 70 days (spiny and non-spiny cultivars) or 90 days (non-spiny cultivars) potentially provides the greatest concentrations of antioxidants through various mechanisms.

REFERENCES

Aherne S A and O'Brien N M 2002. Dietary flavonols: chemistry, food content and metabolism. *Nutrition*, **18**(1): 75-81.

Aminah A and Anna P K 2011. Influence of ripening stages on physico-chemical characteristics and antioxidant properties of bitter gourd (*Momordica charantia*). *International Food Research*, **18**: 895-900.

Anna P 2007. Natural antioxidants and antioxidant capacity of *Brassica* vegetables: A review. *Swiss Society of Food Science and Technology*, **40**: 1-11.

AOAC 2005. *Official Methods of Analysis, Association of Official Analytical Chemists International,* edn. 18, Gaithersburg, MD, USA.

Arbos K A, Freitas R J S, Stertz S C and Dornas M F 2010. Atividade antioxidante e teor de fenólicos totais em hortaliças orgânicas e convencionais. *Food Science and Technology (Campinas)*, **30**(2): 501-506.

Atefeh T, Hossein N and Mohammad A 2013. The effects of planting distances and different stages of maturity on the quality of three cultivars of tomatoes (*Lycopersicon esculentum* Mill). *Notulae Saentia Biologicae*, **5**(3): 371-375.

Boroski M, Aguiar A C, Boeing J S, Rotta E M, Wibby C L, Bonafe E G, Souza N E and Visentainer J V 2011. Enhancement of pasta antioxidant activity with oregano and carrot leaf. *Food Chemistry*, **125**(2): 696-700.

Connor A M, Luby J J, Tong C B S, Finn C E and Hancock J F 2005. Genotype and environmental variation in antioxidant activity, total phenolic content and anthocyanin content among blueberry cultivars. *Journal of American Society and Horticulture Science*, **127**(1): 89-97.

Dorman H J, Bachmayer O, Kosar M and Hiltunen R 2004. Antioxidant properties of aqueous extracts from selected Lamiaceae species grown in Turkey. *Journal of Agricultural and Food Chemistry*, **52**: 762-770.

Gupta S, Jyothi A, Lakshmi, Manjunath M N and Prakash J 2005. Analysis of nutrient and anti nutrient content of underutilized green leafy vegetables. *Journal of Food Science and Technology*, **38**(4): 339-345.

Gupta S and Prakash J 2011. Nutritional and sensory quality of micronutrient-rich traditional products incorporated with green leafy vegetables. *International Food Research Journal*, **18**: 667-675.

John J A and Shahidi F 2010. Phenolic compounds and antioxidant activity of Brazil nut (*Bertholletia excels*). *Journal of Functional Foods*, **2**: 196-209.

Leite C W, Boroski M, Boeing J S, Aguiar A C, Franca P B, Souza N E and Visentainer J 2011. Chemical characterization of leaves of organically grown carrot (*Dacus carota* L.) in various stages of development for use as food. *Food Science and Technology*, **31**(3): 735-738.

Meda A, Lamicn C E, Romito M, Millogo J and Nacoulma O G 2005. Determination of the total phenolic, flavonoid and proline contents in Burkina fasan honey, as well as their radical scavenging activity. *Food Chemistry*, **91**: 571-577.

Nimbkar N 2002. Safflower rediscovered. *Times of Agricultural Journal*, **2**: 32-36.

Nishimiki M, Rao N A and Yagi K 1972. The occurrence of superoxide anion in the reaction of reduced phenazine metho-sulfate and molecular oxygen. *Biochemistry Biophysics Research Communication*, **46**: 849-853.

Peiretti P G, Gai F and Tassone S 2013. Fatty acid profile and nutritive value of quinoa (*Chenopodium quinoa* Willd.) seeds and plants at different growth stages. *Animal Feed Science and Technology*, **183**(1): 56-61.

Polyana B F B, Schuelter J B, Oliveira E B, Nilson E D S, Matsushita M, Celestino C D O and Boroski M J V V 2014. Evaluation of beetroot (*Beta vulgaris* L.) leaves during its developmental stages, a chemical composition study. *Food Science and Technology*, **34**(1): 94-107.

Purseglove J W, Brown E, Green C L and Robbins S R J 1986. Spices. *Tropical Agriculture Series*, Vol. 1, Longman Group Ltd., London.

Rahman M and Rahaman M 2010. Fruit growth of china cherry (*Muntingia Calabura*). *Botanical Research of International*, **3**(2): 56-60.

Schroeter H, Boyd C, Spencer J P E, Williams R J, Cadenas E C and Rice-Evans C 2002. MAPK signaling in neurodegeneration: influences of flavonoids and of nitric oxide. *Neurobiology Aging*, **23**: 861-880.

Shiraghinge F H, Mello P C T, Jacomino A P, Melo A M T, Purquerio L F V and Roquejani M S 2010. Yield and qualitative characterization of fresh market tomato hybrids of Italian and Santa Cruz type. *Journal of Horticultural Bras*, **80**: 292-298.

Singh V, Kolekar N M And Nimbkar N 2013. Maximization of flower yield in safflower (*Carthamus tinctorius* L.). *Journal of Oilseeds Research*, **30**(1): 43-47.

Slinkard K and Singleton V L 1997. Total phenol analyses, automation and comparison with manual methods. *American Journal of Enology and Viticulture*, **28**: 49-55.

Srinivasahan V and Brindha D 2014. Antioxidant and free radical scavenging effect of *Morinda citrifolia* fruit extract. *International Journal of Pharmacy and Pharmaceutical Sciences*, **6**(4): 55-59.

Suneel Kumar E, Aparna Kuna, Padmavathi P, Durga Rani V, Suprana T and Supta Sarkar 2015. Sensory characteristics of different stages of safflower (*Carthamus tinctorius* L.) leaves and leaf powder incorporated products. *Journal of Oilseeds Research*, **32**(1); 56-62.

Verma R, Awasthi M, Modgil R and Dhailwal Y S 2012. Effect of maturity on the physico-chemical and nutritional characteristics of kachnar (*Bauhinia variegate* L.) green buds and flowers. *Indian Journal of Natural Products and Resoures*, **3**: 242-244.

Zheng W and Wang S Y 2001. Antioxidant activity and phenolic compounds in selected herbs. *Journal of Agricultural and Food Chemistry*, **49**(11): 5165-5170.

Evaluation of linseed germplasm for resistance against rust (*Melampsora lini*)

ASHOK KUMAR, SABITA EKKA[1] AND U K TRIPATHI[2]

Shivalik Agricultural Research and Extension Centre, Kangra-176 001, Himachal Pradesh

(Received: February 11, 2016; Revised: March 23, 2016; Accepted: March 28, 2016)

ABSTRACT

Two hundred germplasm lines of linseed were screened against rust disease caused by *Melampsora lini* at two hot spot locations *viz.,* Kangra, Himachal Pradesh and Kanke, Jharkhand for three consecutive *rabi* seasons of 2011-12 to 2013-14. Thirty four entries were highly resistant, 21 were resistant, 19 were moderately resistant, 12 were moderately susceptible and rest of them were susceptible to highly susceptible to rust against the naturally occurring races of *Melampsora lini* in the Kangra valley of Himachal Pradesh. At Kanke, out of two hundred entries evaluated, thirty seven entries were highly resistant, 27 were resistant, 28 were moderately resistant, 23 were moderately susceptible and remaining were susceptible to highly susceptible to rust. Twenty genotypes namely Jabalpur local, KP-13B, Mayurbanj local, MS-3, OP-2-2, Polf-2, Polf-16, KL-1, LC-2014, LC-2127, LCK-9119, LCK-9303, LCK-9320, LCK-9324, SJKO-10, EC-384154, H-43, H-5, ES-44 and LC-2002 had disease score of 0 at both the locations and were rated as highly resistant.

Keywords: Germplasm, Linseed, *Melampsora lini,* Rust, Screening

Linum usitatissimum L. commonly known as linseed or flaxseed is an ancient oilseed and fiber crop. Every part of the linseed plant is utilized commercially either directly or after processing (Tewari and Singh, 2014). Linseed grains contain about 40 per cent oil and 24 per cent crude protein. Recently, incorporation of linseed in food and food products has been gaining importance due to its high content of essential omega-3 fatty acid (alpha-linolenic acid), dietary fiber and natural phenolic antioxidants (Kasote, 2013). About 80 per cent of linseed oil produced utilized in industries and used as drying oil for manufacture of paint, varnish, linoleum, oil cloth, patent leather, printer ink, enamel, sticker, tarpaulin, soap etc. (Singh and Tewari, 2014). Linseed stem yields a valuable fiber, which is known for its strength and durability. Presently linseed crop is being cultivated in more than 50 countries of the world occupying 22.70 lakh ha area with total production of 22.39 lakh tonnes and average productivity of 986 kg/ha. Our national production of 1.47 lakh tonnes is realized from an area of 3.38 lakh ha with low productivity of 435 kg/ha. India is an important linseed growing country in the world ranking third in area after Canada and Kazakhstan and fourth in terms of production after Canada, China and Kazakhstan (Anonymous, 2015). In terms of productivity, India is far below than major linseed growing countries *viz.,* Canada (1728 kg/ha), USA (1659 kg/ha), United Kingdom (1500 kg/ha), China (1000 kg/ha) and Ethiopia (933 kg/ha).

Among the various factors responsible for the low productivity of this crop, diseases are an important yield destabilizing factor. Rust caused by *Melampsora lini* (Ehrenb.) Lev. inflicts severe epidemics year after year with 16-100 per cent yield losses (Sangwan *et al.,* 2005). The severely affected plants are killed prematurely. Affected plants shows shriveled seeds and weakened fiber and stained black. The disease can cause up to 13.1 per cent reduction in oil content in heavily rusted plants (Singh *et al.,* 1981).

M. lini is highly variable autoecious fungus as it completes all the four stages *viz.,* pycnial, aecial, uredial and telial of its life cycle on the linseed plant. Development of cultivars with durable resistance to diseases is the most economic and desired method of plant disease management. The management strategies based on exploitation of host resistance require knowledge of variability in pathogen and intensive screening of germplasm against the prevailing races of the pathogen. Hence, linseed germplasm consisting of 200 entries was evaluated under field conditions for three years for their resistance against rust.

MATERIALS AND METHODS

Two hundred linseed genotypes received from the ICAR-Project Coordinating Unit (Linseed), Kanpur were screened against rust disease at two hot spot locations for rust *viz.,* Kangra, Himachal Pradesh and Kanke, Jharkhand for three winter seasons of 2011-12 to 2013-14. Kangra is located at 32.1°N latitude 76.27°E longitude in the foot hills of north-western Himalayas at an elevation of 700 m above sea level. Linseed rust appears at Kangra every season in moderate to severe form and majority of the races of linseed rust reported from India are known to prevail in the Kangra valley of Himachal Pradesh. Kanke is situated at 23.35°N latitude and 85.33°E longitude having an elevation of 651 m above sea level in the southern part of Chota Nagpur plateau.

[1]Birsa Agricultural University, Kanke, Jharkhand
[2]Chandra Shekhar Azad University of Agriculture and Technology, Kanpur
E-mail: ashokumar59@yahoo.com

Both Kanke and Kangra are having hilly topography and humid sub tropical climate. Rust appears in linseed regularly as weather conditions during crop season of both the locations are favourable for the outbreak and progress of the disease.

Each germplasm entry under test was planted in field in 3m long, 30 cm apart in single rows at both the locations. A highly susceptible variety Chambal was planted after every 6^{th} row of test entries. Sowing was done during the month of November at both the locations during all the crop seasons. Fertilizer application, weeding, irrigation and other intercultural operations were done as per the normal recommended practice. Each test entry was carefully observed for disease symptoms after appearance of disease in the highly susceptible check and final disease severity was recorded at the time of crop maturity. Disease scoring was done on 0-5 rating scale (Saharan, 1988) as described below and entries were categorized as highly resistant to highly susceptible on the basis of highest disease score recorded on that entry during all the crop seasons.

0 = No disease or free (Highly resistant)
1 = 1-10% area of leaves/plant infected (Resistant)
2 = 10.1-25% area of leaves/plant infected (Moderately resistant)
3 = 25.1-50% area of leaves/plant infected (Moderately susceptible)
4 = 50.1-75% area of leaves/plant infected (Susceptible)
5 = Above 75% area of leaves/plant infected (Highly susceptible)

RESULTS AND DISCUSSION

Interaction of linseed genotypes against *M. lini* revealed that out of 200 germplasm entries evaluated at Kangra, 34 entries showed highly resistant, 21 were resistant, 19 were moderately resistant, 12 were moderately susceptible, 11 were susceptible and 102 entries were highly susceptible to rust against the naturally occurring races of *M. lini* in the Kangra valley of Himachal Pradesh (Tables 1 and 2). At Kanke, out of two hundred entries evaluated against the naturally occurring native races of the pathogen, 37 entries were highly resistant, 27 were resistant, 28 were moderately resistant, 23 were moderately susceptible, 25 were susceptible and 60 entries were highly susceptible to rust (Table 3). One hundred and twenty seven entries exhibited moderately susceptible to highly susceptible disease reaction at Kangra whereas, 108 entries showed moderately susceptible to highly susceptible disease reaction at Kanke. Ninety one entries were susceptible to rust at both the locations indicating the occurrence of some common races at both the places. Thirty two linseed entries *viz.,* EC-9826, KL-176, Kota-2, NP(RR)-44, H-8, No. 348, NP-19, NP-47, NP-26, Polf-36, RLC-23, P-42, Polf-25, H-11, KL-168, No. 294, L-43, LCK-8528, LMH-21, No.41-561, RLC-52, Sagar Local, Sirmor-2, Solapur-9, JLT-26, LC-2057(I), LCK-9312, EC-1398, NP-66, Polf-15, Polf-39 and LCK-9414 showed highly resistant to moderately resistant reaction to rust at Kanke, were observed to be moderately susceptible to highly susceptible at Kangra. Similarly, fifteen entries like KL-31, ES-1462, Nagarkot, Polf-5, Polf-17, H-25, NP-40, S-91-11, Rashmi, Polf-29, LC-2023, RL-903, SJKO-17, KL-223 and KL-227 being highly resistant to moderately resistant to rust at Kangra, were observed to be moderately susceptible to highly susceptible to rust at Kanke. This observation strongly suggests the existence of variability in the races of *M. lini* in the two regions.

On the basis of screening of two hundred germplasm entries against rust at both the locations for three years, twenty germplasm entries *viz.,* Jabalpur local, KP-13B, Mayurbanj local, MS-3, OP-2-2, Polf-2, Polf-16, KL-1, LC-2014, LC-2127, LCK-9119, LCK-9303, LCK-9320, LCK-9324, SJKO-10, EC-384154, H-43, H-5, ES-44 and LC-2002 had disease score of 0 at both the locations and were rated as highly resistant. Seventeen entries *viz.,* Kangra local, NP-115, LC-2021, LC-2023, LC-2045, LCK-9436, EC-1497, GS-51, Baner, R-204x4/29, H-12, JRF-3, KP-8, LCK-8722, LCK-152, LCK-9436 and LC-2057(II) resulted in disease score of 1 or low at both the locations were rated as resistant. Twenty two germplasm entries *viz.,* LCK-11, No.-22, KP-4, Polf-11, UP-6, LCK-88311, KL-134, KL-168, L-27, JRF-1(8), H-17, H-15, Polf-23, LCK-87312, NP-71, NP(RR)-93, RLC-45, S-91-26, KL-178, RL-56-6-2, KL-217 and KL-229 had disease score of 2 at any of the locations and were rated as moderately resistant. Thirteen entries *viz.,* LC-2023, Polf-36, Polf-17, RLC-7, P-42, Polf-29, S-91-11, LCK-9312, Nagarkot, KL-168, H-11, Kl-168 and LCK-8520 exhibited disease score of 3 either at Kangra or Kanke, were categorized as moderately susceptible to rust. Fourteen entries like EC-9826, HY-38, KL-31, KL-176, No.-348, RL-39-4, RLC-23, P-650, Sirmor-2, ES-1462, H-25, L-43, LMH-21 and LCK-9414 which exhibited disease score of 4 at any of the location, were rated as susceptible. Rest of the 114 entries were categorized as highly susceptible on the basis of maximum disease score of 5 at any of the location.

Amongst different measures adopted for the control of linseed rust cultivation of resistant varieties is most important. Vasudeva (1962) reported linseed varieties RR-5, RR-9, RR-10, RR-37, RR-38, RR-40, RR-45, RR-197, RR-204, RR-236, RR-262, RR-267 and RR-272 as resistant to all races of rust prevalent in India. Variety T-1192-2 was found resistant in Uttar Pradesh and varieties like K2 and LC-185 were resistant under Punjab conditions (Gill, 1987). Kumar and Gupta (1999) reported eleven entries *viz.,* KL-31, LCK-8773, LCK-9120, LCK-9209, LCK-9324, LCK-9436, LC-2166, LC-2178, DPL-21, LMS-90-2 and Ayogi as free from rust under North Indian conditions. Among these varieties, LCK-9324 and LCK-9436 has also been observed to be highly resistant and resistant, respectively in the present study. The varieties found as highly resistant in the present investigation can be further utilized in the breeding programme for rust resistance in linseed.

Table1 Disease interaction of linseed genotypes against *Melampsora lini*

Sl. No.	Name of the entry	Disease score (0-5 Scale)		Overall Reaction	Sl. No.	Name of the entry	Disease score (0-5 Scale)		Overall Reaction
		Kangra	Kanke				Kangra	Kanke	
(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
1	EC-9826	4(S)	0(HR)	S	101	EC-322646	5(HS)	3(MS)	HS
2	EC-41656	5(HS)	3(MS)	HS	102	EC-322659	5(HS)	4(S)	HS
3	FR-3	5(HS)	4(S)	HS	103	EC-322681	5(HS)	5(HS)	HS
4	Kanpur-41/2	5(HS)	3(MS)	HS	104	IC-199749	5(HS)	5(HS)	HS
5	GS-204	5(HS)	4(S)	HS	105	SJKO-2	5(HS)	5(HS)	HS
6	GS-232	5(HS)	4(S)	HS	106	SJKO-6	5(HS)	5(HS)	HS
7	GS-344	5(HS)	3(MS)	HS	107	SJKO-7	5(HS)	5(HS)	HS
8	GS-362	5(HS)	4(S)	HS	108	SJKO-10	0(HR)	0(HR)	HR
9	H-22	5(HS)	5(HS)	HS	109	SJKO-18	5(HS)	4(S)	HS
10	H-42	5(HS)	5(HS)	HS	110	SJKO-22	5(HS)	5(HS)	HS
11	HY-38	4(S)	4(S)	S	111	SJKO-25	5(HS)	5(HS)	HS
12	ICAR-7	5(HS)	5(HS)	HS	112	SJKO-60	5(HS)	5(HS)	HS
13	ILS-169	5(HS)	4(S)	HS	113	SJKO-62	5(HS)	5(HS)	HS
14	KL-31	2(MR)	4(S)	S	114	SJKO-63	5(HS)	5(HS)	HS
15	Jabalpur local	0(HR)	0(HR)	HR	115	RSJ-29	5(HS)	5(HS)	HS
16	KL-176	4(S)	1(R)	S	116	KL-225	5(HS)	3(MS)	HS
17	Kangra local	0(HR)	1(R)	R	117	RKY-9	5(HS)	5(HS)	HS
18	Kota-2	5(HS)	2(MR)	HS	118	RKY-15	5(HS)	5(HS)	HS
19	KP-4	2(MR)	1(R)	MR	119	RJK-20	5(HS)	5(HS)	HS
20	KP-13B	0(HR)	0(HR)	HR	120	NP(RR)-44	5(HS)	1(R)	HS
21	L-35	5(HS)	5(HS)	HS	121	ES-1462	2(MR)	4(S)	S
22	L-56	5(HS)	3(MS)	HS	122	ES-1476	5(HS)	2(MR)	HS
23	Mayurbanj local	0(HR)	0(HR)	HR	123	Baner	1(R)	0(HR)	R
24	LCK-11	2(MR)	2(MR)	MR	124	ES-16318	5(HS)	3(MS)	HS
25	LCK-41	5(HS)	4(S)	HS	125	RFW-12	5(HS)	5(HS)	HS
26	LCK-8504	5(HS)	4(S)	HS	126	CF white	5(HS)	3(MS)	HS
27	LCK-88311	0(HR)	2(MR)	MR	127	GS-51	1(R)	1(R)	R
28	LS-3	5(HS)	4(S)	HS	128	Nagarkot	1(R)	3(MS)	MS
29	NP(RR)-18	5(HS)	4(S)	HS	129	Kiran	5(HS)	3(MS)	HS
30	MS-3	0(HR)	0(HR)	HR	130	EC-384154	0(HR)	0(HR)	HR
31	MS-4	5(HS)	3(MS)	HS	131	H-8	5(HS)	0(HR)	HS
32	NCL-3512	5(HS)	5(HS)	HS	132	H-10	5(HS)	4(S)	HS
33	T-397	5(HS)	5(HS)	HS	133	R-204x4/29	-	1(R)	R
34	No.-7	3(MS)	5(HS)	HS	134	L-27	2(MR)	1(R)	MR
35	No.-11	5(HS)	5(HS)	HS	135	H-43	0(HR)	0(HR)	HR
36	No.-16	5(HS)	5(HS)	HS	136	JRF-1(8)	0(HR)	2(MR)	MR
37	No.-18	5(HS)	5(HS)	HS	137	GS-401	3(MS)	5(HS)	HS
38	No.-22	2(MR)	2(MR)	MR	138	GS-407	5(HS)	5(HS)	HS
39	No.-348	4(S)	1(R)	S	139	H-5	0(HR)	0(HR)	HR
40	NP-19	5(HS)	2(MR)	HS	140	H-11	3(MS)	0(HR)	MS
41	NP-47	5(HS)	2(MR)	HS	141	H-12	1(R)	1(R)	R
42	NP-26	5(HS)	1(R)	HS	142	H-17	2(MR)	0(HR)	MR
43	NP-115	1(R)	1(R)	R	143	H-15	2(MR)	2(MR)	MR
44	NPHY-38	5(HS)	5(HS)	HS	144	H-24	5(HS)	2(MR)	HS
45	Polf-5	1(R)	5(HS)	HS	145	H-25	0(HR)	4(S)	S
46	Polf-19	5(HS)	4(S)	HS	146	Meera	3(MS)	5(HS)	HS
47	OP-2-2	0(HR)	0(HR)	HR	147	ICAR-2	5(HS)	5(HS)	HS
48	Polf-2	0(HR)	0(HR)	HR	148	JLS-293	5(HS)	3(MS)	HS
49	Polf-16	0(HR)	0(HR)	HR	149	JRF-3	1(R)	0(HR)	R
50	Polf-17	2(MR)	3(MS)	MS	150	Polf-23	0(HR)	2(MR)	MR
51	Polf-36	3(MS)	1(R)	MS	151	Kl-168	3(MS)	0(HR)	MS
52	RL-8-1	5(HS)	5(HS)	HS	152	Kl-169	5(HS)	4(S)	HS

Table 1 (contd...)

(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
53	RL-39-4	4(S)	4(S)	S	153	KP-8	1(R)	1(R)	R
54	RLC-23	4(S)	2(MR)	S	154	L-18	5(HS)	3(MS)	HS
55	P-650	4(S)	4(S)	S	155	LCK-87312	2(MR)	0(HR)	MR
56	Polf-33	5(HS)	5(HS)	HS	156	LCK-8722	0(HR)	1(R)	R
57	RLC-3	5(HS)	3(MS)	HS	157	No-294	5(HS)	2(MR)	HS
58	RLC-7	3(MS)	3(MS)	MS	158	ES-44	0(HR)	0(HR)	HR
59	RLC-34	5(HS)	5(HS)	HS	159	L-43	4(S)	1(R)	S
60	OR-1-4	5(HS)	5(HS)	HS	160	LCK-152	1(R)	1(R)	R
61	P-42	3(MS)	2(MR)	MS	161	LCK-9436	1(R)	0(HR)	R
62	Polf-11	2(MR)	0(HR)	MR	162	LCK-8520	3(MS)	1(R)	MS
63	Polf-34	5(HS)	5(HS)	HS	163	LMH-21	4(S)	1(R)	S
64	Polf-25	5(HS)	1(R)	HS	164	No-41-561	5(HS)	0(HR)	HS
65	Polf-30	5(HS)	3(MS)	HS	165	NP-40	1(R)	5(HS)	HS
66	R-552	5(HS)	4(S)	HS	166	NP-65	5(HS)	5(HS)	HS
67	RLC-52	5(HS)	2(MR)	HS	167	NP-66	5(HS)	1(R)	HS
68	S-91-3	5(HS)	5(HS)	HS	168	NP-71	2(MR)	0(HR)	MR
69	S-91-35	5(HS)	3(MS)	HS	169	Rashmi	1(R)	5(HS)	HS
70	Sagar Local	5(HS)	0(HR)	HS	170	NP-112	5(HS)	5(HS)	HS
71	UP+6	2(MR)	1(R)	MR	171	NPHY-27	5(HS)	5(HS)	HS
72	KL-1	0(HR)	0(HR)	HR	172	Polf-15	5(HS)	0(HR)	HS
73	LC-2014	0(HR)	0(HR)	HR	173	Polf-29	0(HR)	3(MS)	MS
74	LC-2021	0(HR)	1(R)	R	174	RKY-2	5(HS)	4(S)	HS
75	LC-2023	1(R)	0(HR)	R	175	Polf-30	5(HS)	5(HS)	HS
76	LC-2127	0(HR)	0(HR)	HR	176	Polf-39	5(HS)	1(R)	HS
77	LC-2045	1(R)	0(HR)	R	177	NP(RR)-93	2(MR)	2(MR)	MR
78	LCK-9303	0(HR)	0(HR)	HR	178	RLC-45	2(MR)	0(HR)	MR
79	LCK-9320	0(HR)	0(HR)	HR	179	LC-2002	0(HR)	0(HR)	HR
80	RLC-55	5(HS)	4(S)	HS	180	LC-2023	1(R)	3(MS)	MS
81	S-91-11	2(MR)	3(MS)	MS	181	LC-2057(II)	0(HR)	1(R)	R
82	S-91-25	5(HS)	5(HS)	HS	182	S-91-26	2(MR)	2(MR)	MR
83	S-801	5(HS)	5(HS)	HS	183	KL-178	0(HR)	2(MR)	MR
84	Sirmor-2	4(S)	2(MR)	S	184	LCK-9414	4(R)	2(MR)	S
85	Solapur-9	5(HS)	2(MR)	HS	185	RL-56-6-2	1(R)	2(MR)	MR
86	JLT-26	5(HS)	2(MR)	HS	186	RL-903	0(HR)	5(HS)	HS
87	KL-134	2(MR)	0(HR)	MR	187	R-552	5(HS)	5(HS)	HS
88	KL-168	1(R)	2(MR)	MR	188	LCK-8504	5(HS)	5(HS)	HS
89	LC-2057(I)	3(MS)	1(R)	MS	189	SJKO-17	1(R)	5(HS)	HS
90	LCK-9119	0(HR)	0(HR)	HR	190	SJKO-20	5(HS)	5(HS)	HS
91	LCK-9312	3(MS)	2(MR)	MS	191	SJKO-42	5(HS)	5(HS)	HS
92	LCK-9324	0(HR)	0(HR)	HR	192	EC-41590	5(HS)	5(HS)	HS
93	LCK-9436	1(R)	1(R)	R	193	BRM-13	5(HS)	5(HS)	HS
94	EC-1398	5(HS)	2(MR)	HS	194	S-91-25	5(HS)	3(MS)	HS
95	EC-1402	5(HS)	5(HS)	HS	195	KL-217	0(HR)	2(MR)	MR
96	EC-1497	0(HR)	1(R)	R	196	KL-220	5(HS)	3(MS)	HS
97	EC-3152	5(HS)	5(HS)	HS	197	KL-221	3(MS)	5(HS)	HS
98	EC-9204	5(HS)	5(HS)	HS	198	KL-223	1(R)	5(HS)	HS
99	EC-9828	5(HS)	4(S)	HS	199	KL-227	1(R)	5(HS)	HS
100	EC-23595	5(HS)	5(HS)	HS	200	KL-229	2(MR)	0(HR)	MR

HR: Highly resistant, R: Resistant, MR: Moderately resistant, MS: Moderately susceptible, S: Susceptible, HS: Highly susceptible

Table 2 Disease reaction of linseed genotypes against *Melampsora lini* at Kangra

Disease reaction	Name of the genotype
Highly resistant	Jabalpur local, Kangra local, KP-13B, Mayurbanj local, LCK-88311, MS-3, OP-2-2, Polf-2, Polf-16, KL-1, LC-2014, LC-2021, LC-2127, LCK-9303, LCK-9320, LCK-9119, LCK-9324, EC-1497, SJKO-10, EC-384154, H-43, JRF-1(8), H-5, H-25, Polf-23, LCK-8722, ES-44, Polf-29, LC-2002, LC-2057(II), S-91-26, KL-178, RL-903, KL-217
Resistant	NP-115, Polf-5, LC-2023, LC-2045, KL-168, LCK-9436, Baner, GS-51, Nagarkot, H-12, JRF-3, KP-8, LCK-152, LCK-9436, NP-40, Rashmi, LC-2023, RL-56-6-2, SJKO-17, KL-223, KL-227
Moderately resistant	KL-31, KP-4, LCK-11, No.-22, Polf-17, Polf-11, UP-6, S-91-11, KL-134, ES-1462, L-27, H-17, H-15, LCK-87312, NP-71, NP(RR)-93, RLC-45, S-91-26, KL-229
Moderately susceptible	No.-7, Polf-36, RLC-7, P-42, LCK-9312, GS-401, H-11, Meera, Kl-168, LCK-8520, KL-221, LC-2057(II)
Susceptible	EC-9826, HY-38, KL-176, No.-348, RL-39-4, RLC-23, P-650, Sirmor-2, L-43, LMH-21, LCK-9414
Highly susceptible	EC-41656, FR-3, Kanpur-41/2, GS-204, GS-232, GS-344, GS-362, H-22, H-42, HY-38, ICAR-7, ILS-169, Kota-2, L-35, L-56, LCK-41, LCK-8504, LS-3, NP(RR)-18, MS-4, NCL-3512, T-397, No.-11, No.-16, No.-18, NP-19, NP-47, NP-26, NPHY-38, Polf-19, RL-8-1, Polf-33, RLC-3, RLC-34, OR-1-4, Polf-34, Polf-25, Polf-30, R-552, RLC-52, S-91-3, S-91-35, Sagar Local, S-91-25, S-801, Solapur-9, JLT-26, EC-1398, EC-1402, EC-3152, EC-9204, EC-9828, EC-23595, EC-322646, EC-322659, EC-322681, IC-199749, SJKO-2, SJKO-6, SJKO-7, SJKO-18, SJKO-22, SJKO-25, SJKO-60, SJKO-62, SJKO-63, RSJ-29, KL-225, RKY-9, RKY-15, RJK-20, NP(RR)-44, ES-1476, ES-16318, RFW-12, CF white, Kiran, H-8, H-10, GS-407, H-24, ICAR-2, JLS-293, Kl-169, L-18, No-294, No-41-561, NP-65, NP-66, NP-112, NPHY-27, Polf-15, RKY-2, Polf-30, Polf-39, R-552, LCK-8504, SJKO-20, SJKO-42, EC-41590, BRM-13, KL-220

Table 3 Disease reaction of linseed genotypes against *Melampsora lini* at Kanke

Disease reaction	Name of the genotype
Highly resistant	EC-9826, Jabalpur local, KP-13B, Mayurbanj local, MS-3, OP-2-2, Polf-2, Polf-16, Polf-11, Sagar local, KL-1, LC-2014, LC-2023, LC-2127, LC-2045, LCK-9303, LCK-9320, LCK-9119, KL-134, LCK-9324, SJKO-10, Baner, EC-384154, H-8, H-43, H-5, H-11, H-17, JRF-3, KL-168, LCK-87312, ES-44, LCK-9436, No. 41-561, NP-71, RLC-45, LC-2002, KL-229, Polf-15
Resistant	KL-176, Kangra local, KP-4, No.-348, NP-26, NP-115, Polf-36, Polf-25, UP-6, LC-2021, LC-2057(I), LCK-9119, LCK-9436, EC-1497, NP(RR)-48, GS-51, R-204x4/29, L-27, H-12, KP-8, LCK-8722, LCK-152, LCK-8520, LMH-21, NP-46, Polf-39, LC-2057(II)
Moderately resistant	Kota-2, LCK-11, LCK-88311, No.-22, NP-19, NP-47, RLC-23, P-42, RLC-52, Sirmor-2, Solapur-9, JLT-26, KL-168, LCK-9312, EC-1398, ES-1476, JRF-1(8), H-15, H-24, Polf-23, No-294, NP(RR)-93, S-91-26, KL-178, LCK-9414, RL-56-6-2, KL-217
Moderately susceptible	EC-41656, Kanpur-41/2, GS-344, L-56, MS-4, Polf-17, RLC-3, RLC-7, Polf-30, S-91-35, S-91-11, EC-322646, KL-225, ES-16318, CF white, Nagarkot, Kiran, JLS-293, L-18, Polf-29, LC-2023, S-91-25, KL-220
Susceptible	FR-3, GS-204, GS-232, GS-362, HY-38, ILS-169, KL-31, LCK-41, LCK-8504, LS-3, NP(RR)-18, Polf-19, RL-39-4, P-650, R-552, RLC-55, EC-9828, EC-322659, EC-322659, SJKO-18, ES-1462, H-10, H-25, Kl-169, RKY-2
Highly susceptible	H-22, H-42, ICAR-7, L-35, NCL-3512, T-397, No.-7, No.-11, No.-16, No.-18, NPHY-38, Polf-5, RL-8-1, Polf-33, RLC-34, OR-1-4, Polf-34, S-91-3, S-91-25, S-801, EC-1402, EC-3152, EC-9204, EC-23595, EC-322681, IC-199749, SJKO-2, SJKO-6, SJKO-7, SJKO-22, SJKO-25, SJKO-60, SJKO-62, SJKO-63, RSJ-29, RKY-9, RKY-15, RJK-20, RFW-12, GS-401, GS-407, Meera, ICAR-2, NP-40, NP-65, Rashmi, NP-112, NPHY-27, Polf-30, RL-903, R-552, LCK-8504, SJKO-17, SJKO-20, SJKO-42, EC-41590, BRM-13, KL-221, KL-223, KL-227

REFERENCES

Anonymous 2015. *Linseed Annual Report 2014-15.* ICAR-Project Coordinating Unit (Linseed), Kanpur.

Gill K S 1987. *Linseed.* Publications and Information Division, ICAR, Krishi Anusandhan Bhavan, Pusa, New Delhi, 386 pp.

Kasote D M 2013. Flaxseed phenolics as natural antioxidants. *International Food Research Journal*, **20**: 27-34.

Kumar A and Gupta T R 1999. Resistant sources for linseed rust. *Plant Disease Research*, **14**: 90-91.

Sangwan M S, Mehta N and Saharan G S 2005. Fungal diseases of linseed. *In: Diseases of Oilseed Crops.* Saharan G S, Mehta N and Sangwan M S (Eds.), M.S. Indus Publications, New Delhi, pp. 176-201.

Singh B P, Shukla B N and Sharma Y K 1981. Effect of rust infection on oil and protein content of linseed (*Linum usitatissimum*). *JNKVV Research Journal*, **12**: 101.

Saharan G S 1988. Plant disease management in linseed. *Review of Tropical Plant Pathology*, **5**: 119-140.

Singh A and Tewari N 2014. Genetic architecture of yield contributing traits in linseed (*Linum usitatissimum* L.). *Journal of Oilseeds Research*, **31**(2): 167-169.

Tewari N and Singh A 2014. Genetic analysis for seed yield and its contributing traits in linseed (*Linum usitatissimum* L.). *Journal of Oilseeds Research*, **31**(2): 118-122.

Vasudeva R S 1962. Diseases of linseed. *In: Linseed.* Riccharia RH. (Eds.). Indian Central Oilseeds Committee, Hyderabad, India, pp. 119-122.

Impact of commonly used agrochemicals on different fungal and bacterial bio-agents

B GAYATRI[1], R UMAMAHESWARI, M S RAO, P PRABU, K PRITI, G N GRACE, M KAMALNATH, R RAJINIKANTH AND N VIDYASHREE

ICAR-Indian Institute of Horticultural Research, Bengaluru-560 006, Karnataka

(Received: March 15, 2016; Revised: March 25, 2016; Accepted: March 28, 2016)

ABSTRACT

Four fungal bio-agents *viz., Trichoderma harzianum, T. viride, Paecilomyces lilacinus* and *Pochonia chlamydosporia* and four bacterial bio-agents *viz., Bacillus subtilis, B. pumilus, B. amyloliquefaciens* and *Pseudomonas fluorescens* were tested for their *in vitro* compatibility with five fungicides (carbendazim, captan, mancozeb, copper oxychloride and fenamidone + mancozeb) and three pesticides (carbofuran, metam sodium and acephate) at recommended doses of the pesticides and fungicides. The results revealed that carbendazim and metam sodium were highly toxic to all fungal bio-agents and copperoxychloride, mancozeb, fenamidone + mancozeb and metam sodium were highly toxic to all bacterial bio agents. *T. harzianum* exhibited more tolerance to captan than *T. viride, P. chlamydosporia* and *P. lilacinus.* All fungal bio-agents exhibited tolerance to carbofuran and acephate except *P. chlamydosporia.* Carbendazim was comparatively safer to *B. subtilis, P. fluorescens* and *B. pumilus,* but more toxic to *B. amyloliquefaciens. P. fluorescens* was relatively tolerant and *Bacillus* spp. was more sensitive to carbofuran and acephate. This study suggests that it is safe to integrate fungal bio-agents with copper oxychloride, carbofuran and acephate and bacterial bio-agents (except *B. amyloliquefaciens*) with carbendazim in integrated pest management (IPM) programmes.

Keywords: Bio-control agents, Compatibility, Fungicides, Pesticides

Intensive farming and emerging plasticulture technologies have resulted in the excessive use of synthetic chemical pesticides for mitigating the crop loss due to pests, diseases and nematodes which amounts to ₹290 billion per annum (ADB, 2000). Increasing public awareness on the negative effects of these chemicals upon human health and environment like pollution, pesticide residues, pest resistance and resurgence have led to the widespread adoption of IPM approach which involves the use of biological, cultural, physical and chemical measures (Sikora *et al.,* 2005).

In plant protection strategies, microbial biocontrol agents are recommended globally for effective management of diseases and pests, safety to humans and non-target organisms, amenability to individual applications and suitability for integrated pest and disease management approaches (Rao *et al.,* 2015a). Several researchers in the world have well documented the biocontrol efficacy of beneficial microbial agents against plant pathogens and nematodes *viz., Trichoderma harzianum, T. viride, Pseudomonas fluorescens, Bacillus thuringiencis, B. subtilis, B. pumilis, Paeciliomyces lilacinus, Arthrobotrys* spp., *Dactylella oviparasitica, Gliocladium virens, Pasteuria penetrans, Azototobacter chroococum* etc. (Nandakumar *et al.*, 2001; Loganathan *et al.,* 2001; Rao, 2007; Jonathan *et al.,* 2012).

[1]ICAR-Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad-500 030, Telangana State
E-mail: bandaru.gayatri@gmail.com

Indian Council of Agricultural Research (ICAR)-Indian Institute of Horticultural Research (IIHR) is a pioneer institute in India for biocontrol research which has identified and recommended several biocontrol fungi and bacteria against plant parasitic nematodes and associated disease complexes in several horticultural crops. Five IIHR-biocontrol fungal and bacterial agents *viz., Trichoderma harzianum, T. viride, Paecilomyces lilacinus, Pochonia chlamydosporia* and *Pseudomonas fluorescens* are registered as biopesticides under Central Insecticides Board and Registration Committee, Ministry of Agriculture, Faridabad, India and these technologies were transferred to more than 380 industries so far (Rao *et al.,* 2015a; 2015b). Several other Plant Growth Promoting Rhizobacterial strains (PGPR) namely *Bacillus subtilis*, *B. pumilus* and *B. amyloliquefaciens* have also been identified effective against nematodes and associated plant pathogens at ICAR-IIHR.

Within the complex plant protection strategies, it might be necessary to combine biocontrol agents with chemicals (Kredics *et al.,* 2003) and this combination has drawn much attention as an approach to acquire synergistic or additive effect for managing the soil borne pathogens (Sarkar *et al.,* 2010; Mohiddin and Khan, 2013). In agro-ecosystems, there is always a possibility for the interaction of these bio-agents with agro-chemicals as they are applied to seed, soil or both (Vasundra *et al.,* 2015). Farmers too, have the tendency to mix the bioagent formulations with commonly used chemical fungicides or insecticides and apply as a single application to

save labour and time. Hence it is crucial to study the compatibility of the bio-agents with agrochemicals and establish their virulence in the presence of chemicals. Though several researchers have documented the compatibility of *Trichoderma* spp. and *P. fluorescens* (Tapwal *et al.,* 2012; Keshgond and Naik, 2014), reports on the compatibility of fungal bio-agents *P. chlamydosporia* and *P. lilacinus* against nematodes and several other PGPR (*Bacillus* spp.) are meagre or almost lacking. Keeping this in view, this study aims to evaluate the compatibility of different fungal and bacterial bio-agents with commonly used fungicides, insecticides and nematicides in agricultural and horticultural ecosystems under *in vitro* conditions.

MATERIALS AND METHODS

Test bio-agent cultures: All the test strains of biocontrol agents used for the study were native isolates maintained at Nematology lab, ICAR-IIHR, Bengaluru, Karnataka. Fungal biocontrol agents used in the study *viz., Trichoderma harzianum* (strain IIHR Th-2; accession no. ITCC No. 6888), *Trichoderma viride* (strain IIHR Tv-5; accession no. ITCC No. 6889), *Paecilomyces lilacinus* (strain IIHR Pl-2; accession no. ITCC No. 6887), *Pochonia chlamydosporia* (strain IIHR Vc-3; accession no. ITCC No. 6898) were maintained in potato dextrose agar (PDA) medium.

Bacterial bio-agents used in the study *viz., Bacillus subtilis* (strain IIHR Bs-2; accession no. NAIMCC-B-01211), *B. pumilus* (strain IIHR Bp-5; accession no. NAIMCC-B-01213), *B. amyloliquefaciens* (strain IIHR Ba-2) were maintained in nutrient agar (NA) and *Pseudomonas fluorescens* (strain IIHR Pf-2; accession no. ITCC No. B0034) was maintained in King's B medium.

Test agro-chemicals: Five fungicides *viz.,* carbendazim (Bengard 50% W.P., Agricare, Panoli), mancozeb (Dithane M-45 75% WP, Dow Agrosciene India Pvt Ltd., Mumbai), captan (Captaf 50%WP, Rallis India Ltd., Mumbai), copper oxychloride (Blitox 50%WP, Rallis India Ltd., Mumbai) and fenamidone + mancozeb (Sectin 60 WG, Bayer Crop Science Ltd., Gujarat); three insecticides and nematicides *viz.,* carbofuran (Furadan 3G, FMC India Pvt. Ltd., Madhya Pradesh), acephate (Asataf 75 SP, Rallis India Ltd., Mumbai) and metam sodium (metam sodium 42%, Sai Samarth Chemicals, Vadodara) were tested in this study.

***In vitro* compatibility test**: To study the compatibility of bio-agents *in vitro,* poisoned food technique (Grover and Moore, 1961) method was used. Stock solutions of agro-chemicals (recommended dosage as given in the formulations) were prepared by dissolving the calculated quantities of chemical in sterile distilled water. The stock solution of chemical was added in appropriate quantities to molten medium (PDA for fungal bio-agents and NA for bacterial bio-agents) to obtain the required concentrations and were mixed thoroughly by gentle shaking. Twenty ml of molten medium was poured into 90-mm sterilized Petri plates and allowed for solidification. The plates were then inoculated with 7-mm discs of fresh culture for fungal agents. For the bacterial bio-agents, one day old cultures of the bacteria was taken, serially diluted and inoculated by pour plate technique. Five replicates were used for each chemical and arranged in completely randomized design. PDA and NA plates without chemicals were used as controls and the inoculated plates were incubated at 28±2ºC. Radial growth of fungus was recorded at five days after inoculation. Percentage inhibition of radial growth of fungus was calculated based on control plate colony diameter as per Sundar *et al*. (1995).

$$\text{Per cent Inhibition} = [(X - Y)/X] \times 100$$

X is radial growth of fungus in the control plates (mm)
Y is radial growth of fungus in the treated plates (mm).

For bacteria, colony characters were observed after 48 h and colony forming unit (cfu $x10^8$) count was taken. The per cent inhibition in cfu count compared to control was calculated based on the number of cfu as per the above formula. All the data were statistically analysed after suitable transformations and based on ANOVA, the means were compared by Duncan's Multiple Range Test (P=0.01).

RESULTS AND DISCUSSION

Compatibility of fungal bio-agents: In the present study, different fungicides and pesticides showed different reactions to the fungal bio-agents tested for their compatibility. Among all the fungicides tested, carbendazim was found to be highly toxic and completely inhibited the growth of all the fungal bio-agents tested *viz., T. viride, T. harzianum, P. lilacinus* and *P. chlamydosporia* (Fig.1 and Table 1). Also, it was observed that all the fungal bio-agents were sensitive to captan (65 to 84% inhibition) with *T. harzianum* showing more tolerance than *T. viride, P. chlamydosporia* and *P. lilacinus.* Mancozeb, copper oxychloride and fenamidone + mancozeb were comparatively safer to *T. harzianum,* however sporulation of *T. viride* was affected by these chemicals (Fig. 1A to 1J and Table 1).

It was obvious from the present study that all the fungal bio-agents were highly sensitive to carbendazim. Several earlier reports have also proved the incompatibility of *T. viride* and carbendazim (50% W.P.) wherein carbendazim completely inhibited the growth of the fungus (Ramarethinam *et al.,* 2001). Madhusudhan *et al.* (2010) also reported 100% inhibition of *T. viride* isolates T_1 and T_2 even at 50 ppm. Maximum inhibition concentrations (ED90) of carbendazim 50% WP was reported to be less than 25 µg/ml (Gaur and Sharma, 2010). In the present study, captan

exhibited significant incompatibility with all the fungal bio-agents. *T. harzianum* was more tolerant than *T. viride* to mancozeb, copper oxychloride and fenamidone + mancozeb. This falls in line with earlier reports wherein toxicity of contact fungicides was lower than that of systemic ones, among which copper oxychloride and copper hydroxide were highly compatible (Sarkar *et al.,* 2010). Bagwan (2010) reported the sensitivity of *Trichoderma* spp. to captan, who also found that thiram, copper oxychloride and mancozeb were comparatively safer to *Trichoderma* spp. Vasundra *et al.* (2015) reported high compatibility of *T. viride* with mancozeb (3000 ppm) which recorded 7% inhibition. Similarly, Madhavi *et al.* (2011) observed high compatibility of *T. viride* with mancozeb, imidacloprid and tebuconazole.

Table 1 Compatibility of the fungal bio-agents with fungicides and pesticides

Fungal bio-agents	Per cent inhibition in radial growth of fungus							
	Captan	Mancozeb	Copper oxychloride	Fenamidone + mancozeb	Carbendazim	Carbofuran	Acephate	Metam Sodium
Trichoderma harzianum	65.56[a] (54.07)	25.07[a] (29.91)	5.56[a] (13.37)	12.00[a] (20.19)	100.00 (89.36)	4.89[a] (12.57)	7.11[a] (14.89)	100.00 (89.36)
Trichoderma viride	70.89[b] (57.36)	35.33[b] (36.45)	12.98[b] (21.01)	18.22[b] (25.19)	100.00 (89.36)	10.67[b] (18.92)	8.44[a] (16.68)	100.00 (89.36)
Paecilomyces lilacinus	84.00[c] (66.43)	73.78[c] (59.19)	23.56[c] (28.99)	28.89[c] (32.5)	100.00 (89.36)	45.33[c] (42.32)	40.44[b] (39.47)	100.00 (89.36)
Pochonia chlamydosporia	83.78[c] (64.31)	90.22[d] (71.89)	84.89[d] (67.20)	100.00[d] (79.37)	100.00 (89.36)	85.33[d] (67.52)	49.33[c] (44.62)	100.00 (89.36)
CD (0.01)	2.45	4.70	4.79	3.52	NS	4.39	6.04	NS
SEd (±)	0.84	1.61	1.64	1.20		1.50	2.06	
CV (%)	2.17	5.16	7.95	4.56		6.73	11.31	

Figures in parentheses are arcsine transformed values

Numerical values followed by different alphabets indicate they are significantly different from each other (P=0.01)

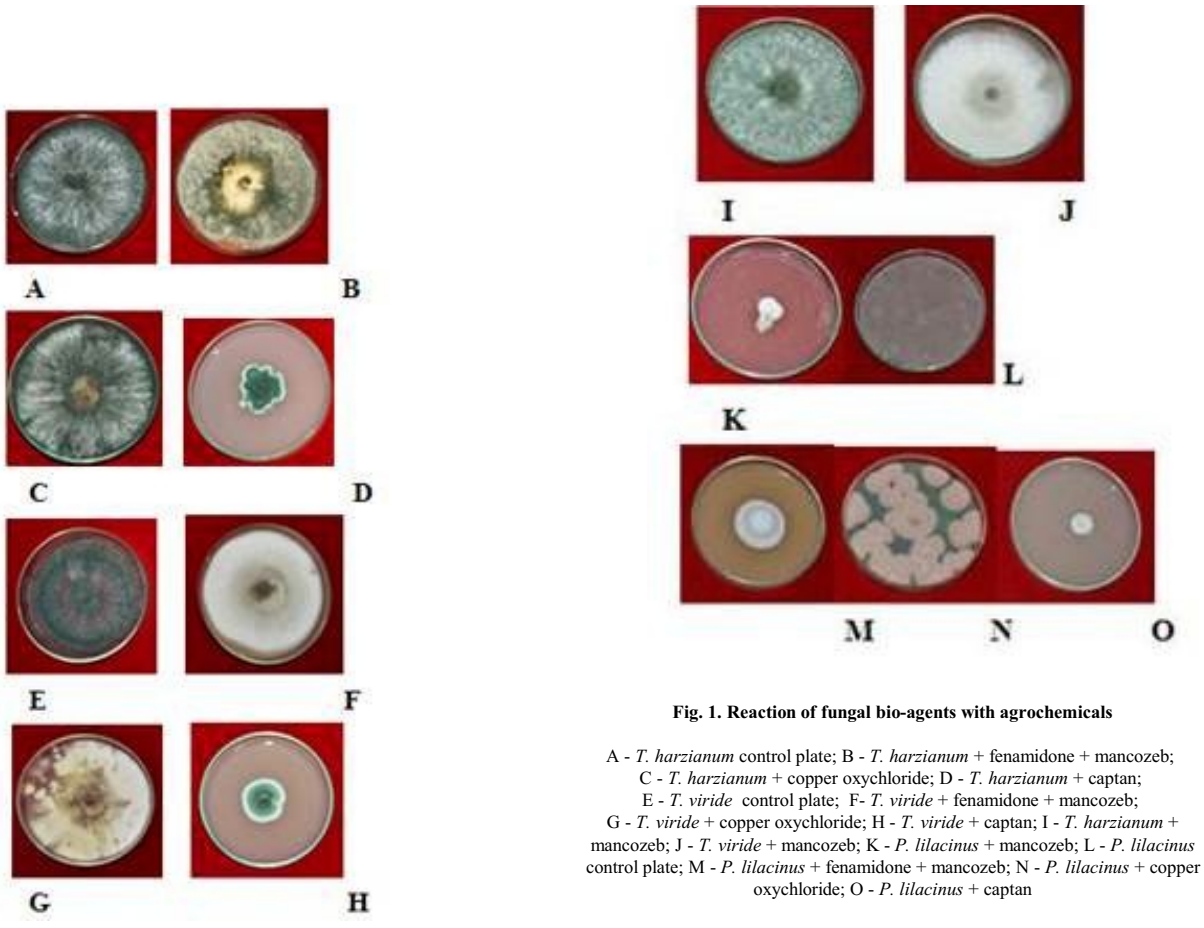

Fig. 1. Reaction of fungal bio-agents with agrochemicals

A - *T. harzianum* control plate; B - *T. harzianum* + fenamidone + mancozeb; C - *T. harzianum* + copper oxychloride; D - *T. harzianum* + captan; E - *T. viride* control plate; F- *T. viride* + fenamidone + mancozeb; G - *T. viride* + copper oxychloride; H - *T. viride* + captan; I - *T. harzianum* + mancozeb; J - *T. viride* + mancozeb; K - *P. lilacinus* + mancozeb; L - *P. lilacinus* control plate; M - *P. lilacinus* + fenamidone + mancozeb; N - *P. lilacinus* + copper oxychloride; O - *P. lilacinus* + captan

It was also obvious from the present results that metam sodium was highly incompatible with the fungal bio-agents while carbofuran and acephate were compatible with *Trichoderma* spp. This, however, contradicts earlier reports by Bheemaraya *et al.* (2012) wherein *Trichoderma* spp. was found highly incompatible with carbofuran, indoxacarb and chlorpyriphos. Also, the current study showed significantly higher sensitivity of *P. chlamydosporia* than *P. lilacinus* to all the fungicides tested. Similarly in earlier reports, *P. chlamydosporia* exhibited less tolerance to carbendazim, metalaxyl, captan, mancozeb, thiram and nemacur. The safe tolerance limit for *P. chlamydosporia* was 37.5 µg of carbendazim/ml, 75 µg of captan/ml, 110 µg of mancozeb/ml and 250 µg of nemacur/ml (Mohiddin and Khan, 2013).

Regarding the chemical pesticides tested for compatibility, metam sodium was highly toxic and completely inhibited the fungal growth. *Trichoderma* spp. were found compatible with carbofuran and acephate, with *T. harzianum* being more compatible than *T. viride* (Table 1). With respect to nematophagous fungal bio-agents, *P. lilacinus* was tolerant to fenamidone + mancozeb and copper oxychloride but inhibited by mancozeb (Fig. 1K to 1O). *P. chlamydosporia* was very sensitive to all the fungicides tested (84-100% inhibition). With regard to other pesticides tested, *P. lilacinus* showed moderate tolerance to carbofuran and acephate (40-45% inhibition). However, *P. chlamydosporia* was more sensitive to carbofuran than acephate (Table 1).

Compatibility of bacterial bio-agents: All the bacterial bio-agents were highly incompatible with fungicides copper oxychloride, fenamidone + mancozeb, mancozeb and captan. Carbendazim was comparatively safer to *B. subtilis, P. fluorescens* and *B. pumilus,* but more toxic to *B. amyloliquefaciens* (Table 2; Figure 2). With respect to the compatibility of chemical pesticides, metam sodium was highly inhibitory to all the bacterial bio-agents tested. *P. fluorescens* was relatively tolerant to carbofuran and acephate. However, *Bacillus* spp. were more sensitive to carbofuran and acephate (Table 2).

Table 2 Compatibility of the bacterial bio-agents with fungicides and pesticide

Bacterial bio-agents	Per cent inhibition of cfu							
	Captan	Mancozeb	Copper oxychloride	Fenamidone + mancozeb	Carbendazim	Carbofuran	Acephate	Metam Sodium
Bacillus subtilis	93.95[a] (62.15)	100.00 (89.36)	100.00 (89.36)	100.00 (89.36)	53.22[a] (52.88)	96.74[c] (79.71)	96.69[b] (79.53)	100.00 (89.36)
Bacillus pumilus	99.84[b] (87.95)	100.00 (89.36)	100.00 (89.36)	100.00 (89.36)	74.38[c] (59.70)	87.94[b] (69.69)	96.20[b] (78.77)	100.00 (89.36)
Bacillus amyloliquefaciens	99.73[b] (87.24)	100.00 (89.36)	100.00 (89.36)	100.00 (89.36)	97.52[d] (81.44)	96.03[c] (78.52)	99.42[c] (85.71)	100.00 (89.36)
Pseudomonas fluorescens	100.00[c] (89.36)	100.00 (89.36)	100.00 (89.36)	100.00 (89.36)	62.56[b] (52.28)	33.12[a] (34.77)	62.64[a] (52.33)	100.00 (89.36)
CD (0.01)	1.60	NS	NS	NS	6.13	7.27	1.78	NS
SEd (±)	0.55				2.1	2.49	0.61	
CV (%)	1.03				5.53	5.99	1.30	

Figures in parentheses are arcsine transformed values;
Numerical values followed by different alphabets indicate they are significantly different from each other (P=0.01)

Regarding the bacterial bio-agents, carbendazim was found safer and copper oxychloride, mancozeb, fenamidone + mancozeb and captan were highly toxic. Similar results were reported by Khan and Gandopadhyay (2008) wherein carbendazim was the least toxic to *P. fluorescens* strain PFBC-25 while captan was most inhibitory. Keshgond and Naik (2014) reported minimum inhibition of *P. putida* with carbendazim and carbofuran whereas complete inhibition was observed with mancozeb, captan, indoxacarb and novaluron. Mohiddin and Khan (2013) reported that the bacterial bio-agents *P. fluorescens* and *B. subtilis* were found more tolerant to fungicides than the biocontrol fungi. Since some bacteria can use pesticides as nutrients, they can tolerate high concentrations of chemicals (Aislabie and Jones, 1995). Also in the current study, metam sodium was highly incompatible with all the bacterial bio-agents tested while *P. fluorescens* was more compatible to carbofuran and acephate. This falls in line with earlier studies which reported the compatibility of *P. fluorescens* with carbofuran (Jayakumar *et al.,* 2003; Senthilkumar and Ramakrishnan, 2004).

In the present study, the differential response of the bio-agents with fungicides and insecticides might be due to the variability in their inherent ability to degrade these chemicals. It may be concluded that it is safe to integrate fungal bio-agents *Trichoderma* spp. with mancozeb, copper oxychloride, carbofuran and acephate; *P. lilacinus* with fenamidone + mancozeb and copper oxychloride; bacterial

bio-agents, *Bacillus* spp. except *B. Amyloliquefaciens* with carbendazim and *P. fluorescens* with carbofuran and acephate. This study also suggests cautious approach with highly incompatible agrochemicals like carbendazim and metam sodium for fungal bio-agents and copper oxychloride, fenamidone + mancozeb, captan, mancozeb and metam sodium for bacterial bio agents. Hence, to ensure sustainability of biocontrol agents in the agro-ecosystems it is vital to consider the results of this study for management of soil borne pathogens including nematodes in open fields and protected cultivation.

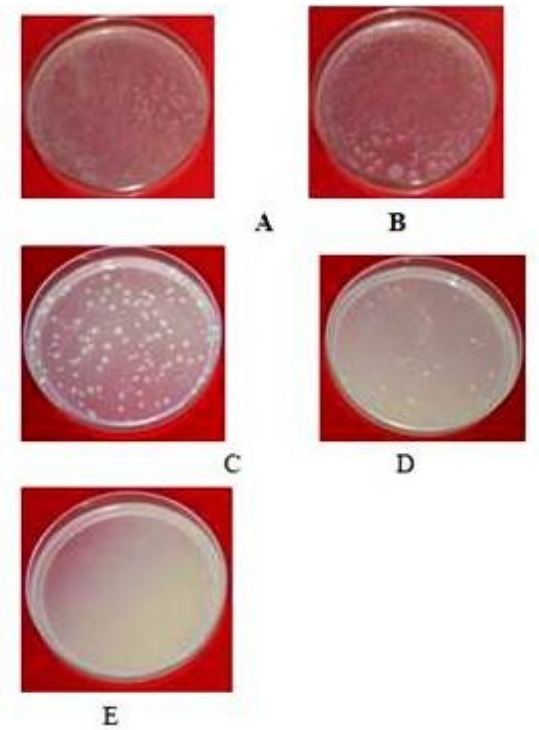

Fig. 2. Reaction of bacterial bio-agents with agrochemicals
A - *B. subtilis* control plate; B - *B. amyloliquefaciens* control plate;
C - *B. subtilis* + carbendazim; D - *B. pumilus* + carbendazim;
E - *B. amyloliquefaciens*+ carbendazim

ACKNOWLEDGEMENT

The authors acknowledge Dr. T. Manjunatha Rao, Director (I/C), ICAR-Indian Institute of Horticultural Research, Bengaluru for providing facilities and Dr. S. Sriram, Principal Scientist, Plant Pathology for his valuable guidance to conduct this study as a part of Professional Attachment Training Programme of the senior author at ICAR-IIHR, Bengaluru.

REFERENCES

ADB 2000. *Rural Asia: Beyond the Green Revolution,* Asian Development Bank, Philippines, pp. 60-61.

Aislabie J and Jones LG 1995. A review of bacterial degradation of pesticides. *Australian Journal of Soil Research*, **33**: 925-942.

Bagwan N B 2010. Evaluation of *Trichoderma* compatibility with fungicides, pesticides, organic cakes and botanicals for integrated management of soil borne diseases of soybean [*Glycine max* (L.) Merril]. *International Journal of Plant Protection*, **3**(2): 206-209.

Bheemaraya M B P, Ramesh K, Vendan T and Rao A Y S 2012. Compatibility of *Trichoderma* spp. with commonly used fungicides, insecticides and plant extracts. *Indian Journal of Plant Protection*, **40**(2): 118-122.

Gaur R B and Sharma R N 2010. Biocontrol of root rot in cotton and compatibility of potential bio-agents with fungicides. *Indian Journal of Plant Protection*, **38**(2): 176-182.

Grover R K and Moore D J 1961. Adaptation of *Sclerotinia fructicola* and *Sclerotinia laxa* to higher concentrations of fungicides. *Phytopathology*, **51**: 399-401.

Jayakumar J S, Ramakrishnan S and Rajendran G 2003. Evaluation of *Pseudomonas fluorescens* strains isolated from cotton rhizosphere against *Rotylenchulus reniformis. SAARC Journal of Agriculture*, **2**: 153-156.

Jonathan E I, Ramakrishnana S, Umamaheshwari R and Prabu S 2012. Prospects of *Pochonia chlamydosporia* in nematode management. *In: Status and Prospects for Enhancing the Uptake of Antagonistic Organisms for Nematode Management in India*, Nagesh M, Bhummanavar B S, Kumar N K K (eds.), National Bureau of Agriculturally Important Insects, Bangalore, India, pp.12-30.

Keshgond R S and Naik M K 2014. Studies on compatibility of *Pseudomonas putida* with fungicides, insecticides and plant extracts. *Journal of Pure and Applied Microbiology*, **8**(1): 767-770.

Khan M A and Gandopadhyay S 2008. Efficacy of *Pseudomonas fluorescens* in controlling root rot of chickpea caused by *Macrophomina phaseolina. Journal of Mycology and Plant Pathology*, **38**: 580-587.

Kredics L, Antal Z, Manczinger L, Szekeres A, Kevei F and Nagy E 2003. Influence of environmental parameters on *Trichoderma* strains with biocontrol potential. *Food Technology and Biotechnology*, **41**: 37-42.

Loganathan M, Swarnakumari N, Sivakumar M, Prakasam V, Mohan L, Ramaraj B and Samiyappan R 2001. Biological suppression of fungal nematode complex diseases of major cruciferous vegetables. *South Indian Horticulture*, **49**: 296-300.

Madhavi G B, Bhattiprolu I and Reddy S L V B 2011. Compatibility of biocontrol agent *Trichoderma viride* with various pesticides. *Journal of Horticultural Sciences*, **6**(1): 71-73.

Madhusudhan P, Gopal K, Haritha V, Sangale R and Rao S V R K 2010. Compatibility of *Trichoderma viride* with fungicides and efficiency against *Fusarium solani*. *Journal of Plant Diseases*, **5**(1): 23-26.

Mohiddin F A and Khan M R 2013. Tolerance of fungal and bacterial biocontrol agents to six pesticides commonly used in the control of soil borne plant pathogens. *African Journal of Agricultural Research*, **8**: 5272-5275.

Nandakumar R, Babu S, Viswanathan R, Sheela J, Raguchander T and Samiyappan R 2001. A new bio-formulation containing plant growth promoting rhizobacterial mixture for the management of sheath blight and enhanced grain yield in rice. *Biocontrol*, **46**: 493-510

Ramarethinam S, Murugesan N V and Marimuthu S 2001. Compatibility studies of fungicides with *Trichoderma viride* used in commercial formulation. *Pestology*, **25**(5): 2-6.

Rao M S 2007. Papaya seedlings colonized by the bio-agents *Trichoderma harzianum* and *Pseudomonas fluorescens* to control root-knot nematodes. *Nematologia Mediterranea*, **35**: 199-203.

Rao M S, Umamaheswari R, Chakravarty A K, Grace G N, Kamalnath M and Prabhu P 2015a. A frontier area of research on liquid biopesticides: The way forward for sustainable agriculture in India. *Current Science*, **108**(9): 1590-1592.

Rao M S, Umamaheswari R and Chakravarty A K 2015b. Plant parasitic nematodes: a major stumbling block for successful crop protection under protected conditions in India. *Current Science*, **108**(1): 13-14.

Sarkar S, Narayanan P, Divakaran A, Balamurugan A and Premkumar R 2010. The *in vitro* effect of certain fungicides, insecticides and biopesticides on mycelia growth in the biocontrol fungus *Trichoderma harzianum*. *Turkish Journal of Biology*, **24**: 399-403.

Senthilkumar T and Ramakrishnan S 2004. Studies on the compatibility of *Pseudomonas fluorescens, Trichoderma viride* and carbofuran 3G and their influences on *Meloidogyne incognita* in okra. *Annals of Plant Protection Sciences*, **12**(1): 140-142.

Sikora R A, Bridge J and Starr J L 2005. Management practices: an overview of integrated nematode management technologies. *In: Plant Parasitic Nematodes in Subtropical and Tropical Agriculture,* Luc M, Sikora R A, Bridge J (Eds.), CABI Publishing, Wallingford, UK, pp.793-826.

Sundar A R, Das N D and Krishnaveni D 1995. In-vitro antagonism of *Trichoderma* spp. against two fungal pathogens of castor. *Indian Journal of Plant Protection*, **23**: 152-155.

Tapwal A, Kumar R, Gautam N and Pandey S 2012. Compatibility of *Trichoderma viride* for selected fungicides and botanicals. *International Journal of Plant Pathology*, **3**: 89-94.

Vasundra P, Rangaswamy V and Johnson M 2015. Compatibility studies with fungicides, insecticides and their combinations on *Trichoderma viride* in *in-vitro* conditions. *International Journal of Scientific and Engineering Research*, **6**(2): 310-316.

Safflower (*Carthamus tinctorius* L.) yield forecasting in India - an application of Auto Regressive Integrated Moving Average (ARIMA) model

K ALIVELU, P PADMAVATHI, C SARADA, P LAKSHMAMMA AND M SANTHA LAKSHMI

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

(Received: March 8, 2016; Revised: March 17, 2016; Accepted: March 24, 2016)

ABSTRACT

The present study was carried out for forecasting the safflower productivity of India by fitting univariate Auto Regressive Integrated Moving Average (ARIMA) models. The data on safflower yield collected from 1965-66 to 2013-14 has been used for present study. The order of an ARIMA model is usually denoted by the notation ARIMA (p,d,q), where p is the order of the autoregressive part; d is the order of the differencing; q is the order of the moving-average process. For different values of p and q, various ARIMA models were fitted and appropriate model was chosen corresponding to minimum value of Akaike information criteria (AIC), Schwarz-Bayesian information criteria (SBC). ARIMA (1, 1, 2) model was found suitable for all India safflower yield with minimum MAPE (5.4).

Keywords: ARIMA model, Forecasting, Safflower, Yield

Safflower (*Carthamus tinctorius* L.), commonly known as *kardi* is one of the important *rabi* oilseed crops of the country. India is in first place in terms of area and production in the world with an area of 1.5 lakh ha and production of 1.13 lakh tonnes with a yield of 638 kg/ha (2013-14). Safflower is mainly grown in Maharashtra, Karnataka to some extent in Gujarat and parts of Andhra Pradesh, Madhya Pradesh, Orissa, Bihar, etc. (Paroda, 2013; Indu and Singh, 2014). Forecasting of crop yield based on time series data is an important task and facilitates efficient planning of cropping systems. A time series is a collection of observations of well-defined data items obtained through repeated measurements over time. The main objectives of time series analysis are to develop a model and estimate the parameters and forecast the future values of time series. ARIMA models have been used for forecasting rice productivity and production of Odisha (Tripathi *et al.,* 2014) and sugarcane yield of Tamilnadu (Suresh, 2011). Apart from agricultural crops milk production in India was forecasted using time-series modelling techniques (Pal *et al.,* 2007). The objective of our present study was using ARIMA models developed by Box and Jenkins (1976) to forecast safflower yield of India.

MATERIALS AND METHODS

Time series data covering the period of 1965-2014 was used for the study. The data were collected from Indiaagristat. One of time series models which is popular and mostly used is ARIMA model. ARIMA (p, d, q) model is a mixture of Autoregressive (AR) and Moving average (MA) model. The general form of ARIMA (p, d, q) described by Judge *et al.* (1988). ARIMA methodology is categorized in to identification, estimation, diagnostic checking and forecasting stages.

Identification: The first step in applying ARIMA model is to check for stationarity i.e. series remains constant level over time. The method to check for stationarity is to plot the data and check the autocorrelation function. If the graph of ACF (Auto Correlation Function) cuts of or dies down quickly, the series is stationary. The non-stationary series made stationary by differencing the data series. This is done by subtracting the observation in the current period from the previous one. If this transformation is done only once to a series it is said to be first differencing i.e., d=1. This process essentially eliminates the trend if the series is growing at a fairly constant rate. If it is growing at an increasing rate, the series has to be differenced again. Another important procedure in identification stage is to decide the values of p and q. They can be estimated by observing the graphs of ACF and PACF (Pindyk and Rubinfeld, 1991).

Estimation, diagnostic checking and forecasting: The model was estimated using SAS 9.3 software with PROC ARIMA procedure. The first check was by plotting the ACF of residuals of the fitted model. When the graph shows no trend with rectangular scatter around a zero horizontal level then the model was best fitted model. Second check was straight line graph when normal scores were plotted against residuals. Another check was residuals were plotted against fitted values the graph should be having no pattern. Lowest Akaike Information Criteria (AIC) also used to select the best model. Mean Absolute Percentage Error (MAPE) was used as measure of accuracy of the models. Using the best model, forecasts were made.

RESULTS AND DISCUSSION

The Fig.1. shows the trend, ACF and PACF of safflower yield in India over 49 years. From the figure it is evident that

the ACF declines very slowly and after the first lag the PACF drops and all lags after that are statistically insignificant. It indicates the non stationarity in the mean yield. The results concluded that the highly significant chi square value indicating the absence of white noise (uncorrelated) of the series (Table 1).

So the non stationary series made to stationary by differencing technique. Differencing changes the variable under consideration (Chatfield, 1975; Cressie, 1988). PAC function of the first differenced series was used to determine p to be 1. Several tentative models were fitted with different q values and the best fitted model is selected based on the minimum AIC, SBC and MAPE. ARIMA (1, 1, and 2) model was found suitable for all India safflower yield with minimum MAPE (5.4). After fitting the best model, residuals were tested for autocorrelation analysis. By observing the insignificant values, it can be concluded that the fitted model is a good fit.

On the basis of fitted model the mathematical model obtained as

$$y_t = 0.562\ y_{t-1} + \varepsilon_t + 0.105\ \varepsilon_{t-1} - 0.755\ \varepsilon_{t-2}$$

Normality test was done by plotting the histogram of residuals indicating the best fit of the model. ARIMA (1, 1, 2) was taken for 30 years ahead forecasts for safflower. India yield which are given in table 3 with standard error and upper lower confidence limits. Forecasts of safflower yield showed an increasing trend from 690 kg/ha in 2015 to 831 kg/ha. The area under safflower is coming down from 2.79 lakh ha during 11th plan to 1.78 lakh ha during 2013-14. Safflower cultivation in non-traditional areas like rice fallows may add additional area under safflower and following good production practices and implementation of technology can achieve increasing trend in yield.

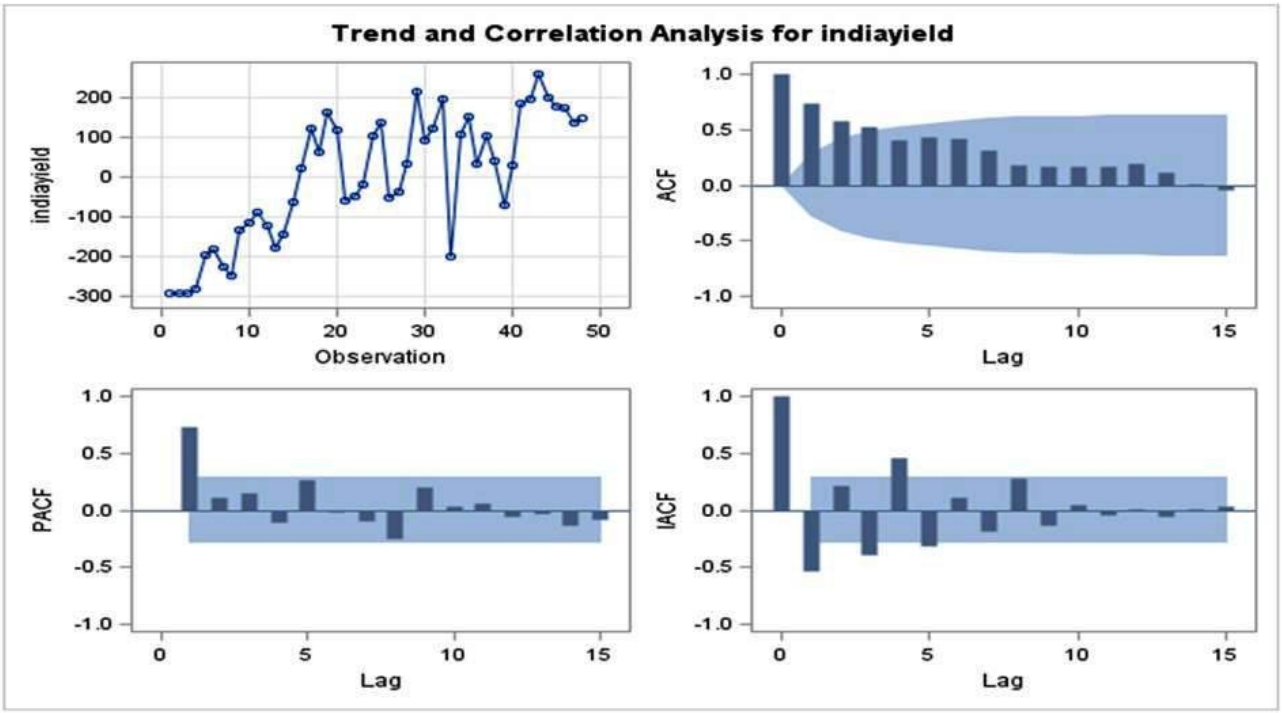

Fig. 1. Trend, ACF and PACF of safflower yield in India

Table 1 Autocorrelation-check for white noise

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	88.55	6	<.0001	0.729	0.583	0.527	0.398	0.432	0.413
12	103.74	12	<.0001	0.309	0.179	0.166	0.167	0.169	0.189

Table 2 Autocorrelation check of residuals

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	3.73	3	0.29	0.03	0.06	-0.07	-0.17	0.03	0.17
12	7.57	9	0.58	0.05	-0.08	-0.06	-0.02	0.00	0.22
18	11.58	15	0.71	0.09	0.01	-0.03	-0.19	-0.09	0.01
24	15.83	21	0.78	-0.02	-0.08	-0.13	-0.16	-0.01	0.01

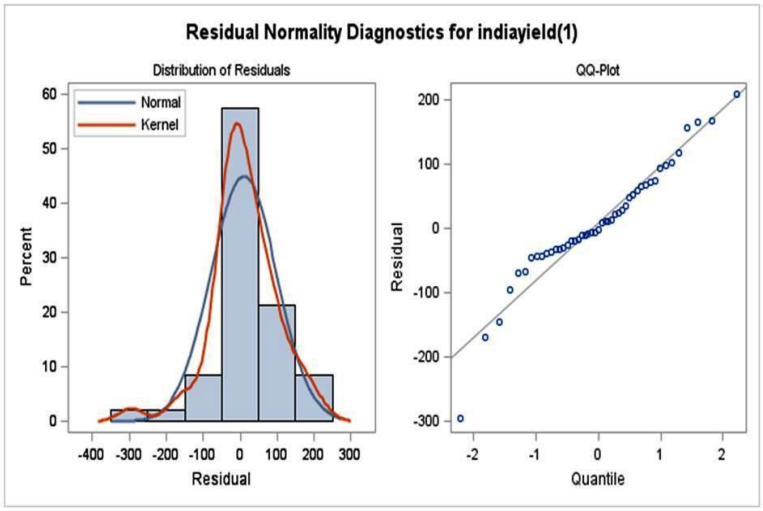

Fig. 2. Normality test for residuals

Table 3 Forecast of safflower yield

Year	Forecast	Std Error	95% Confidence Limits		
2012	662.13	119.992	426.95	897.311	±235.18
2013	671.535	120.52	435.321	907.749	±236.21
2014	680.939	121.045	443.696	918.182	±237.24
2015	690.343	121.568	452.075	928.611	±238.26
2016	699.747	122.088	460.459	939.036	±239.28
2017	709.152	122.607	468.847	949.456	±240.30
2018	718.556	123.123	477.239	959.872	±241.31
2019	727.96	123.637	485.636	970.284	±242.32
2020	737.364	124.149	494.037	980.692	±243.32
2021	746.769	124.659	502.442	991.096	±244.32
2022	756.173	125.167	510.851	1001.5	±245.32
2023	765.577	125.672	519.264	1011.89	±246.3133
2024	774.981	126.176	527.681	1022.28	±247.3006
2025	784.386	126.678	536.102	1032.67	±248.2839
2026	793.79	127.178	544.527	1043.05	±249.2634
2027	803.194	127.675	552.955	1053.43	±250.2389
2028	812.598	128.171	561.388	1063.81	±251.2108
2029	822.003	128.665	569.824	1074.18	±252.1789
2030	831.407	129.157	578.264	1084.55	±253.1432

REFERENCES

Box G E P and Jenkins G M 1976. *Time Series Analysis. Forecasting and Control*. San Francisco, Holden-Day, California, USA.

Chatfield C 1975. *The Analysis of Time Series: Theory and Practice.* Chapman and Hall, London.

Cressie N 1988. A graphical procedure for determining non-stationary in time series. *JAS,* **83**: 1018-1015.

Indu S and Singh J 2014. Stability analysis in safflower (*Carthamus tinctorius* L.). *Journal of Oilseeds Research*, **31**(1): 29-32.

Judge G G R, Carter Hill, Willium E G and I Helmut I 1988. *Introduction to the Theory and Practice of Econometrics,* edn. 2, John Wiley and Son, INC, New York, USA.

Pal S, Ramasubramanian V and Mehta S C 2007. Statistical models for forecasting milk production in India. *Journal of Indian Society of Agricultural Statistics*, **61**(2): 80-83.

Paroda R S 2013. The Indian oilseeds scenario : challenges and opportunities. *Journal of Oilseeds Research*, **30**(2): 111-126.

Pindyk R S, Daniel and Rubinfed L 1991. *Economic Models and Economic Forecasts,* edn. 3, McGraw Hill International editions (Economic Survey), New York, USA.

Tripathi R, Nayak A K and Raja R 2014. Forecasting rice productivity and production of Odisha, India using Autoregressive Integrated Moving Average Models. *Advances in Agriculture*, ID 621313, 9 p.

Suresh K K and Priya S R K 2011. Forecasting sugarcane yield of Tamilnadu using ARIMA models. *Sugar Technology*, **13**(1): 23-26.

Combining ability studies in sunflower (*Helianthus annuus* L.)

N VAIRAM AND R P GNANAMALAR

Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai-625 104, Tamil Nadu

(Received: October 7, 2015; Revised: February 17, 2016; Accepted: February 27, 2016)

ABSTRACT

Combining ability studies were made in sunflower using line x tester analysis with three CMS lines and ten testers. Ten important yield traits *viz.,* days to 50% flowering, number of leaves/plant, plant height, stem girth, head diameter, number of seeds/head, autogamy per cent, 100-seed weight, seed yield/plant and oil content were studied. Non-additive gene action was predominant for all the traits. Based on general combining ability of parents, the line 234 A was found to be good general combiner for days to 50% flowering, stem girth, head diameter, number of seeds/head, 100-seed weight, seed yield/plant and oil content. Three testers *viz.,* RHA 83R6, RHA 17 and DRSF 110 R exhibited higher *gca* effects for most of the yield traits and these parents can be considered as good general combiners. The hybrid NDCMS 1A x RHA 6D-5-3-6 possessed superior *sca* effects for six traits *viz.,* days to 50% flowering, head diameter, number of seeds/head, autogamy per cent, 100-seed weight and seed yield/plant. Three hybrids *viz.,* 234 A x DRSF 111 R, NDCMS 1A x RHA 83R6 and 234 A x RHA 859-2 can be considered as good specific combiners for exploitation of yield and its components. Hybrid 234 A x RHA RR 2 was the best for stem girth, head diameter, 100-seed weight and seed yield/plant. These above mentioned hybrids can be considered as good specific combiners.

Keywords: GCA, Hybrid, Non-additive, SCA, Sunflower

Sunflower (*Helianthus annuus* L.) is one of the major oilseed crops in the World and it is considered as good quality oil due to high concentration of polyunsaturated fatty acids. Modern sunflower breeding began with the development of F_1 hybrids, after the discovery of cytoplasmic male sterility (CMS) (Leclercq, 1969) and fertility restorer genes (Kinman, 1970) which shifted the interest from population breeding to heterosis breeding. The study of combining ability is useful in testing of hybrid combinations and in choice of the desirable parents for use in heterosis breeding. One of the techniques, which is widely used to extract information about the potentiality of the parental lines and the gene action governing the inheritance of traits is Line x Tester (L x T) analysis. With a view to identify the lines with good combining ability and to identify the good specific crosses for further exploitation, the present investigation was under taken at the Agricultural College and Research Institute, Madurai during the year 2010-2011 involving three CMS lines *viz.,* NDCMS 1A, 234 A and COSF 1A and ten testers *viz.,* RHA 6D-5-3-6, RHA 83R6, RHA MR-1-1, DRSF 110 R, RHA 17, RHA 273, RHA RR 2, RHA 859-2, DRSF 111 R and LTRR 1822. Crossing was effected in the Line x Tester fashion and the resultant 30 hybrids were subjected to combining ability studies. The genotypes were raised in randomized block design with two replications wherein each replication was represented by three rows of 3 m length. Observations were made on ten traits *viz.,* days to 50% flowering, number of leaves/plant, plant height (cm), stem girth (cm), head diameter (cm), number of seeds/head, autogamy (%), 100-seed weight, seed yield/plant and oil content (%).

The analysis of variance showed significant differences among the genotypes for all the ten characters studied (Table 1). The gene action governing different traits were inferred from combining ability. The variance due to specific combining ability was higher for all the traits studied. The σ^2D values were also found to be higher than σ^2A for all the characters studied. Predominance of dominance genetic variance for all the traits indicated the influence of non additive gene action as reported by Gouri Shankar *et al.* (2007), Khan *et al.* (2008) and Mohanasundaram *et al.* (2010). Dhillon (1975) opined that the combining ability provides useful information on the choice of parents in terms of expected performance of the hybrids and progenies. The general combining ability effects quantitatively measure the comparative performance of parents in relation to others. Out of 13 parents, for seed yield/plant, the *gca* effects of lines ranged from -9.42 (COSF 1A) to 5.15 (234 A) and of the testers ranged from -1.51 (RHA 6D-5-3-6) to 18.91 (RHA 83R6). Positive significant *gca* effects were recorded by the line 234 A and four testers *viz.,* RHA 83R6, DRSF 110 R, DRSF 111 R and LTRR 1822. The line 234 A exhibited higher *gca* effects for days to 50% flowering, stem girth, head diameter, number of seeds/head, 100-seed weight, seed yield/plant and oil content. Three testers *viz.,* RHA 83R6, RHA 17 and DRSF 110 R exhibited higher *gca* effects for most of the traits studied so these parents can be considered as good combiners (Table 2). Hybridization helps to augment

the desirable genes of various parents in one combination. Specific combining ability (*sca*) is defined as the deviation from mean performance predicted on the basis of general combining ability and *sca* is due to non additive gene action. Irrespective of the general combining ability of parents, certain combination of parents can give superior hybrids (Table 3). Among 30 hybrids, NDCMS 1A x RHA 6D-5-3-6 possessed superior *sca* effects for six traits *viz.,* days to 50% flowering, head diameter, number of seeds/head, autogamy per cent, 100-seed weight and seed yield/plant. Thirteen hybrids recorded positive significant *sca* effects. The *sca* effects for single plant yield ranged from -1.37 (234 A x DRSF 110 R) to 47.99 (NDCMS 1A x RHA 83R6). Five hybrids *viz.,* NDCMS 1A x RHA 83R6, 234 A x DRSF 110 R, 234 A x DRSF 111 R, COSF 1A x RHA MR-1-1 and COSF 1A x DRSF 111 R showed positive significant *sca* effect. Three hybrids *viz.,* 234 A x DRSF 111 R, NDCMS 1A x RHA 83R6 and 234 A x RHA 859-2 can be considered as good specific combiners and the combination 234 A x RHA RR 2 was the best for stem girth, head diameter, 100-seed weight and seed yield/plant. So these five hybrids can be considered as good specific combiners for exploitation of yield and its components.

Table 1 Analysis of variance (Mean Squares)

Source of variation	d.f.	Days to 50% flowering	Number of leaves/plant	Plant height	Stem girth	Head diameter	No of seeds/head	Autogamy %	100-seed weight	Seed yield/ plant	Oil content
Replication	1	0.96	7.53	11.64	0.04	0.64	2156.7	1.64	0.01	0.04	0.01
Parents	12	15.94*	18.49*	987.47*	7.29*	25.43*	101034.8*	57.76*	9.30*	322.31*	9.78*
Error	12	0.53	3.77	51.76	0.35	1.44	825.0	2.05	0.02	3.16	1.47
Replication	1	0.66	8.21	0.03	2.18	0.61	5219.2	4.01	0.02	13.68	2.68
Hybrids	29	16.79*	24.81*	815.39*	2.69*	24.93*	107258.4*	44.83*	10.87*	745.45*	12.26*
Error	29	0.43	6.52	107.28	0.43	0.68	375.0	12.73	0.02	1.59	1.37

*Significant at 5% level **Significant at 1% level

Table 2 General combining ability effects of parents for yield and yield contributing characters

Parents	Days to 50% flowering	Number of leaves/plant	Plant height	Stem girth	Head diameter	No of seeds/head	Autogamy %	100-seed weight	Seed yield/ plant	Oil content (%)
NDCMS 1A	-0.16	-1.32*	-4.76*	-0.18	-0.79**	-53.52**	0.88	-0.11**	4.27**	-0.25
234 A	-1.10**	0.20	15.49**	0.86**	1.72**	99.91**	0.34	1.23**	5.15**	0.97**
COSF 1A	1.25**	1.12	-10.73**	-0.69**	-0.93**	-46.39**	-1.21	-1.13**	-9.42**	-0.72
SE	0.14	0.57	2.31	0.14	0.18	4.33	0.79	0.03	0.28	0.26
RHA 6D-5-3-6	-2.35**	-0.78	6.22	-0.16	0.55	-88.06**	-0.50	-1.37**	-1.51**	-0.34
RHA 83R6	-1.09**	2.60*	3.00	0.11	2.44**	76.57**	1.50	-0.27**	18.91**	1.06*
RHA MR-1-1	-0.86**	-0.92	1.63	-0.35	-1.55**	-156.33**	0.21	-0.44**	-2.25**	0.61
DRSF 110 R	0.46	0.97	13.67**	0.39	2.41**	268.50**	4.12**	-0.47**	5.59**	2.03**
RHA 17	-0.92**	0.95	12.44**	0.62*	0.89*	162.54**	0.02	0.71**	5.58**	-1.18*
RHA 273	-1.69**	-0.52	-7.31	-0.74*	1.92**	-163.53**	-2.82	0.92**	-9.81**	-1.96**
RHA RR 2	0.41	-2.72*	-22.30	-0.78**	-1.76**	-209.40**	-1.23	0.04	-13.67**	-2.53**
RHA 859-2	4.28**	-4.45*	-1.10	0.13	0.94**	120.24**	0.66	-0.78**	3.78**	-1.24*
DRSF 111 R	3.59**	3.05*	1.20	0.47	-1.99**	160.60**	-0.98	1.59**	0.92	1.81**
LTRR 1822	-1.82**	1.82	-7.45	0.31	-3.86**	-171.13**	-1.01	0.07	-7.54**	1.74**
SE	0.26	1.04	4.22	0.26	0.33	7.90	1.45	0.06	0.51	0.47

* Significant at 5% level ** Significant at 1% level

Table 3 Specific combining ability effects of hybrids for yield and yield contributing characters

Hybrids	Days to 50% flowering	Number of leaves/ plant	Plant height	Stem girth	Head diameter	No of seeds/ head	Autogamy %	100-seed weight	Seed yield/plant	Oil content (%)
NDCMS 1A x RHA 6D-5-3-6	-3.68 **	-2.33	-2.53	-0.99*	1.99 **	178.05 **	6.54 *	1.33 **	2.89 **	0.70
NDCMS 1A x RHA 83R6	0.06	-3.66	2.84	0.25	2.38 **	177.42 **	1.98	0.89 **	47.99 **	1.90 *
NDCMS 1A x RHA MR-1-1	-1.13 *	1.25	10.61	0.81	3.07 **	-10.18	-3.90	-0.08	17.61 **	0.05
NDCMS 1A x DRSF 110 R	-0.69	-0.88	9.17	0.36	-2.60 **	-279.71 **	-8.33 **	0.62 **	-16.07 **	-2.37 **
NDCMS 1A x RHA 17	2.79 **	-3.01	-6.39	0.82	-0.71	-157.95 **	3.55	0.83 **	-13.59 **	1.63
NDCMS 1A x RHA 273	1.06 *	-1.00	7.75	-0.26	0.49	-70.08 **	-0.53	1.19 **	1.11	0.52
NDCMS 1A x RHA RR 2	1.36 **	1.55	-13.66	-0.76	-5.52 **	116.99 **	1.62	-3.62 **	-11.25 **	0.54
NDCMS 1A x RHA 859-2	-0.66	2.19	-12.31	-0.50	-0.64	-38.35 **	-5.31 *	-0.94 **	-15.16 **	1.00
NDCMS 1A x DRSF 111 R	2.37 **	3.89 *	10.94	0.56	0.40	-74.61 **	-1.66	-0.40 **	-12.04 **	-3.90 **
NDCMS 1A x LTRR 1822	-1.46 **	2.02	-6.41	-0.31	1.15	158.42 **	6.03 *	0.18	-1.48	-0.08
234 A x RHA 6D-5-3-6	1.61 **	1.35	-10.32	-0.47	-1.38 *	-134.18 **	-4.04	-1.67 **	7.56 **	0.38
234 A x RHA 83R6	-0.85	2.57	-16.21 *	-0.77	-3.07 **	-305.91 **	-2.77	-3.39 **	-36.59 **	-2.42 **
234 A x RHA MR-1-1	0.81	2.84	-7.74	-0.23	0.83	-40.11 **	-3.64	1.25 **	-8.89 **	-3.32 **
234 A x DRSF 110 R	0.45	-1.15	-17.67 *	-0.01	3.79 **	150.56 **	8.86 **	-2.76 **	-1.37	2.02 *
234 A x RHA 17	-1.02 *	1.87	9.91	-1.39 **	-2.05 **	157.82 **	-3.47	-2.48 **	2.92 **	1.02
234 A x RHA 273	0.60	1.34	0.26	0.18	-2.41 **	-37.61 *	1.21	1.63 **	-8.33 **	-1.05
234 A x RHA RR 2	-0.55	2.34	32.59 **	2.34 **	6.43 **	-79.04 **	-2.69	4.84 **	3.82 **	-0.69
234 A x RHA 859-2	-0.62	-3.18	7.14	1.09 *	1.91 **	225.72 **	7.55 **	0.12	25.08 **	0.28
234 A x DRSF 111 R	-3.39 **	-3.08	-21.31 **	-0.75	-3.30 **	171.06 **	4.29	0.45 **	18.70 **	2.08 *
234 A x LTRR 1822	2.98 **	-4.90 *	23.34 **	0.02	-0.75	-108.31 **	-5.29 *	2.02 **	-2.91 **	1.70
COSF 1A x RHA 6D-5-3-6	2.08 **	0.98	12.85	1.46 **	-0.61	-43.88 **	-2.49	0.34 **	-10.45 **	-1.08
COSF 1A x RHA 83R6	0.80	1.10	13.37	0.52	0.69	128.49 **	0.79	2.51 **	-11.40 **	0.52
COSF 1A x RHA MR-1-1	0.31	-4.09 *	2.86	-0.58	-3.90 **	50.29 **	7.55 **	-1.17 **	-8.72 **	3.27 **
COSF 1A x DRSF 110 R	0.25	2.03	8.50	-0.35	-1.19	129.16 **	-0.53	2.14 **	17.44 **	0.35
COSF 1A x RHA 17	-1.77 **	1.14	-3.51	0.56	2.76 **	0.12	-0.08	1.65**	10.67 **	-2.65 **
COSF 1A x RHA 273	-1.65 **	-0.34	-8.02	0.07	1.92 **	107.69 **	-0.67	-2.82 **	7.22 **	0.53
COSF 1A x RHA RR 2	-0.80	-3.89 *	-18.93 *	-1.58 **	-0.91	-37.94 **	1.07	-1.22 **	7.43 **	0.15
COSF 1A x RHA 859-2	1.28 **	1.00	5.17	-0.59	-1.27 *	-187.38 **	-2.24	0.82 **	-9.92 **	-1.28
COSF 1A x DRSF 111 R	1.02 *	-0.81	10.37	0.18	2.90 **	-96.44 **	-2.64	-0.04	-6.66 **	1.82 *
COSF 1A x LTRR 1822	-1.52 **	2.88	-16.93 *	0.29	-0.40	-50.11 **	-0.74	-2.21 **	4.39 **	-1.62
SE	0.464	1.806	7.324	0.467	0.583	13.693	2.523	0.105	0.891	0.830

* Significant at 5% level ** Significant at 1% level

REFERENCES

Allard R W 1960. *Principles of Plant Breeding.* John Wiley and Sons Inc. New York.

Dhillon B S 1975. The application of partial diallel crosses in plant breeding- a review. *Crop Improvement*, **2**: 1-7.

Gouri Shankar V, Ganesh M, Ranganatha A R G, Suman A and Sridhar V 2007. Combining ability studies in diverse CMS sources in sunflower. *Indian Journal of Agricultural Research*, **41**(3): 171-176.

Kempthorne O 1957. *An Introduction of Genetics Statistics*. The Iowa University Press.

Khan H, Hidayat-ur-Rahman H Ahmad, Haidar Ali, Inamullah and Mukhtar Alam 2008. Magnitude of combining ability of sunflower genotypes in different environments. *Pakistan Journal of Botany*, **40**(1): 151-160.

Kinman M L 1970. New development in the USDA and State Experiment Station, Sunflower Breeding Programme. Proceedings of the Fourth International Sunflower Conference, Memphis,Tennessa, pp. 181-183.

Leclercq P 1969. Line sterile cytoplasmique chezk tournesol. *Ann. Amelior Planta*, **12**: 99-106.

Mohanasundaram K, Manivannan N and Vindhyavarman P 2010. Combining ability analysis for seed yield and its components in sunflower (*Helianthus annuus* L.). *Electronic Journal of Plant Breeding*, **1**(4): 864-868.

Sprague G F and Tatum L A 1942. Genetic and specific combining ability in single crosses of corn. *Journal of American Society of Agronomy*, **34**: 923-932.

Combining ability analysis for yield and yield contributing attributes in linseed (*Linum usitatissimum* L.)

ACHILA SINGH AND NALINI TEWARI

C.S. Azad University of Agriculture and Technology, Kanpur-208 002, Uttar Pradesh

(Received: February 22, 2016; Revised: March 7, 2016; Accepted: March 28, 2016)

ABSTRACT

The combining ability analysis from eleven parental lines in diallel cross in linseed (*Linum usitatissimum* L.) exhibited highly significant *gca* and *sca* effects from all the traits under study. This signified the importance of additive and non-additive gene effects in controlling the inheritance of characters. Parents, LC-185, Sweta and T-397 were identified as best general combiner for seed yield per plant. Twenty six cross combinations out of 55 showed significant and desirable *sca* effects for seed yield/plant. Best crosses on the basis of *sca* effects were Sweta x T 397, EC 41498 x1/76 , R-17x1/76, N- 3 x T-397 and J- 23 x LC 185.

Keywords: Combining ability, Diallel cross, Gene action, Hybrid, Linseed

Linseed (*Linum usitatissimum* L.) also known as flaxseed belongs to family Linaceae. It is generally known for seed types and flax is commonly grown for fiber types. Nevertheless, both having 2n=30 chromosomes are perfectly crossable and there is no barrier to the gene flow. Linseed owing to its various uses is considered important in oilseeds economy of the country (Singh and Tewari, 2014). Every part of linseed is used directly or after processing. With a view to have a holistic approach and sound scientific planning for breeding desirable varieties, seed yield and some of the important yield components were considered for their genetic analysis by adopting classical diallel technique (Tewari and Singh, 2014).The knowledge of combining ability is useful to assess nicking ability of parents and to elucidate the nature and magnitude of gene action involved. The concept of combining ability has assumed greater importance in plant breeding as it permits the prediction of the efficiency of parents based on early generation performance besides enabling to study the comparative performance of genotypes/lines in hybrid combination. The *gca* effect is primarily a function of additive gene effects and additive x additive interaction. The additive effects are mainly due to polygenes which act in additive manner, expressing fixable effects, while *sca* effects represents non-additive type of gene action. Non-additive gene action results from the effect of dominance epitasis and various other interactions which are non-fixable. The present investigation was carried out to know the gene action for certain quantitative characters and to identify certain parents/crosses for their utilization in future breeding programme.

The present experiment was conducted at Oilseed Research Farm, C.S. Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh during *rabi* 2010-11. The material consisted of eleven parents and their F_1s were raised in Randomized Block Design with three replications. Each genotype was sown in 2 rows of 3m length with row to row and plant to plant spacing of 40 cm and 10 cm, respectively. Recommended doses of 80 kg N, 40 kg P_2O_5 and 15 kg K_2O/ha were applied to raise a healthy crop. Observations were recorded on ten randomly selected plants in each entry for nine quantitative traits *viz.,* days to 50% flowering, days to maturity, plant height (cm), number of primary branches/plant, number of capsules/plant, number of seeds/capsule, 100-seed weight (g) , harvest index (%) and seed yield/plant (g). Combining ability analysis was performed according to the procedure suggested by Griffing (1956) Method 2, Model I.

The analysis of variance (Table 1) revealed that both *gca* and *sca* variances were highly significant for all the traits indicating the importance of both additive and non-additive genetic components in controlling the expression of these characters and the parents and their progenies differed for their combining ability effects. The ratio of being less than unity indicated the involvement of the non-additive gene action in inheritance of all the traits except plant height and 100-seed weight. Similar findings were observed by Tewari *et al.* (2004) and Singh *et al.* (2004). The presence of predominantly large amount of non-additive gene action would necessitate to maintenance of heterozygosity in the population. Since, this type of gene action in not fixable, therefore, breeding method such as biparental mating followed by recurrent selection may hasten the rate of genetic improvement for these traits whereas, the ratio of *gca* and *sca* variance components ($\hat{\sigma}^2 g / \hat{\sigma}^2 s$) was more than unity for plant height and 100-seed weight. This indicated that additive type of gene action played greater role in the inheritance of these characters. To exploit the additive genetic variance in the improvement of such characters, pedigree method of breeding can be used.

Table 1 Analysis of variance for combining ability of seed yield and its components in linseed

Source	Df	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of primary branches/plant	Number of capsules/plant	Number of seeds/capsule	100-seed weight (g)	Seed yield/plant (g)	Harvest index (%)
Gca	10	240.36**	22.91**	256.41**	11.80**	7492.23**	1.33**	0.08**	3.45**	79.43**
Sca	55	21.12**	2.61**	16.73**	5.75**	6794.16**	0.48**	0.005**	16.35**	9.74**
Error	130	0.91	0.64	0.50	0.19	13.68	0.04	0.00	0.36	0.22
$\sigma^{\wedge 2}g$		16.86	1.56	18.43	0.46	53.69	0.05	0.006	-0.99	5.36
$\sigma^{\wedge 2}s$		20.20	1.96	16.23	5.55	6780.47	0.44	0.005	15.99	9.51
$\sigma^{\wedge 2}g / \sigma^{\wedge 2}s$		0.83	0.79	1.13	0.08	0.008	0.11	1.20	-0.06	0.56
$(\sigma^{\wedge 2}g / \sigma^{\wedge 2}s)^{0.5}$		1.09	1.12	0.93	3.45	11.23	2.98	0.91	$	1.33

** = Significant at 1% level; $=Due to negative estimate of $\sigma^2 g$ the degree of dominance not worked out.

A critical examination of *per se* performance of parental genotypes and their *gca* effects revealed positive relationship (Table 2). Estimation of *gca* effects revealed that none of the parents was found good general combiner for all the attributes. However, on the basis of overall performance the varieties LC 185, T-397, Sweta and R-17 were found to be good combiner for seed yield/plant as well as for most of its important component traits, a composite of these lines or an inter mating population involving all possible crosses among them subjected to parental mating in early generation will be expected to offer the maximum promise in breeding for high yield. Therefore these varieties may be utilized in hybridization programme for improving seed yield.

Breeder's interest normally rests in obtaining transgressive segregants through crosses in order to produce homozygous lines in autogamous crops like linseed. In the present investigation, none of the crosses expressed good combining ability for all the traits under study. Out of 55 crosses, twenty for days to 50% flowering, eight for days to maturity, twenty three for plant height, fourteen for dwarfness, five for number of primary branches/plant, thirty two for number of capsules/plant, eleven for number of seeds/capsule, twenty seven for 100-seed weight and twenty eight for harvest index were observed exhibiting significant and desirable *sca* effects. A critical review of results of specific combining ability effects for seed yield/plant and their performance in other attributes revealed that 26 hybrids exhibited significant and desirable *sca* effects for seed yield/plant. Three cross combinations involved all the three possible combinations between the parents with high x low *gca* effects *viz.,* high x high, high x low and low x low. A good cross combination does not always accrue as a result of crossing between high x high or high x low combiners. Low x low combiners are likely to yield sometimes best combiners.

The cross combination Sweta x T-397 could be places in the first category where both the parents had significant and desirable *gca* effects for seed yield/plant (Table 3). This cross is valuable because of the presence of additive x additive type of gene interaction. It is therefore, desirable that biparental mating programme on the model of design III presented by Comstock and Robinson (1948) may be followed in order to get transgressive segregants from such crosses involving high x high combiners. The cross Sweta x T-397 may be effectively utilized in appropriate breeding programmes for the improvement of seed yield.

Table 2 Estimates of (*gca*) effects and *per se* performance of parents for seed yield and its components

Parents	Days to 50% flowering		Days to maturity		Plant height (cm)		No. of primary branches/plant		No. of capsules/plant		No. of seeds/capsule		100-seed weight (g)		Seed yield/ plant (g)		Harvest index (%)	
	gca	*per se*	*gca*	*per se*	*gca*	*per se*	*gca*	*per se*	*gca*	*per se*	*gca*	*per se*	*gca*	*per se*	*gca*	*per se*	*gca*	*per se* perform-ance
N-3	-0.674**	77.00	-1.378**	152.67	-3.891**	65.73	-1.000**	7.43	-36.585**	126.53	0.032	7.40	0.041**	0.87	-0270	7.07	3.057**	39.07
Jawahar -23	-5.622**	63.33	-0.147	153.00	-0.574**	73.88	-0.575	7.20	-14.210**	166.17	0.071	7.40	0.054**	0.89	0.226	8.79	2.001**	35.86
R-17	-2.212**	71.00	0.315	156.00	-4.150**	72.58	-1.024**	8.53	-1.046	214.20	-0.494**	6.95	0.103**	0.86	0.411	11.90	1.768**	34.36
Sweta	2.685**	75.67	0.238	156.33	2.591**	75.05	1.540**	7.63	11.915**	165.47	0.553**	8.57	-0.060**	0.77	0.380*	8.87	-0.916**	34.89
T-397	-2.776**	65.67	0.417	156.67	-1.059**	70.73	-0.323	4.47	18.037**	126.32	-0.036	7.65	0.010**	0.87	0.841**	6.41	0.204	38.36
Gaurav	7.198**	83.00	-0.019	154.67	6.158**	82.31	1.460**	6.59	-22.683**	74.26	0.232**	7.23	0.051**	0.92	-0.035	4.42	-4.096**	18.40
Shubhra	-3.469**	73.00	-3.172**	149.67	-6.098**	66.32	-0.381	7.70	-32.574**	112.63	-0.153**	7.37	0.094**	0.95	0.199	6.81	3.454**	39.37
LC-185	5.644**	85.33	0.853**	156.67	-0.080	72.63	0.919*	9.00	17.283**	164.17	0.346**	9.35	-0.149**	0.56	0.405*	5.90	-2.792**	27.999*
EC-41498	0.249	76.33	0.904**	158.33	4.621**	87.72	-0.667	5.60	22.712**	174.27	-0.095	7.27	0.029**	0.86	-0.659**	6.26	0.085	31.34
1/76	-4.879**	58.00	0.658	159.00	-4.105**	61.57	0.599	6.90	36.927**	92.33	-0.181**	8.22	-0.081**	0.62	0.220	3.25	-0.079	32.13
NP-22	4.455**	86.00	1.930**	159.00	6.586**	82.27	-0.548	6.33	0.224	115.53	-0.275**	8.20	-0.091**	0.58	-0.908**	4.98	-2.688**	34.03

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

Table 3 Estimates of *sca* effects and *per se* performance of best crosses for yield and its components

Characters/ Cross	Day to 50% flowering		Days to maturity		Plant height (cm)		Number of primary branches/plant		Number of capsules/plant		Number of seeds/capsule		100-seed weight (g)		Seed yield/plant (g)		Harvest index(%)	
	sca	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean
Sweta x T-397	-0.000	74. 67	1.158	157.33	2.502**	79.12	3.456**	14.04	180.64**	468.70	-0.234	7.67	-0.099**	0.71	8.527**	22.60	-0.443	34.48
EC 41498 x 1/76	0.205	70.33	-1.483*	155.00	-1.062	74.59	0.645	9.94	156.555**	474.30	-0.323	6.78	0.016**	0.82	8.206**	20.62	-0.057	35.58
R 17 x 1/76	9.333**	77.00	-0.227	155.67	-1.044	65,83	1.448	10.39	98.398**	392.39	0.792**	7.50	-0.049**	0.83	6.946**	20.43	3.003**	40.32
N 3 x T397	-2.974**	68.33	-0.226	154.33	-0.212	69.97	1.179	9.22	44.552**	284.11	-0.095	7.28	0.066**	0.98	6.083**	10.51	1.678**	40.57
J 23 x LC 185	3.154**	77.33	0.774	157.00	-2.979**	71.50	2.749**	12.46	60.878**	322.06	0.084	7.88	0.001	0.76	5.830**	18.51	1.887**	36.733
Gaurav x 1/76	-0.744	76.33	-4.227**	151.33	-4.585**	72.60	2.297	13.72	42.225**	314.58	0.900**	6.53	0.060**	0.89	4.432**	17.47	4.144**	35.60
J 23 x NP22	-4.256**	69.33	0.697	158.00	4.288**	85.43	0.176	8.42	52.913**	297.03	0.305	7.48	0.002	0.82	4.203**	16.38	-2.581**	32.36
Gaurav x Shubhra	-2.821**	75.67	1.004	153.33	4.108**	79.30	-0.776	9.67	23.317**	226.17	0.422**	7.88	0.051**	1.05	3.719**	16.74	1.944**	36.93
N 3 x LC 185	-4.128**	75.00	-0.662	154.33	2.805**	73.97	-0.285	8.99	19.823**	258.63	-0.093	7.67	-0.014	0.74	3.422**	15.60	1.645**	37.54
LC 185 x NP22	-2.256**	82.00	0.030	158.33	8.705**	90.34	0.692	10.43	111.586**	387.20	0.131	7.58	0.036**	0.65	3.333**	14.88	-0.981*	29.17

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

The crosses R-17 x 1/76, N-3 x T-397, R-17 x NP-22, N-3 x Sweta, Sweta x LC -185, T-397 x Gaurav and T-397 x Shubra displayed significant and desirable *sca* effects for yield, involved at least one parent exhibiting significant *gca* effect and could be placed in high x low category (Table 4). These results are in accordance with Tripathi *et al.* (2011). In such type of crosses additive gene action present in good combiner and complementary epistatic gene action present in poor combiner, acted in the complementary fashion to minimize desirable effects which could be exploited by selection of desirable homozygous lines among progenies derived from the cross. Recurrent selection procedure with random mating is expected to offer tremendous potential for the improvement of population of linseed crop. For the remaining cross combinations, *sca* effects for seed yield were associated with low x low gene effects, indicating the preponderant of non-additive type of gene action which could be early exploited by any classical breeding programme.

Table 4 Best specific crosses exhibiting maximum *sca* effects for seed yield/plant and their performance for other traits

Cross	*Per se* Performance	*sca* effect	*gca* effect		Other characters with significant *sca* effects in desirable direction
			P_1	P_2	
Sweta x T-397	22.60	8.527**	0.380*	0.841**	Plant height **, number of primary branches/plant**, number of capsules/plant**
EC 41498 x 1/76	20.62	8.206**	-	0.220	Number of capsules/plant**, 100-seed weight **, days to maturity**
R 17 x 1/76	20.43	6.946**	0.411*	0.220	Number of capsules/plant**, number of seeds/capsule**, harvest index**
N 3 x T-397	19.51	6.083**	-	0.841**	Days to 50% flowering**, number of capsules/plant**, 100-seed weight**, harvest index**
J 23 x LC 185	18.51	5.830**	0.226	-	Number of primary branches/plant**, number of capsules/plant**, harvest index**
Gaurav x 1/76	17.47	4.432**	0.220	-	Days to maturity**, number of capsules/plant**, 100-seed weight**, harvest index**
J 23 x NP 22	16.38	4.203**	0.226	-	Days to 50% flowering**, plant height**, number of capsules/plant**
Gaurav x Shubhra	16.74	3.719**	-	0.199	Days to 50% flowering**, plant height**, number of capsules/plant **, number of seeds/capsule**, 100-seed weight**, harvest index**
N 3 x LC 185	15.60	3.422**	-	-	Days to 50% flowering**, plant height**, number of capsules/plant**, harvest index**
L C 185 x NP 22	14.18	3.333**	-	-	Plant height**, number of capsules/plant**, 100-seed weight**, days to 50% flowering**
R17 x NP 22	14.68	2.324**	0.411*	-	Number of capsules per plant**, harvest index**, days to 50% flowering**, days to maturity**
N3 x Shweta	15.26	2.294**	-	0.380*	Plant height **
Shweta x LC 185	14.87	2.036**	0.380**	-	Plant height **, number of capsules/plant**
T397 x Gaurav	15.44	1.775**	0.841**	-	Number of primary branches/plant**, number of capsules/plant**, 100-seed weight**
T397 x Shubhra	15.08	1.180**	0.841*	0.199	Days to 50% flowering**, 100-seed weight**, harvest index**

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

REFERENCES

Comstock R E and Robinson H F 1948. The components of genetic variance in population of biparental progenies and their use in estimating degree of dominance. *Biometrics*, **4**: 254-266.

Griffing B 1956. Concept of general and specific combining ability in selection to diallel crossing systems. *Australian Journal of Biological Sciences*, **9**: 463-493.

Singh H C, Dixit R K, Pathak R K, Singh R and Tewari N 2004. Genetic analysis of quality traits in linseed (*Linum usitatissimum* L.). *Indian Journal of Agricultural Biochemistry*, **7**(1): 27-29.

Singh A and Tewari N 2014. Genetic analysis for seed yield and its contributing traits in linseed (*Linum usitatissimum* L.). *Journal of Oilseeds Research*, **31**(2): 118-122.

Tewari N, Dixit R K and Singh H L 2004. Combining ability analysis for seed yield and its components in linseed (*Linum usitatissimum* L.). *Journal of Oilseeds Research*, **21**(2): 343-345.

Tewari N and Singh A 2014. Genetic architecture of yield contributing traits in linseed (*Linum usitatissimum* L.). *Journal of Oilseeds Research*, **31**(2): 167-169.

Tripathi S, Mishra V and Tripathi H D 2011. Combining ability analysis of yield and its components in linseed (*Linum usitatissimum* L.). *Current Advances in Agricultural Sciences*, **3**(2): 93-95.

Identification of critical P level for sunflower (*Helianthus annuus* L.) in solution culture for P acquisition

A AZIZ QURESHI AND LAKSHMI PRAYAGA

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

(Received: March 8, 2016; Revised: March 17, 2016; Accepted: March 24, 2016)

ABSTRACT

Solution culture experiment was conducted during November 2012 at ICAR-Indian Institute of Oilseeds Research, Hyderabad with a protocol to identify the critical level of phosphorus (P) in nutrient solution suitable to produce initial growth of sunflower that could be able to distinguish the deficiency effect from sufficient level. The study showed that 2.0ppm P was found to be critical in solution to arrest the normal growth of shoot, root, dry matter and P uptake at 30 days of sowing. The regression coefficient obtained between total dry matter and P levels in solution culture was found be to highly significant (R^2=0.97). The best fit curve through quadratic equation was found to be $Y= -0.0496x^2+0.713x +0.5932$. The results obtained in this study would provide the basis for conducting rapid screening of sunflower genotypes for P acquisition and identification of distinct changes in root modifications against P stress or starvation during the initial plant growth period (up to 30-45 days).

Keywords: Critical P level, P acquisition, Sunflower

Phosphate is one of the key substrates in energy metabolism and biosynthesis of nucleic acids and membranes. It also play an important role in photosynthesis, respiration, and regulation of a number of enzymes. Among the many inorganic nutrients required by plants, P is one of the most important elements that significantly affect the plant growth and metabolism and its acquisition by plants is one of the more thoroughly studied aspects of plant nutrition. Low availability of P is a major constraint for crop production in many low-input systems of agriculture worldwide. Recently, identification of plants types or genotypes for high phosphorus acquisition in low or marginal soil is gaining importance for identifying traits for high P acquisition or high P use efficiency of acquired P and for developing new varieties or hybrids that would be suitable to grow with less P inputs. It has been reported that P acquisition is basically controlled by genes and their expression is manifested under interaction in stress situation through changes in root morphology characteristics (Shi *et al.,* 2013; Gamuyao *et al.,* 2012). Genotypes respond differently to low P situation and those that have high P acquisition under P stress or starvation exhibit variations in the root growth and *vice-versa*. Response of root growth to P application in most of the annual crops is seen in early growth stage of the crops (<30-45 days). Hence, screening of genotypes or germplasm is must to identify such traits for tailoring high P acquisition varieties and hybrids in coming future. Field screening large number of sunflower genotypes is laborious and time consuming. Reports have shown that rapid screening of genotypes for P acquisition for short duration under P stressed conditions in rice (Yuchun Guo *et al.,* 2002; Li *et al.,* 2007), wheat (Hayes *et al.,* 2004), groundnut (Amit Kumar *et al.,* 2009), mustard (Zhang Hai *et al.,* 2011; Zhon Xin *et al.,* 2012) and common bean (Namayanja *et al.,* 2014) has been quite success. In the present study an attempt has been made to standardize a protocol to identify the critical level of phosphorus (CLP) in nutrient solution that limits the sunflower total dry matter production. The CLP can be fixed as the minimum level of P to be supplied (as P stress) for rapid screening of sunflower genotypes against full strength P in nutrient solution to study the root traits for P acquisition.

A glasshouse experiment was conducted with nine levels of P *viz.,* 0, 2, 3, 4, 5, 6, 7, 8 ppm and full strength check (i.e., 62 ppm), respectively in Hoagland's nutrient solution. Completely randomized design was adopted with five replications. Sunflower hybrid DRSH-1 was selected as test crop for the study. To one litre capacity HDPE (high density polyethylene) pots, 1000mL Hoagland's nutrient solution of desired P concentration was added. The composition of Hoagland's nutrient solution and details to maintain different strengths of P is given in Table 1. Seeds were allowed to germinate in pre-acid washed quartz sand and were carefully transplanted to pots in solution culture. Seedlings were secured in the hole of asbestos sheet with the help of non-absorbent cotton allowing the root to dip in nutrient solution and the shoot to grow upright. Seedlings were aerated daily with electric operated aerator and the whole solution was replaced weekly while the evaporated volume was made up daily. The plants were allowed to grow and after 30 days, growth parameters namely shoot length, number of leaves, root length, shoot and root dry matter, root/shoot ratio, total dry matter were recorded for all the treatments. Plant samples were dried in oven at 70 ± 10°C, powdered and digested with di-acid [nitric acid (HNO_3):

perchloric acid ($HClO_4$), 10:4] mixture. The plant P content was estimated by the vanadomolybdo-phosphoric acid yellow colour method (Jackson, 1973). P uptake was calculated as the product of P content and total dry-matter. Statistical parameters like analysis of variance, regression and coefficient of determination (R^2) were worked out as per the method outlined by Gomez and Gomez (1984).

Table 1 Composition of full strength Hoagland's nutrient solution with (+P) and without P (-P) nutrient

Different salt solutions of 1*M* strength	Quantity of solution for +P (ml/L)	Quantity of solution for -P (ml/L)
KNO_3	6	6
$Ca(NO_3)_2.4H_2O$	4	4
$NH_4H_2PO_4$*	2	0
$MgSO_4.7H_2O$	1	1
KCl	1	1
H_3BO_3	1	1
$MnSO_4.H_2O$	1	1
$ZnSO_4.7H_2O$	1	1
H_2MoO_4	1	1
Fe-citrate	1	1
NH_4Cl	0	2
$Ca(NO_3)_2.4H_2O$	6	6

* Volume of 1*M* $NH_4H_2PO_4$ was adjusted w.r.t. P concentration in the treatments (mg/L) as 2.0mL required for obtaining full strength P solution (62 mg/L)

In Hoagland's nutrient solution, nine levels of phosphorus 0, 2, 3, 4, 5, 6, 7, 8 ppm and full strength (62ppm) were maintained to find out the minimum P concentration required to produce significantly lowest dry matter from nearest high level to standardize the critical concentration of P required to develop the protocol for rapid screening of sunflower genotypes in solution culture suitable for identification of changes in root morphology against phosphorus starvation. The data presented in Table 2 indicate the effect of different P levels on growth parameters of sunflower grown in solution culture up to 30 day stage. Shoot length of sunflower seedling was drastically reduced at 4.0ppm P which was significantly lower than the value obtained at 8.0ppm, however, it was at par with the growth produced between 3.0 to 7ppm. The lowest shoot length was noticed due to 2.0ppm P solution concentration and this level was found to be critical for shoot growth of sunflower and suitable for standardization of protocol for rapid screening of sunflower genotypes. On the other hand, the shoot length due to P levels beyond 4.0ppm up to full strength had produced similar growth. Similarly, Amit Kumar *et al.* (2009) adopted solution culture with sufficient and deficient P levels for screening groundnut lines for identifying P acquisition root traits. It was evident from the results presented in the table 2 where these treatments (> 2 to < 8ppm, respectively) were statistically at par to each other. It was interesting to note that at lower levels of P, the root length of seedlings was greater compared to sufficient levels (i.e. above 5.0ppm) and this might be due to the response against P starvation in nutrient solution. Further, there was no significant difference in the root length due to P levels. However, the results showed that root dry matter weight was highly influenced by P levels in solution culture. The effect of P levels *viz.,* 0, 2, 3 and 4ppm was on par to each other on shoot/root ratio (Table 2). At 30 day growth stage the highest shoot and root dry matter was noticed in full strength solution (62ppm) while lowest in zero ppm (Fig. 2). The minimum growth at 0 ppm may be due to the endosperm nutrient support from the seed. The shoot, root dry weights and total dry matter produced at 2.0ppm P were found to be significantly lowest from the nearest (3.0ppm) concentration of P level in solution. Hence, 2.0ppm P could be critical level in solution for sunflower for P starvation tolerance. The relationship between P levels in nutrient solution and the total dry matter of sunflower up to 30 days was subjected to best fit and the quadratic equation obtained showed highly significant coefficient of regression value (R^2= 0.91) has been depicted in Fig. 1. The predicted declined growth of sunflower due to critical P (2.0ppm) was identified between 0 and 3ppm in the graph.

Table 2 Effect of P concentrations on growth parameters of sunflower in solution culture at 30 days

P levels in nutrient solution (ppm)	Shoot length (cm)	Root length (cm)	Shoot weight (g)	Root weight (g)	Total dry matter (g)	Shoot/ root ratio
0	16.4	32.6	0.30	0.16	0.46	1.82
2	24.5	31.4	1.38	0.71	2.09	1.94
3	25.6	32.7	1.54	0.78	2.32	1.98
4	26.3	31.2	1.75	0.82	2.58	2.13
5	29.2	26.8	2.01	0.84	2.85	2.40
6	28.6	28.4	2.17	0.84	3.00	2.59
7	28.4	32.8	2.19	0.88	3.07	2.51
8	29.9	29.7	2.34	0.91	3.25	2.58
62 (Full strength)	31.3	30.6	2.88	1.12	4.00	2.60
CD (0.05%)	3.6	6.3	0.18	0.10	0.20	0.31

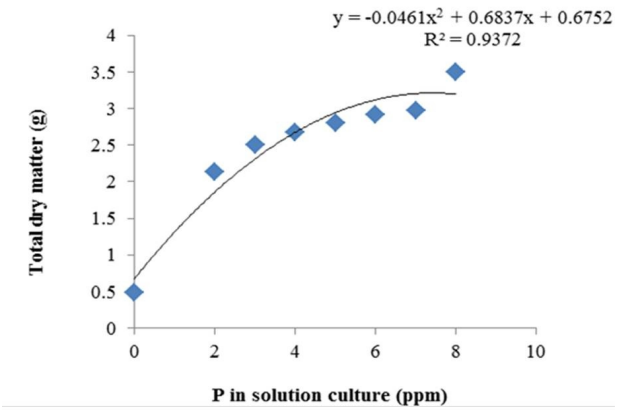

Fig. 1. Regression curve for solution P concentration and total dry matter

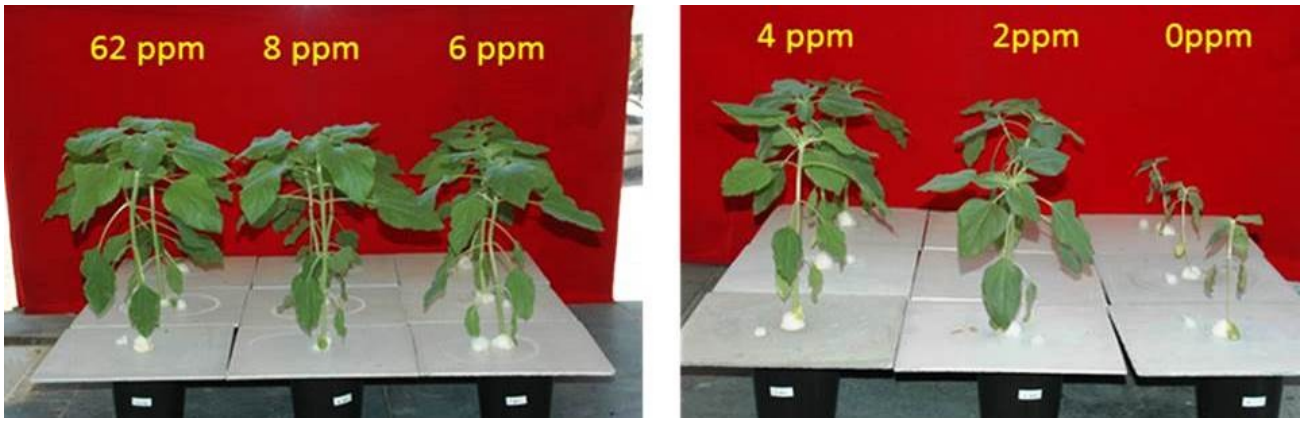

Fig. 2. Response of sunflower growth to different P levels in nutrient solution

Table 3 Effect of P levels on P concentration and uptake in sunflower seedlings in solution culture at 30 days

P levels in nutrient solution (ppm)	Shoot P content (%)	Root P content (%)	Shoot uptake (mgP/pl)	Root uptake (mgP/pl)	Plant uptake (mgP/pl)
0	0.41	0.59	0.12	0.10	0.23
2	0.70	1.27	0.96	0.90	2.05
3	0.79	1.34	1.21	1.04	2.47
4	0.72	1.18	1.25	0.97	2.44
5	0.96	1.58	1.93	1.32	3.61
6	1.18	1.77	2.55	1.48	4.42
7	1.77	1.77	3.88	1.52	5.41
8	1.35	1.90	3.16	1.72	5.28
62 (Full strength)	3.38	7.86	9.73	8.77	22.44
CD (0.05%)	0.13	0.51	0.35	0.64	0.84

Phosphorus (P) levels in solution culture significantly influenced the shoot, root and plant P content and uptake. The corresponding data has been presented in Table 3. P contents in shoot due to 2.0, 3.0 and 4.0ppm did not differ significantly but were at par to each other however, it was found to be significantly low compared to high levels of P (> 5.0ppm). The treatment with 2.0ppm recorded lowest P content and corresponding shoot uptake (0.96mgP/pl). Root P content was higher than shoot at 2.0 ppm but corresponding root uptake was lower than shoot which may be ascertained due low root biomass against shoot. The phosphorus uptake by sunflower seedlings at 30 day period was 2.05mgP/plant at 2.0 ppm and 2.47mgP/pl at 3.0 ppm. This could be attributed to lowest total dry matter (2.09 g/pl) produced with 2.0ppm P (Table 2). However, the highest P uptake (22.4 mgP/pl) was noticed due to full strength nutrient solution. It is imperative that better root-shoot growth and total dry matter might have contributed towards highest uptake.

The solution culture studies revealed that 2.0 ppm P was critical to attain distinctly low dry matter yield of sunflower. This study could be further applied to soils with low P status for simulating natural growth medium. Rapid screening of genotypes up to 30-45 days will coincide the maximum root growth/uptake of most of the annual crops against P starvation and help in identifying genotypes with root traits for high P acquisition suitable for marginal soils.

ACKNOWLEDGEMENT

The authors highly acknowledge the Director for encouraging and providing facilities to take up the rapid screening studies in sunflower under control conditions.

REFERENCES

Amit Kumar, Kusuma P and Gowda M C V 2009. Genotypic variation for root traits in groundnut germplasm under phosphorus stress conditions. *Journal of SAT Agricultural Research*, **7**: 1.

Gamuyao R, Chin J H, Pariasca Tanaka J, Pesaresi P, Catausan S, Dalid C, Slamet-Loedin I, Tecson-Medoza E M, Wissuwa M

and Heuer S 2012. The protein kinase Pstol1 from traditional rice confers tolerance of phosphorus deficiency. *Nature*, **488** (7412): 535-539.

Gomez K A and Gomez A A 1984. *Statistical Procedure for Agricultural Research*, edn. 2, Wiley, New York.

Hayes J E, Zhu Y G, Mimura T and Reid R J 2004. An assessment of the usefulness of solution culture in screening for phosphorus efficiency in wheat. *Plant and Soil*, **261**: 91-97.

Jackson M L 1973. *Soil Chemical Analysis.* Prentice Hall Pvt. Ltd., New Delhi.

Li Y T, Luo A C, Wei X H and Yao X G 2007. Genotypic variation of rice in phosphorus acquisition from iron phosphate: Contribution of root morphology and P uptake kinetics. *Russian Journal of Plant Physiology*, **54**(2): 230-236.

Namayanja A, Semoka J, Buruchara R, Nchimbi S and Waswa M 2014. Genotypic variation for tolerance to low soil phosphorous in common bean under controlled screen house conditions. *Agricultural Sciences*, **5**: 270-285.

Shi T, Li R, Zhao Z, Ding G and Long Y 2013. QTL for yield and their association with functional genes in response to phosphorus deficiency in *Brassica napus. PloS ONE*, **8**(1): 54559.

Yuchun Guo, Wenxiong Lin, Qiumei Shi, Yiyuan Liang, Fangyu Chen, Huaqin He and Kangjing Liang 2002. Screening methodology for rice genotypes with high phosphorus use efficiency at their seedling stage. *Chinese Journal of Applied Ecology*, **13**(12): 1587-1591.

Zhang Hai W, Huang Yu, Xiang Sheng Y E and FangSen X U 2011. Genotypic variation in phosphorus acquisition from sparingly soluble P sources in related to root morphology ad root exudates in *Brassica napus. Science China Life Sciences,* **54**(12): 1134-1142.

Zhou Xin B, Huang Jian-Guo, Zhou Yong-Xiang and Shi Wei Ming 2012. Genotypic variation of rape in phosphorus uptake from sparingly soluble phosphate and its active mechanism. *African Journal of Biotechnology*, **11**(3): 3061-3069.

Productivity of groundnut (*Arachis hypogaea* L.) as influenced by varieties and plant densities

H BHARGAVI, M SRINIVASA REDDY, S TIRUMALA REDDY, P KAVITHA, U VIJAYA BHASKAR REDDY AND P V RAMESH BABU

Agricultural College, Acharya N.G. Ranga Agricultural University, Mahanandi-518 502, Andhra Pradesh

(Received: May 3, 2015; Revised: February 18, 2016; Accepted: February 23, 2016)

ABSTRACT

A field experiment was conducted during *rabi* season to study the influence of different levels of plant densities on growth and yield parameters of groundnut varieties. The experiment was conducted with three varieties and four levels of plant densities replicated thrice. Among the varieties, TCGS-29 (Narayani) significantly produced tallest plants over K6 and TAG-24. LAI of the varieties was not significant except at 60 days after sowing (DAS). At 60 DAS, significantly the highest LAI was recorded with K6 and the lowest was recorded with TAG-24. The dry matter produced by TAG-24 was statistically lowest at 30 and 60 DAS. However the same variety produced significantly highest dry matter during harvest over the other varieties tested. For all the varieties tested, the plant height was most influenced by different plant densities. However, the LAI and dry matter production significantly increased with increased population levels. With regard to pod production, haulm yield and harvest index all the varieties produced statistically similar yield. However, variation in density of planting resulted in production of significantly lower pod yield with 33.3 plants/m^2 and the rest of the treatments produced statistically equal yield. However, superior haulm yield was recorded with 66.6 plants/m^2.

Keywords: Groundnut, Growth parameters, Plant density, Variety, Yield parameters

Groundnut (*Arachis hypogaea* L.) is an important food legume and an oilseed crop. In India the productivity of groundnut is low (1164 kg/ha) and its productivity in Andhra Pradesh (876 kg/ha) is lower compared to national average. Determination of the optimum plant population is a major agronomic goal for optimizing the yield. Sowing at precise seed rate results in optimizing the plant population and also reduces the seed cost. Maximum yield can be obtained only if the plant community produces enough leaf area to provide maximum isolation interception during reproductive growth. Equidistant spacing between plants will maximize yield because it minimizes inter plant competition. The optimum plant density at one site may not apply at other locations because of regional variations in weather and soil factors which mean further trails are needed at each site to validate general recommendations.

A field experiment was conducted during *rabi,* 2012 to study the influence of different levels of plant densities on growth and yield parameters of groundnut varieties at College Farm, Agricultural College, Mahanandi, Kurnool District, Andhra Pradesh. The soil of the experimental site was sandy loam and it was slightly alkaline in reaction with a pH of 7.98, EC of 0.06 dS/m and low in organic carbon (0.46%) and available nitrogen (266 kg/ha), medium in available phosphorous (96.6 kg P_2O_5/ha) and high in available potassium (674.3 kg K_2O/ha). The experiment was laid out in factorial randomized block design and replicated thrice. The treatment consisted of three varieties *viz.,* V_1: K6, V_2: TAG-24 and V_3: TCGS-29 (Narayani) and four plant densities *viz.,* D_1: 30 x 10 cm, D_2: 22.5 x 10 cm, D_3: 30 x 5 cm and D_4: 22.5 x 5 cm. Nitrogen, phosphorous and potassium were applied in the form of urea, single super phosphate and muriate of potash. Entire dose of nitrogen (20 kg/ha) phosphorous (40 kg P_2O_5/ha) and potassium (50 kg K_2O/ha) were applied as basal at the time of sowing. One inter cultivation followed by two hand weedings in rows was taken at 20 and 30 days after sowing (DAS). All the plots were irrigated uniformly as and when required. Totally five irrigations were given during crop growth period. Plant height (cm) was measured from the base of the plant to the tip of the top most leaf at 30, 60, 90 DAS and at harvest. Data on yield attributes, pod and haulm yield were recorded at harvest. Economics was calculated based on present market price of yield and inputs.

TCGS-29 significantly produced tallest plants over K6 and TAG-24. With respect to LAI, except at 60 DAS the LAI of the varieties were not significantly differed. At 60 DAS, significantly highest LAI was recorded with K6 and the lowest was recorded with TAG-24. Similar results was observed by Hirwe *et al.* (2005). At 30 DAS, higher dry matter production (110 g/m^2) was produced by TCGS-29 and it was comparable with K6. At 60 DAS, K6 produced higher drymatter production (430 g/m^2) and TAG-24 had produced higher drymatter production (753 g/m^2) at 90 DAS and was comparable with K6 and TCGS-29.

Table 1 Influence of varieties and plant densities on plant height, leaf area index and drymatter production

Treatment	Plant height (cm)				Leaf area index				Drymatter production (g/m^2)		
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS
Varieties											
K6	17.4	42.5	49.1	45.0	1.2	2.7	2.9	1.5	107	430	576
TAG -24	13.5	28.7	35.6	35.6	1.0	1.5	3.0	1.9	86	311	753
TCGS 29	15.8	39.9	49.7	52.9	1.3	2.1	2.4	1.9	110	400	568
SEm±	0.58	1.21	0.84	2.01	0.07	0.14	0.19	0.16	5.1	30.3	53.6
CD 5%	1.7	3.6	2.5	5.9	NS	0.4	NS	NS	18	89	157
Plant spacing (cm)											
30 x 10 (3.33 lakh plants/ha)	15.6	34.7	45.7	43.0	0.7	1.9	2.5	1.6	62	231	362
22.5 x10 (4.44 lakh plants/ha)	14.8	35.4	43.0	48.0	0.9	1.8	1.9	1.3	77	339	494
30X5 (6.66 lakh plants/ha)	16.6	38.1	46.0	44.5	1.4	2.0	2.9	1.9	124	363	647
22.5 x 5 (8.88 lakh plants/ha)	15.4	39.9	44.6	42.5	1.6	2.8	3.8	2.1	140	589	1028
SEm±	0.67	1.40	0.97	2.32	0.08	0.16	0.21	0.19	6.8	35.0	61.9
CD 5%	NS	NS	NS	NS	0.3	0.5	0.6	0.6	20.23	102.6	181.8
Varieties x Plant spacing											
SEm±	1.18	2.43	1.69	4.03	0.14	0.29	0.38	0.34	11.9	60.6	107.4
CD 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2 Influence of varieties and plant densities on number of pods/plant, number of kernels/pod, kernel weight and shelling percentage

Treatment	No. of pods/plant	No. of kernels/pod	100-kernel weight (g)	Shelling percentage
Varieties				
K6	13	2	38.2	72
TAG -24	16	2	37.4	74
TCGS 29	9	2	38.0	72
SEm±	0.6	0.02	0.24	0.2
CD 5%	2	NS	NS	0.7
Plant spacing (cm)				
30x10 (3.33 lakh plants/ha)	13	2	38.0	72
22.5x10 (4.44 lakh plants/ha)	14	2	37.9	73
30x5 (6.66 lakh plants/ha)	13	2	37.6	72
22.5x5 (8.88 lakh plants/ha)	11	2	38.0	72
SEm±	0.7	0.03	0.27	0.3
CD 5%	2	NS	NS	0.8
Varieties x Plant spacing				
SEm±	1.27	0.06	0.48	0.45
CD 5%	NS	NS	NS	NS

Taller plants (48.0 cm) were produced by a spacing of 22.5 x 10 cm which was statistically at par with rest of the treatments. The spacing of 22.5 x 5 cm was found significantly superior over rest of the treatments in increasing leaf area index (LAI). The increase in LAI with increase in plant population was due to more number of plants per unit area. At harvest, LAI decreased due to reduced number of green leaves per plant. Plant spacing of 22.5 x 5 cm was found to be significantly superior in producing maximum dry matter (g/m^2) at all the crop stages. An increase in dry matter accumulation with increase in plant density was also reported by Mukhtar *et al.* (2012). The interaction effect between varieties and plant spacings on growth parameters were non significant.

Significantly highest number of pods/plant were obtained with TAG-24 (16) followed by K6 (13) and TCGS-29(9). Higher number of pods in TAG-24 was due to production of more branches/plant in turn more flowers and pegs. The effect of varieties, plant densities and its interaction on number of kernels/pod was found to be non-significant and this indicates that number of seeds/pod was more of genetically controlled factor and is less influenced by plant densities. These results are in accordance with the findings of Konlan *et al.* (2013).

The effect of varieties, plant densities and its interaction on 100-kernel weight was found to be non-significant. It

indicates that 100-kernel weight was more of genetically controlled factor and is less influenced by plant densities. Similar findings were reported by Kaushik and Chaubey (2000). Shelling percentage recorded with TAG-24 (73.67) was significantly more compared to other varieties. Higher shelling percentage with TAG-24 might be due to its thin shell development and channelization of more photosynthates from pod wall to kernel.

Number of pods/plant was superior with a plant density of 4.44 lakhs/ha (13.88) over the other plant densities *viz.,* 3.33 lakhs/ha (13.33) and 6.66 lakhs/ha (12.77) and these results were at par with each other. Lower number of pods were recorded with 8.88 lakhs/ha (11.22). These results might be due to sufficient space available for individual plants (at plant density of 4.44 lakhs/ha) which grown vigorously and produced more branches, pegs and more pods/plant. Plants at higher densities (closer plant densities) experienced inter and intra plant competition for space, light, nutrients and moisture and resulted in more partitioning efficiency. These results are in accordance with the findings of Ahmed *et al.* (2011). The number of kernels per pod and the kernel weight were not influenced by plant densities. Shelling percentage obtained with a plant density of 4.44 lakhs/ha (73.27) was significantly maximum over the other plant densities 8.88 (72.29), 6.66 (72.27) and 3.33 (72.13) lakhs/ha which were at par with each other. Similar findings was reported by Hirwe *et al.* (2005). The interaction effect between varieties and plant spacings on yield attributes of number of pods/plant, number of kernels/pod, kernel weight and shelling percentage were non-significant.

The pod yield was not significantly differed among varieties. However, the variety TAG-24 produced highest pod yield (2732 kg/ha) followed by K6 (2630 kg/ha) and TCGS-29 (2688 kg/ha). Similarly haulm yield was not significantly differed with varieties. Among three varieties, Narayani recorded maximum haulm yield (4833 kg/ha) followed by K6 (4558 kg/ha) and TAG-24 (4441 kg/ha).

The highest pod yield was recorded at a spacing of 22.5 x 10 cm which was significantly superior over 30 x 10 cm and 30 x 5 cm and comparable with 22.5 x 5 cm. Plant spacing of 30 x 5 cm was found to be significantly superior in producing highest haulm yield. These results are in accordance with the findings of Ahmed *et al.* (2011) and Kathirvelan and Kalaiselvan (2006). Among the varieties tested harvest index of groundnut was not significantly influenced.

However, plant densities have significant influence on harvest index. Significantly higher harvest index was recorded with a plant density of 4.44 lakhs/ha (41.74) followed by 8.88, 6.66 and 3.33 lakhs/ha (40.53, 33.49 and 32.53, respectively). Similar findings obtained by Jadhav *et al.* (2000). The interaction effect between varieties and plant densities indicated that the variety K6 gave significantly more harvest index at a plant density of 4.44 lakhs/ha as well as less harvest index was also recorded with K6 at a plant density of 8.88 lakhs/ha compared to other tested varieties.

From above investigation it can be concluded that the choice of the variety in groundnut has no much impact on pod yield, haulm yield and harvest index and sowing of groundnut at a spacing of 22.5 cm x 10 cm in *rabi* was more beneficial to get higher yields.

Table 3 Influence of varieties and plant densities on pod yield, haulm yield and harvest index

Treatment	Pod yield (kg/ha)	Haulm yield (kg/ha)	Harvest index (%)
Varieties			
K6	2631	4558	38
TAG -24	2732	4442	38
TCGS 29	2689	4833	35
SEm±	197.0	125.2	1.7
CD 5%	NS	NS	NS
Plant spacing (cm)			
30x10 (3.33lakh plants/ha)	2218	4533	33
22.5x10 (4.44 lakh plants/ha)	3044	4411	42
30x5 (6.66 lakh plants/ha)	2445	4989	33
22.5x5 (8.88 lakh plants/ha)	3028	4511	41
SEm±	227.5	144.6	1.9
CD 5%	667	424	6
Varieties x Plant spacing			
SEm±	557.1	250.5	3.4
CD 5%	NS	NS	10

REFERENCES

Ahmed M, El Naim, Mona A, Eldouma and Abdu E A 2011. Influence of plant spacing and weeds on growth and yield of peanut (*Arachis hypogaea* L.) in rainfed of Sudan. *Advances in Life Sciences*, **1**(2): 45-48.

Hirwe N A, Ulemalle R B, Kubde K J and Chikate R R 2005. Effect of plant density on growth and yield of groundnut under polythene film mulch. *Annals of Plant Physiology*, **19**(2): 245-246.

Jadhav G S, Shinde B A and Suryawanshi M W 2000. Comparative performance of groundnut (*Arachis hypogaea* L.) genotypes under varying row and plant spacing in post-monsoon environment. *Journal of Oilseeds Research*, **17**(1): 70-76.

Kathirvelan P and Kalaiselvan P 2006. Growth characters, physiological parameters, yield attributes and yield as influenced by the confectionary groundnut varieties and plant population. *Research Journal of Agriculture and Biological Sciences*, **2**(6): 287-291.

Kaushik M K and Chaubey A K 2000. Response of rainy season bunch groundnut (*Arachis hypogaea* L.) to row spacing and seed rate. *Crop Research*, **20**(3): 407-410.

Konlan S, Sarkodie-Addo J, Asare E, Adu-Dapaah H and Kombiok M J 2013. Groundnut (*Arachis hypogaea* L.) varietal response to spacing in the humid forest zone of Ghana. *Journal of Agricultural and Biological Science*, **8**(9): 642-651.

Mukhtar A A, Babaji B A, Ibrahim S, Mani H, Mohammad A A and Ibrahim A 2013. Dry matter production and harvest index of groundnut (*Arachis hypogaea* L.) varieties under irrigation. *Journal of Agricultural Science*, **5**(8): 153-168.

Identification of genotypes for high water use efficiency and root traits in castor (*Ricinus communis* L.)

RAMESH THATIKUNTA, A SIVA SANKAR, L SAGARIKA, GOUTHAMI PALLE, J SREELAKSHMI, V GOURI SHANKAR, CH V DURGA RANI AND B LAVANYA

Professor Jayashankar Telangana State Agriculture University, Rajendranagar-500 030, Hyderabad, Telangana State

(Received: July 31, 2015; Revised: October 10, 2015; Accepted: March 5, 2016)

ABSTRACT

Castor (*Ricinus communis* L.) is an important non-edible oilseed crop of the world. Under rainfed situations the crop yields are low. Crop improvement programmes aim at improvement in seed yield, oil content and tolerance to biotic and abiotic stresses. Traits that contribute to water use efficiency (WUE) and improved productivity have not been adequately characterized in castor. In the present study, thirty five genotypes of castor were grown in a temporarily constructed elevated root study structure to characterize for superior shoot and root system architectural (RSA) traits. Genotypes showed variation in characters that contributed to superior WUE and seed yield. Extrinsic WUE recorded with photosynthetic system ranged between 2.63 to 16.76 µmol CO^2/mmol H_2O. Intrinsic WUE values ranged between 36.1 to 53.3 µmol CO_2/mmol H_2O. Photosynthesis and stomatal conductance values recorded ranged from 13.1 to 21.6 µmol CO_2 /m^2/s and 0.521to 0.647 mmol H_2O/m^2/s. Greening index (SCMR) values ranged between 37 to 54. High Greening index was recorded in RG-48, Kranthi, PCS-230, SKI-215 and Haritha. SLA values ranged between 2.29 to 5.23 dm^2/g. Low SLA types include RG-48, Kranthi, PCS-230, SKI-215 and Haritha. Carbon isotope discrimination (CID) value ranged between 17.49 to 19.52 per mill. Low discrimination to $\Delta^{13}C$ included genotypes PCS-330, Kranthi, PCS-230 and PCS-265. Tap root length ranged from 67 to 234 cm. Long tap root was recorded in PCS 324, Haritha, Kranthi, PCS-171, PCS 328, PPL 109, RG-47, RG-48 and SKI-215. Total root volume ranged from 34 to 276 cm^3. TDM ranged from 93.4 to 338.7 g. Seed yield ranged from 52 to 163 g/plant. Kranthi, RG-48, Haritha, PCS 171, PCS-230 and SKI-215 showed four to seven superior shoot root and seed yield characters have been proposed as superior WUE genotypes.

Keywords: Castor, Root system architectural traits, Water use efficiency

Castor is an important non-edible crop cultivated in tropical and subtropical regions of the world. Tolerance to environmental stresses is one of the strengths of castor. This crop is well suited to rainfed or dry land situations. However, productivity of Andhra Pradesh state where the crop is chiefly cultivated as rainfed is 677 kg/ha *vis-a-vis* 1417 kg/ha of India, 1760 kg/ha of Gujarat and world average of 850 kg/ha. Measurement of relevant crop physiological responses can lead to further insights into various aspects of crop growth and development. Improvement in water use patterns can lead to significant increase in seed yield in dry lands by 49, 57 and 29% in case of chickpea, pigeonpea and groundnut (Udaya Kumar *et al.,* 2002). Literature on root traits in castor is meagre. Identification of variability by screening of genotypes for yield contributing traits is a research priority in castor. Therefore, the present study was taken up to identify genotypes with superior shoot and root system architectural (RSA) traits that contribute to high water use efficiency and seed yield.

Thirty five castor genotypes were obtained from Regional Agricultural Research Station, Prof. Jayashankar Telangana State Agricultural University, Palem; Sardar Krishi Nagar, Gujarat and Directorate of Oilseeds Research, Hyderabad. Genotypes utilized in the study are given in Table 1. Genotypes utilized include elite varieties, germplasm lines and breeding lines. The accessions were planted in *rabi,* 2013 in randomized block design in a specially designed elevated root study structure with 25 m length, 4 m width and 1.5 m height with a permanent wall separating the replications to enable root studies. RSA traits i.e., tap root length, root volume and root dry weight were characterized by dismantling the side walls of root structure at 120 DAS. The removed plant was washed very slowly to remove the mud adhering to the roots. In lab, root portion was cut off and characterized. WUE has been evaluated either as extrinsic WUE (µmol CO_2 mmol/1 H_2O) i.e., the ratio of leaf assimilation rate (A or Pn) (µmol CO_2 m^2/s) to leaf transpiration rate (E) (mmol H_2O m^2/s) and intrinsic WUE (µmol CO_2 mmol/1 H_2O) i.e., the leaf-level ratio of photosynthesis (A or Pn) (µmol CO_2 m^2/s) to stomatal conductance (gs) (mmol H_2O m^2/s) (an indication of leaf transpiration), has been widely used to screen for heritable genotypic variation in water use characteristics of crops (Poni *et al.*, 2009; Gilbert *et al.*, 2011). Greening index (SCMR), Specific Leaf Area (SLA) (ratio of leaf area to dry weight and expressed as dm^2/g) were calculated as these are considered as surrogates or alternate approaches to measure WUE. Greening index values were recorded between 8.00 to

9.30 hours with the help of hand held Minolta SPAD chlorophyll meter (Minolta Corp., Ramsey, New Jersey, USA). TDM (shoot and root together) and seed yield from three spike orders were quantified at harvest of crop. Carbon Isotope Discrimination (CID or $\Delta^{13}C$) expressed as per mill (%), also a surrogate of WUE was quantified by feeding leaf samples into Isotope ratio mass spectrometer (IRMS) at the National Facility for Stable Isotopes, University of Agricultural Sciences, Bengaluru. Genotypes which showed least discrimination for isotope values were preferred. The data was statistically analyzed and treatments were compared at 5% significance.

Table 1 List of thirty five castor genotypes utilized in the study

Elite varieties	Germplasm lines	Breeding lines	
Haritha	RG-1	PCS-106	PCS-278
Kiran	RG-1354	PCS-324	PCS-293
Kranthi	RG-1686	PCS-171	PCS-302
	RG-20	PCS-224	PCS-312
	RG-43	PCS-228	PCS-315
	RG-47	PCS-230	PCS-318
	RG-48	PCS-236	PCS-328
	RG-67	PCS-252	SKI-215
		PCS-265	PPL-109
		PCS-320	DCS-78
		PCS-330	DPC-9
		M-574	JP-65

It is postulated that genetic improvement in WUE could lead to improved yield under limited water conditions. Physiological traits like greening index, SLA and CID values were correlated with WUE and these traits could be used as surrogates in selection of high WUE types (Chuni Lal *et al.,* 2006). Castor, on the contrary, displays high photosynthetic capacity under humid conditions and responds favourably to high temperature, high light and high CO_2 concentrations, which is sustained by high chlorophyll, soluble protein and Rubisco content (Dai *et al.,* 1992). However, measurement of stomatal conductance by porometer compared to gravimetric methods showed several drawbacks as it depended on choosing a leaf, time of sampling and throughput (Vadez *et al.,* 2013). Selection of crop species with enhanced rates of photosynthetic CO_2 fixation by conventional breeding programmes, enable increased crop biomass by enhancing photosynthesis. Castor genotypes showed rate of photosynthesis values that ranged from 13.1 to 21.6 µmol $CO_2/m^2/s$ and stomatal conductance of 0.521to 0.647 mmol $H_2O/m^2/s$. Castor genotype PCS-320 recorded maximum extrinsic WUE (16.76 µmol/CO_2/mmol H_2O) followed by RG-67, JP-65, M-574 and Kiran (12.69 to 10.57) which were on par. Five genotypes *viz.,* PCS-320, PPL-109, M-574, PCS-265 and PCS-106 recorded superior intrinsic WUE (53.3 to 47.9 µmol/CO_2/mmol H_2O). Kranthi recorded minimum values (Table 2).

Greening index has been suggested to be used as a rapid and reliable measure to identify genotypes with low SLA. Genotypes with low SLA showed thick, small, green leaves also an indication of high greening index. Low SLA and high greening index traits are suggested to be used in screening of genotypes for drought tolerance and high yield (Udaya Kumar *et al.,* 2002). Seven genotypes recorded high greening index values and included Kranthi (54), RG-47 (54), Haritha (53), PCS-230 (50), SKI-215 (49), RG-48 (47) and PCS-278 (47). Six of these genotypes recorded low SLA that ranged between 2.29 to 2.68 dm^2/g (Table 2).

PCS-330 showed significantly lower $\Delta^{13}C$ values (17.49%) followed by Kranthi (17.88%), PCS-230 (17.94%) and PCS-265 (18.01%). These four genotypes which showed less discrimination are considered to have high WUE. Among these, Kranthi and PCS 230 showed low SLA and high greening index.

RSA traits have been very difficult to pinpoint because of lack of accurate phenotyping methods, poor mathematical descriptions and strong G x E interactions. Five genotypes (SKI-215, RG-48, Kranthi, Haritha and PCS-328) recorded longer tap root lengths (219-234 cm). PCS-320 recorded a minimum of 61 cm. Maximum root volume was recorded in nine genotypes *viz.,* SKI-215, Kranthi, RG-48, Haritha, RG-47, PCS-324, PCS-171, PPL-109, RG-1686 which were on par (244 to 276 cm^3). Minimum root volume was recorded in M-574 (20 cm^3). Root volume increased by 124.8% along with root length at higher CO_2 level under drought stress that resulted in superior WUE (Vanaja *et al*., 2008).

The ability of a plant to exploit nutrients and moisture via improved root volume and root length are well known to contribute to increased dry matter production and grain yield. Seven genotypes *viz.,* Kranthi, RG-48, Haritha, SKI-215, PCS-328, RG-47 and PCS-324 recorded maximum dry matter production (324.6 to 354.5g). RSA traits like root length, root volume, root dry weight showed strong positive correlation with TDM and hence the genotypes with better root characters and TDM are considered as best castor lines for WUE and root characters (Lakshmamma *et al.,* 2010a).

Seed yield/plant was high in Kranthi (163 g) and was on par with RG-48 (149 g), Haritha (141 g) and SKI-215 (129 g). These genotypes recorded other superior characters like high TDM, greening index, low SLA, low CID values (Table 2). Minimum seed yield was recorded in RG-1 (46 g). High pod yield coupled with high WUE and which showed significant positive relationship with total dry matter productivity has been reported in castor (Lakshmamma *et al.,* 2010b). In the present study eight characters *viz.,* greening index (>49), SLA (<2.64 dm^2/g), TDM (>314.5 g), root length (>192.6 cm), root volume (>249 cm^3), extrinsic WUE (>8 µmol CO_2/mmol H_2O), intrinsic WUE (>45 µmol CO_2/mmol H_2O) and CID (<18.01 ‰) have been considered

for selection of genotypes with superior WUE traits combined with seed yield. Six genotypes showed at least two superior characters. Genotypes with superior characters included PCS-171 with high taproot length, root volume, seed yield; RG-48 with high taproot, root volume, greening index, low SLA, total dry matter, seed yield and SKI-215 with high tap root, root volume, greening index, total dry matter and seed yield (Table 3).

From these studies, it is concluded that genotypes vary with respect to the characters or traits that contribute to their superior performance. Two elite varieties (Kranthi, Haritha), one germplasm line (RG-48) and three advanced breeding lines (PCS-171, PCS-230 and SKI-215) showed four to seven superior shoot and root traits combined with high seed yield have been proposed as best WUE genotypes. RG-48, PCS-171 and SKI-215 with superior plant characters could be used in trait based breeding approaches for crop improvement.

Table 2 WUE and root traits and their contribution to seed yield in castor genotypes

Genotypes	Extrinsic WUE µmol CO^2/mmol H_2O (A E-1)	Intrinsic WUE µmol CO_2/mmol H_2O (A/gs)	Greening index	SLA (dm^2/g)	$\Delta^{13}C$ (%)	Taproot length (cm)	Root volume (cm^3)	TDM (g/ plant)	Seed yield (g/plant)
PCS-324	5.79	38.1	45	3.18	18.11	213	234	324.6	105
DCS-78	3.45	43.6	45	4.76	18.51	86	71	172.5	90
DPC-9	3.54	38.5	43	3.34	19.11	144	200	162.8	69
Haritha	3.87	43.9	53	2.29	19.22	223	259	344.3	141
JP-65	11.45	42.8	38	4.81	18.94	99	88	137.5	71
Kiran	10.57	38.1	41	2.68	18.99	109	99	146.2	104
Kranthi	2.63	36.1	54	2.16	17.88	225	268	354.5	163
M-574	11.94	48.6	39	3.94	19.37	71	20	100.8	59
PCS-106	9.75	47.9	41	5.23	18.28	172	45	227.2	58
PCS-171	8.06	40.1	44	4.44	18.58	201	249	257.4	102
PCS-224	8.37	42.3	44	3.53	18.25	76	67	294.3	57
PCS-228	8.02	42.9	42	3.38	18.45	168	205	80.2	61
PCS-230	3.25	45.6	50	2.64	17.94	92	53	314.5	61
PCS-236	7.06	42.3	41	2.78	19.21	82	165	118.6	57
PCS-252	6.22	43.2	39	5.16	18.94	148	146	261.3	88
PCS-265	6.17	48.3	39	4.95	18.01	185	176	104.5	75
PCS-320	16.76	53.3	45	4.24	19.15	61	158	213.2	60
PCS-278	6.39	44.2	47	2.43	19.48	92	106	300.9	60
PCS-293	5.08	39.2	41	5.31	19.52	163	79	285.2	59
PCS-302	5.47	45.2	44	3.72	19.65	135	193	196.7	71
PCS-312	4.93	40.9	42	3.11	19.61	190	133	237.4	94
PCS-315	4.93	48.2	44	3.64	19.21	67	241	93.4	61
PCS-318	4.18	43.6	39	5.04	19.25	121	34	317.5	75
PCS-328	4.32	42.2	41	2.94	18.31	219	110	332.6	106
PCS-330	3.98	42.7	41	4.18	17.49	115	241	276.4	51
PPL-109	4.35	48.6	45	4.61	18.62	196	245	246.8	90
RG-1	3.52	43.3	37	4.35	18.42	127	120	184.2	46
RG-1354	3.74	42.6	42	2.99	18.53	152	211	157.4	59
RG-1686	3.52	42.2	46	4.57	18.82	156	244	302.75	59
RG-20	3.92	41.7	45	4.07	19.15	132	128	207.6	79
RG-43	3.77	42.5	45	3.84	18.21	181	222	200.4	86
RG-47	3.44	45.1	54	2.38	18.74	208	255	328.9	63
RG-48	4.07	45.5	47	2.47	18.73	228	263	349.7	149
RG-67	12.69	39.5	41	2.86	19.22	168	268	127.4	52
SKI-215	3.52	43.1	49	2.58	19.13	234	276	338.7	129
SEm ±	0.83	2.59	2.53	0.165	--	14.36	11.65	16.81	0.28
CD (P=0.05)	2.42	7.51	7.31	0.478	--	41.47	33.64	48.53	0.57

Table 3 Castor genotypes with better root and shoot characters

Character	Value	Superior genotypes
Extrinsic WUE (A E^{-1})	>8	PCS-320, RG-67, JP-65, M-574 and Kiran
Intrinsic WUE (A g_{s-}^{1})	>45	PCS-320, PPL-109, M-574, PCS-265 and PCS-106
Greening index	>49	RG-48, Kranthi, PCS-230, SKI-215 and Haritha
Low specific leaf area (dm^{-2} g)	< 2.64	RG-48, Kranthi, PCS-230, SKI-215 and Haritha
^{13}C (‰)	<18.01	PCS-330, Kranthi, PCS-230 and PCS-265
High tap root length (cm)	>192.6	PCS-324, Haritha , Kranthi, PCS-171, PCS- 328, PPL-109, RG-47, RG-48 and SKI-215
High root volume (cm^3)	>249	RG-48, Kranthi, SKI-215, Haritha and PCS-171
High total dry matter (g/plant)	>314.5	Kranthi, RG-48, Haritha, SKI-215, PCS-328, RG-47 and PCS-324
Seed yield (g/plant)	>102	RG-48, Kranthi, SKI-215, Haritha, Kiran and PCS-171

ACKNOWLEDGEMENT

Authors sincerely acknowledge the financial support provided to carry out the present work under the UGC, MRP, New Delhi, No. 40-40/2011 (SR) with the corresponding author.

REFERENCES

Chuni Lal, Hariprasanna K, Rathnakumar A L, Gor H K and Chikani B M 2006. Gene action for surrogate traits of water-use efficiency and harvest index in peanut (*Arachis hypogaea*). *Annals of Applied Biology*, **148**: 165-172.

Dai Z G, Edwards E, Maurice S and Ku B 1992. Control of photosynthesis and stomatal conductance in *Ricinus communis* L. (castor bean) by leaf to air vapor pressure deficit. *Plant Physiology*, **99**: 1426-1434.

Gilbert M E, Maciej A Z and Holbrook M N 2011. Independent variation in photosynthetic capacity and stomatal conductance leads to differences in intrinsic water use efficiency in 11 soybean genotypes before and during mild drought. *Journal of Experimental Botany*, **62**: 2875-2887.

Lakshmamma P, Lakshmi P and Prabhakara R N 2010a. Traits related to water use efficiency in castor (*Ricinus communis* L.). *Journal of Oilseeds Research*, **27**: 220-222.

Lakshmamma P, Lakshmi P and Sarada C 2010b. Evaluation of castor (*Ricinus communis*) germplasm for water use efficiency (WUE) and root characters. *Indian Journal of Plant Genetic Resources*, **23**: 276-279.

Poni S, Fabio B, Silvia C, Matteo G, Duilio P and Federica C 2009. Performance and water-use efficiency (single-leaf vs. whole-canopy) of well-watered and half-stressed split-root *Lambrusco grapevines* grown in Po Valley (Italy). *Agriculture Ecosystem and Environment*, **129**: 97-106.

Udaya Kumar M, Madhura J N, Aarati P and Srikanth B V 2002. Increasing drought resistance in some oilseed crops - options and approaches. *In: Oilseeds and Oils Research and Development Needs.* M Rai, Singh H and Hedge D M (Eds.), Indian Society of Oilseeds Research, Rajendranagar, Hyderabad. pp. 286-314.

Vadez V, Rao J S, Bhatnagar-Mathur P and Sharma K K 2013. DREB1A promotes root development in deep soil layers and increases water extraction under water stress in groundnut. *Plant Biology*, **15**: 45-52.

Vanaja M, Jyothi M, Ratnakumar P, Vagheera P, Raghuram Reddy P and Jyothi Lakshmi N 2008. Growth and yield responses of castor bean (*Ricinus communis* L.) to enhanced CO_2 levels. *Plant Soil and Environment*, **54**: 38-46.

Influence of biocontrol agents and fungicides on vegetative parameters of groundnut (*Arachis hypogaea* L.) under greenhouse conditions

S AMEER BASHA, G RAGHAVENDRA, A V RAMANJANEYULU AND A SRINIVAS

RARS, Prof. Jayasankar Telangana State Agricultural University, Palem-509 215, Telangana State

(Received: March 16, 2015; Revised: February 20, 2016; Accepted: February 22, 2016)

ABSTRACT

In the present study the compatibility of various plant growth promoting organisms [*Pseudomonas fluorescens* (Pf), *Trichoderma viride* (Tv) and *Rhizobium* (Rhi)] along with fungicides (mancozeb, tebuconazole and carbendazim + mancozeb) was tested on groundnut crop (cv. K-6) variety under greenhouse conditions. At 45 days after sowing (DAS), maximum (109) number of root nodules was observed in plants treated with combination of biocontrol agents *Pf, Tv* and *Rhi.* Maximum (1314.7 mm) root length was observed in *Pf* and *Rhi* combination while root area was recorded to be maximum (1341.8 mm^2) in *Rhi* treatment. Root diameter (3.7 mm), root hairs (79.5) and chlorophyll content (51.7) were significant in *Pf* and *Rhi* combination. At 90 DAS, boosting effect on root nodules with maximum number (111) was seen in seeds treated with combination of biocontrol agents *Pf, Tv* and *Rhi.* Root length was prominent (1775.5 mm) in *Tv* treated plants whereas root area was maximum (1865.6 mm^2) in *Pf* and *Rhi* combination. Maximum root diameter (4.8 mm) was found in *Pf* and *Rhi* combination whereas *Pf, Tv* and *Rhi* combination showed significant (108.5) root hair number. *Pf* treated plants showed remarkable (60.3) chlorophyll content compared to other treatments. The study showed increase in overall growth parameters in biocontrol agents treated plants followed by fungicides.

Keywords: Compatibility, Fungicides, Groundnut, *P. fluorescens, Rhizobium, T. viride*

Groundnut (*Arachis hypogaea* L.) is one of the major crops grown worldwide as a source of oil and protein. Though lot of research work has been carried out on impact of inputs factors (seed, fertilizer, plant protection chemicals and irrigation) which are influencing production and productivity of groundnut, but the information on cost effective input factors like plant growth promoting rhizobacteria (PGPR) is scanty. PGPR are the group of microorganisms that live in rhizospheric soil and enhances plant growth by different mechanisms (Ameer *et al.,* 2006) which include production of phytohormones against phytopathogenic microorganisms, siderophores (Sarma *et al.,* 2007) and the synthesis of antibiotics, enzymes and antimicrobial compounds (Sajeli *et al.,* 2014). Among PGPR, *Pf* and *Rhi* species are important because of their ability to colonize root system efficiently and nitrogen fixing capability, respectively. Use of biocontrol agents like *Trichoderma viride* (*Tv*) is gaining importance because of their dual activity *viz.,* biocontrol activity and plant growth promotion. *Tv* can promote plant growth in many crops by colonizing root surface and cortex (Poldma *et al.,* 2000) and also improve productivity (Harman *et al.,* 2004). Fungicides are being used for various purposes like seed treatment and control of different soil borne diseases as compared to insecticides and other agrochemicals. Information on compatibility among PGPR, bio-control agents and fungicides is utmost important to have synergistic effect on crop growth and development. Hence, study was conducted to know the compatibility among biocontrol agents and fungicides and their effect on growth parameters of groundnut crop.

Email: ameer_sajeli786@yahoo.co.in

Soil sample from rhizosphere of groundnut crop was collected from farmers field of Gundoor village of Mahabubnagar District, Telangana State, India. Healthy plants were selected, uprooted and the roots with enclosed soil were placed in plastic bags and stored at 4°C. To isolate *Pf* strain from the soil sample, 10 g of soil/plant was mixed with 90 mL of sterile distilled water. Serial dilution (10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5} and 10^{-6}) was made, around 0.1 mL from each dilution was spread on Kings 'B' media (KB) plate using L-shaped glass rod and incubated at 25°C for 24 hours. After development of colonies, plates were viewed under UV transilluminator and fluorescent *Pf* colonies were identified and picked. The colony was transferred on to KB agar plate for further purification and transferred on to KB slant and stored at refrigeration temperature for further use.

Rhizobium strain was isolated from nodules of groundnut collected from farmers fields of Vattem village of Mahabubnagar District, Telangana State, India during the year 2011. Active nodules were selected and surface sterilized with 3% hypochlorite solution followed by rinsing five times with sterile distilled water. Nodules were dissected with sterile glass rod and were transferred on to yeast extract mannitol agar (YEMA) plates. Isolate was purified and

transferred on to YEMA agar slants and stored at 4°C for further use.

Trichoderma viride (*Tv*) was isolated from soil samples collected from the fields of Regional Agricultural Research Station (RARS), Palem, Mahabubnagar District, Telangana State, India. Serial dilution (10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5} and 10^{-6}) of the samples was made and spread on already prepared Potato Dextrose Agar (PDA) plates and then incubated at 25 ± 2°C for 4 days. The green conidia forming fungal bodies were selected, observed under microscope and transferred on to PDA medium and incubated at 26°C for 7-8 days. The culture was transferred on to PDA slants and maintained 4°C for further use.

Pf and *Rhi* strains were screened for their sensitivity towards commercially used fungicides by disc-diffusion method. Solutions of different fungicides (mancozeb, carbendazim + mancozeb, tebuconazole) were prepared at 1-4 % w/v concentrations. Filter paper discs (5 mm diameter) were made by adding four different concentrations of prepared stock solutions to evaluate the concentrations equivalent to, above and below the recommended dose of test fungicides. A 100 L of individual bacterial culture (10^7 cells/mL harvested at early logarithmic growth) was spread on KB agar plates with sterile glass spreader aseptically. These discs were placed at equidistance on the agar surface in duplicate after drying. Plate with filter paper disc dipped in sterile distilled water was used as control. The plates were incubated for one day at 28 ± 2º C and observed for growth around filter paper disc.

Tv was screened for its sensitivity towards the fungicides by poisoned food technique. Recommended doses of fungicides were dissolved in 100ml of Potato Dextrose Agar (PDA) medium and poured in 9cm Petri-plate. Media was allowed to solidify and mycelial block of 3mm diameter was removed from 7-day old *Tv* culture and placed in inverted position on PDA and incubated at 25°C for 4-days. PDA plate with media alone was used as control.

Pf and *Rhi* strains were tested against *Tv* grown in Petri dishes containing PDA medium in dual culture plate technique. The test bacterial strains were streaked at a distance of 5 cm from the agar discs (5 mm in diameter) of *Tv* in square shape. The culture plates were sealed with plastic wrap and later the plates were incubated for eight days at 28º C.

Pot experiment was conducted at RARS, Palem during 2013 using kadiri-6 (K-6) groundnut variety. Soil was brought in to the laboratory and autoclaved in the containers at 121°C for 30 minutes. Autoclaved sterile soil was filled in the pots (38 x 30 cm) in randomized block design with three replications. A total of ten treatments were imposed along with an un-inoculated control. Treatments used were as follows T_1- uninoculated control, T_2 - *Tv* (10g/kg seed), T_3- *Pf* (10g/kg seed), T_4-*Rhi* (10g/kg seed), T_5- *Tv* + *Pf* (10g/kg seed), T_6- *Tv* + *Pf* + *Rh* (10g/kg seed), T_7-Mancozeb @ 3g/kg of seed, T_8- *Pf* + *Rhi* @ 10g/kg of seed, T_9-Tebuconazole @ 1g/kg of seed, T_{10}- Saff (Mancozeb + Carbendizam) @ 3g/kg seed with *Pf* (10 g/kg of seed). Four seeds per treatment per replication/pot were sown after 12 hours of respective treatments. The parameters like number of root nodules per plant, root length, root area, root diameter, root hairs, chlorophyll content and dry weight of root and plant were recorded twice at 45 and 90 DAS. Root characteristics were recorded using Delta-T scan device (Delta - T scan complete test and recalibration reference target set type CTS) and leaf chlorophyll content was recorded using SPAD chlorophyll meter (Nigam and Aruna, 2008). The average number of root nodules per plant, dry weight of root and plant were recorded manually. Data was analyzed using OPISTAT WIN software.

A perusal of data in Table 1 indicated the compatibility of *Pf*, *Tv*, *Rhi* strains and fungicides (mancozeb, carbendazim+ mancozeb, tebuconazole) tested in the experiment. Improvement in all the parameters like root length, root area, root diameter, number of root hairs, chlorophyll content, dry matter of roots as well as total plant was witnessed when crop progressed from 45 to 90 DAS.

At 45 DAS, significantly more number of root nodules (109.0) were observed when seeds were treated with combination of biocontrol agents (*Pf, Tv* and *Rhi*) irrespective of crop growth stage. The trend was similar at 90 DAS with maximum root nodules (111.0) recorded in the above combination. Longer roots were observed when seed treatment was done with either combination of *Pf* and *Rhi* or *Rhi* alone at 45 DAS. However, at 90 DAS, seed treatment with *Tv* alone (1775.5 mm) enabled plants to produce significantly longer roots and was at par with that of mancozeb (1634.8 mm), tebuconazole (1628.4 mm), *Rhi* (1380.9 mm), *Pf* (1339.7 mm), *Pf* + *Rhi* (1316.0 mm) and *Tv* + *Pf* + *Rhi* (1239.4 mm). On the other hand, *Pf* + *Tv* (1036.0 mm), and carbendazim + mancozeb + *Pf* (864.2 mm) treatments were found to be significantly inferior to rest of the treatments. This studies was supported by earlier reports by Chet *et al.* (1997) which showed considerable increase in the yield of plants when treated with spores from *Tv*. The improvement of plant resistance towards various diseases by *Tv* can be attributed to the multiple mechanisms involved (Podile and Kishore, 2002).

Though significantly more root area has been recorded with *Rhi* treatment (1341.8 mm^2), it was at par with that of *Pf*+*Rhi* (1318.3 mm^2), tebuconazole (1294.3 mm^2) and *Tv* + *Pf* + *Rhi* (1007 mm^2) at 45 DAS. While at 90 DAS, *Pf* + *Rhi* treatment (1865.6 mm^2) was significantly superior to other treatments barring *Rhi* (1842.4 mm^2), *Tv* (1421.1 mm^2), tebuconazole (1414.1 mm^2) and mancozeb (1385.4 mm^2). No significant outcome in root diameter was recorded at 45 days. Seed treatment with *Pf* + *Rhi* (4.8) being at par with tebuconazole (4.6) and *Tv* + *Pf* + *Rhi* (4.2) was found to be significantly superior to all other treatments in respect of root diameter at 90 DAS.

Table 1 Compatibility of *Pf, Rhizobium, T.viride* and fungicide under *in vitro* condition

Treatments	*Pf*	*Rhi*	Tv	Mancozeb	Carbendazim + Mancozeb	Tebuconazole
Pf	+	+	+	+	+	+
Rhi	+	+	+	+	+	+
Tv	+	+	+	+	+	+
Mancozeb	+	+	+	+	+	+
Carbendazim + Mancozeb	+	+	+	+	+	+
Tebuconazole	+	+	+	+	+	+

Table 2 Effect of plant growth promoting rhizobacteria and fungicides on growth parameters of groundnut (K-6)

Treatment	Average no. of root nodules		Root length (mm)		Root area (mm^2)		Root diameter (mm)		No. of root hairs		Chlorophyll content		Dry weight plant (g)		Dry weight root (g)	
	45	90	45	90	45	90	45	90	45	90	45	90	45	90	45	90
Control	48.0	49.0	294.6	883	547.8	921.6	2.7	3.2	12.3	91.5	47.9	50.7	9	36.5	3	4.0
Tv	47.0	47.0	494.6	1775.5	765.3	1421.1	2.8	4.0	35.5	91.0	48.1	54.7	11	22.5	3.5	4.5
Pf	67.0	68.0	663.8	1339.7	880.1	1224.6	3.0	3.8	26.5	95.0	50.3	60.3	10.5	17.0	3	5.0
Rhi	79.0	79.0	1182.5	1380.9	1341.8	1842.4	2.3	3.7	65.0	74.0	49.8	55.1	10.5	41.0	3.5	4.5
Tv and *Pf*	76.0	77.0	643.1	1036.0	927.8	1218.7	2.9	3.0	41.3	62.5	50.9	54.8	9.5	29.0	3.5	4.0
Tv+*Pf*+Rhi	109.0	111.0	551.5	1239.4	1007.0	1161.9	2.9	4.2	33.0	108.5	47.4	54.2	10	14.0	3.5	4.5
Mancozeb	49.0	49.0	346.7	1634.8	652.2	1385.4	2.8	3.3	20.0	106.0	48	53.7	9	12.5	3.5	5.5
Pf + *Rhi*	87.5	87.5	1314.7	1316.0	1318.3	1865.6	3.7	4.8	79.5	96.0	51.7	53.7	11.5	23.0	3.5	4.5
Tebuconazole	60.0	62.0	731.3	1628.4	1294.3	1414.1	3.1	4.6	44.8	84.5	46.7	57.7	10.5	34.0	3.5	3.5
Carbendazim+ Manzobeb +*Pf*	67.0	68.0	583.8	864.2	782	861.5	2.8	3.5	28.8	63.0	49	56.5	8.5	42.0	3	3.0
SEm	2.975	3.314	105.639	164.804	136.874	159.171	0.250	0.260	4.894	10.119	0.440	1.120	0.859	3.468	0.204	0.412
CD at 1%	8.907	9.382	316.300	493.451	409.826	476.586	N.S.	0.779	14.655	30.297	1.317	3.353	N.S.	10.384	N.S.	1.233
CV (%)	7.473	7.781	26.882	21.794	24.912	20.703	14.912	12.009	21.933	20.933	1.556	3.519	14.870	22.124	10.554	16.645

Number of root hairs produced was significantly higher due to seed treatment with either combination of *Pf* and *Rhi* (79.5) or *Rhi* (65) alone as compared to rest of the treatments under test at 45 DAS. On the other hand, at 90 DAS combination of *Tv* + *Pf* + *Rhi* (108.5) when used for seed treatment produced significantly more root hairs. However, it was at par with that of mancozeb (106), *Pf* + *Rhi* (96), *Pf* (95), *Tv* (91), tebuconazole (84.5) and control (91.5).

When *Pf* was used alone (50.3) or along with *Rhi* (51.7) or *Tv* (50.9) produced plants with statistically same chlorophyll content and were significantly superior to other treatments at 45 DAS. *Pf* (60.3) which was at par with tebuconazole (57.7) was found to be significantly superior to others with regard to chlorophyll content at 90 DAS. Similar results of *Pf* influence on chlorophyll content were reported by Songsri *et al.* (2009).

Treatments did not differ significantly from each other at 45 DAS in respect of dry matter of roots or total plant at 45 DAS. However, significant differences were observed at 90 DAS. Seed treatment with carbendazim+mancozeb+*Pf* (42.0) resulted in significantly higher plant dry matter production over rest of the treatments baring tebuconazole (34.0), *Rhi* (41.0). *Tv* (4.5), *Rhi* (4.5) and *Pf* (5.0) either alone or in different combinations of three or seed treatment with mancozeb alone resulted in significantly higher root dry matter at 90 DAS as compared to rest of the treatments (Table 2). Many workers had reported on growth promotion activity of *Pf, Tv* and their combinations in different crops (Ganesan and Sekar, 2012; Meena and Marimuthu, 2012; Ramesh and Korikanthimath, 2006; Manjula *et al.,* 2004).

Increased seed germination ratio with fungicidal seed treatment in groundnut has been reported by Akgul *et al.* (2011). Ezzahiri and Khattabi (2001) observed that application of tebuconazole lead to increase in the plant growth. Mc Lean *et al.* (2001) in their investigations found that groundnut co-inoculated with mancozeb and *Tv* showed good productivity. The above results conclude that good plant growth promoting activity was observed in combination of biocontrol agents (*Pf*, *Tv* and *Rhi*). Some of fungicides also showed plant growth promoting activity but next only to combinations of biocontrol agents (*Pf* and *Tv*) and biofertilizer (*Rhi*). The present study is an initiative and it helps in understanding and employing *Pf, Tv* and *Rhi* as biocontrol agents and plant growth promoters that helps in increasing vigor of plant.

REFERENCES

Akgul D K, Ozgonen H and Ali Erkilic 2011. The effect of seed treatment with fungicides on stem rot caused by *Sclerotium rolfsii* in peanut. *Pakisthan Journal of Botany*, **43**(6): 2991-2996.

Ameer B S, Sarma B K, Singh D P, Annapurna K and Singh U P 2006. Differential methods of inoculation with PGPR induce synthesis of phenylalanine ammonia lyase and phenolic compounds differentially in chickpea (*Cicer arietinum*). *Folia Microbiology*, **51**(5): 463-468.

Chet I, Inbar J and Hadar I 1997. Fungal antagonists and mycoparasites. *In*: Wicklow D T and Soderström B (Eds.), *The Mycota IV: Environmental and Microbial Relationships,* Springer-Verlag, Berlin, pp. 165-184.

Ezzahiri B and Khattabi 2004. Sclerotiumin the Doukkala, Marocco Region: Present Situation and Control Techniques. 67th IIRB Congress, Bruxelles, Belgium.

Ganesan S and Sekar R 2012. *Fluorescent Pseudomonas* as plant growth promoting *Rhizobacteria* and biocontrol agents in groundnut crop (*Arachis hypogaea* L.). *International Journal of Applied Bio Research*, **12**: 1-6.

Harman G E, Howell C R, Viterbo A, Chet I and Lorito M. 2004. *Trichoderma* species - opportunistic, avirulent plant symbionts. *Natural Review of Microbiology*, **2**: 43-56.

Manjula K, Krishna Kishore G, Girish A G and Singh S D 2004. Combined application of *Pseudomonas fluorescens* and *Trichoderma viride* has an improved biocontrol activity against stem rot in groundnut. *Plant Pathology Journal*, **20**(1): 75-80.

Mc Lean, Hunt J and Stewart A 2001. Comparison of biocontrol agent *Trichoderma harzianum* C52 with selected fungicides. *New Zealand Plant Protection*, **54**: 84-88.

Meena B and Marimuthu T 2012. Effect of application methods of *Pseudomonas fluorescens* for the late leaf spot of groundnut management. *Journal of Biopesticide*, **5**(1): 14-17.

Nigam S N and Aruna R 2008. Stability of soil plant analytical development (SPAD) chlorophyll meter reading (SCMR) and specific leaf area (SLA) and their association across varying soil moisture stress conditions in groundnut (*Arachish ypogaea* L.). *Euphytica*, **160**(1): 111-117.

Podile A R and Kishore G K 2002.Biological control of peanut diseases. *In:* Gnanamanickam S and Marcel Dekker (Eds.), *Biological Control of Crop Diseases*, New York, pp.131-160.

Poldma P, Jaaksor K, Merivve A and Albrecht A 2000. *Trichoderma viride* promotes growth of cucumber plant. *In*: *Proceeding of the International Conference on Development of Environmental Friendly Protection in the Baltic Region*. Transactions of Estonia Agricultural University 209, Estonia supplement, pp. 28-29.

Ramesh R and Korikanthimath V S 2006. Management of groundnut root rot by *Trichoderma viridae* and *Pseudomonas fluorescens* under rainfed condition. *Indian Journal of Plant Production*, **34**(2): 239-241.

Sajeli A B, Basha S A, Raghavendra G, Kumar M N, Singh Y, Patil J V, Tanemura Y and Fujimoto Y 2014. Isolation and biochemical characterization of antimicrobial cyclic dipeptides from *Pseudomonas fluorescens* and their efficacy on sorghum grain mold fungi. *Chemistry and Biodiversity*, **11**: 92-100.

Sarma B K, Ameer Basha S, Singh D P and Singh U P 2007. An alternative approach to protecting chickpea (*Cicer arietinum*) from stem rot caused by *Sclerotinia sclerotiorum. Crop Protection*, **26**: 1042-1048.

Songsri P S, Jogloy C, Holbrook T, Kesmala N, Vorasoot C, Akkasaeng A and Patanothai 2009. Association of root, specific leaf area and SPAD chlorophyll meter reading to water use efficiency of peanut under different available soil water. *Agricultural Water Management*, **96**: 790-798.

Laboratory evaluation of medicinal plant extracts against *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae)

P MANJU*, K KUMAR[1], V GOPAL AND PRAKASH YOGANANDAM

Mother Theresa Post Graduate Research Institute of Health Sciences, Puducherry-605 006, Puducherry UT

(Received: February 8, 2016; Revised: February 20, 2016; Accepted: March 2, 2016)

ABSTRACT

Pesticidal activity of selected six medicinal plant extracts using acetone and methanol were evaluated against third instar larvae of *Spodoptera litura* at 250, 500, 750 and 1000 ppm concentrations under laboratory condition. Results indicated that methanolic extracts found to be superior to acetone extracts. Lower LD_{50} values ranging from 223.5 to 313.4 ppm was observed for *Melia azedarach, Pongamia pinnata* and *Murraya koengi* resulted in higher mortality of *S. litura* (75.6 to 94.5%).

Keywords: Medicinal plants, Pesticidal activity, *Spodoptera litura*

The tobacco caterpillar, *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae), is one of the most important insect pests of agricultural crops in the Asian tropics. It is a polyphagous and most destructive pest and has about 150 host species causing heavy economic loss every year (Venkataiah *et al.,* 2015; Rao *et al.,* 1993). Out of 150 globally recorded host plants of *S. litura,* 60 are known only from India. The young larvae of *S. litura* voraciously feed on leaves, less or more completely defoliating the plants making insecticidal application mandatory for the cultivation of various crops (Choudhary *et al.,* 2014), in particular, oilseed crops *viz.,* soybean, groundnut, castor and sunflower.

Application of chemical pesticides was done to overcome the *S. litura* problem. But, insect resistance, residue contamination of human foods, mammalian toxicity and pollution to the environment were caused by the application of the pesticides (Khanna *et al.,* 2011). In order to overcome these undesirable problems, numerous secondary compounds from plants are being studied as ecofriendly bio-pesticide. Hence, the present study was conducted to evaluate the pesticidal activity of six medicinal plants using methanol and acetone extracts against the cut worm, *Spodoptera litura.*

A bioassay experiment was conducted by following range finding test to screen for pesticidal activity of various medicinal plants against *S. litura* at Department of Entomology in Pandit Jawaharlal Nehru College of Agriculture & Research Institute, Karaikal during January to June, 2015. The field collected egg masses of *S. litura* were used to initiate the mass culturing under laboratory conditions. The egg masses were kept in the egg cage. After emergence, first instar larvae were transferred to the castor leaves. The newly emerged larvae when settled on the leaves, the leaves were taken and kept in the conical flask containing water. Five day old larvae were transferred to plastic buckets with castor leaves kept in conical flask containing water at the rate of 25 larvae/bucket. The leaves were changed and the faecal pellets removed from the container for every 24hours. The grown up larvae were allowed to pupate in soil. Moths was collected on emergence and released in oviposition cage for egg laying (Govindan *et al.,* 2010).

Leaves of *Adhatoda vasica.* L. (Acanthaceae), *Calotropis gigantea* L. (Asclepiadaceae), *Melia azedarach* Cav. (Meliaceae), *Murraya koenigii* L. (Rutaceae), *Pongamia pinnata* L. (Fabaceae) and *Vitex negundo* L. (Verbenaceae) were collected from various parts of Karaikal, Union territory of Puducherry, India during 2014. Fresh leaves of plant samples were shade dried and ground into uniform powder. Dry powder of each plant sample was extracted with the organic solvents *viz.,* acetone and methanol using soxhlet apparatus for 8 hours. Fresh extracts were prepared as and when required for the study.

Experiment consists of graded concentrations of medicinal plant extracts *viz.,* 250, 500, 750 and 1000 ppm and was tested against the third instar larvae of *S. litura* on different medicinal plant extracts for the duration of 72 hour period by leaf disc bioassay method. Castor leaf of 6 cm diameter discs were used in the leaf dipping method. These leaf discs were kept individually in glass Petri dishes after air drying. Pre-starved third instar larvae were released at 30 numbers with ten larvae in each Petri plate and the experiment was replicated three times. Observations were made for 72 hours and results were recorded and subjected to Finney's method of probit analysis and LD_{50} were determined. Critical difference values were calculated at 5

[1]Department of Agricultural Entomology, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal- 609 603, Puducherry UT; *E-mail:cogonman@gmail.com

per cent probability level and the treatment mean values of the experiments were compared using Duncan's Multiple Range Test (DMRT).

Results of the present study indicated that the percentage mortality of *S. litura* at 250, 500, 750 and 1000 ppm ranged from 0.0 to 44.4, 0.0 to 62.2, 0.0 to 77.8 and 0.0 to 94.5 per cent, respectively (Table 1). It was interesting to note that there was no significant difference in the percentage mortality of *S. litura* among the treatments at various concentrations except at 1000 ppm. However, significantly higher percentage mortality was observed in methanol (94.5) and acetone (91.3) extracts of *Melia azedarach.* Presence of limonoids (Carpinella *et al.,* 2003), a tetranortriterpenes in the leaves and seeds of *M. azedarach,* which act as stomach poison, found to cause damage to the midgut epithelium (Al-Mehmadi and Al-Khalef, 2010) and high larval mortalty (Defago *et al.,* 2009). Similar effect was observed for *Hyblaea purea* (Senthilkumar *et al.,* 2012) and *Spodoptera exigua* (Travis and Ken, 2012). *P. pinnata* found to be better biopesticidal source followed by *M. azedarach.* Methanolic extracts of *P. pinnata* showed the maximum growth reduction (Kumar *et al.,* 2006) and higher larval mortality of *S. litura* (Prathibhav *et al.,* 2010). All the earlier findings are in conformity with the present findings.

The probit analysis of medicinal plant extracts against the third instar larvae of *S. litura* are presented in the Table 2. The extracts of medicinal plant species in methanol and acetone were used for the experiments by leaf disc bioassay method. The chi square value ranged from 0.248 to 0.697 irrespective of the treatments in acetone and 0.034 to 3.652 were observed in methanol extracts against the *S. litura.* It was found that chi square value is significant and showed homogeneity.

Table 1 Per cent larval mortality of *Spodoptera litura* at various concentration of medicinal plant extracts

Species	Extract	Per cent larval mortality			
		250 ppm	500 ppm	750 ppm	1000 ppm
Adhatoda vasica	Methanol	22.3±13.5^{a} (23.3)	42.2±21.2^{a} (39.2)	60.0±11.5^{a} (51.1)	64.4±12.4^{ab} (53.9)
	Acetone	24.4±4.4^{a} (29.5)	26.7±3.9^{a} (30.9)	46.7±10.2^{a} (42.9)	57.8±19.8^{b} (49.9)
Calotropis gigantea	Methanol	37.8±5.9^{a} (37.8)	44.4±19.4^{a} (41.4)	57.8±5.9^{a} (49.5)	62.2±21.8^{ab} (53.5)
	Acetone	20.0±3.6^{a} (26.4)	31.1±14.6^{a} (32.9)	44.5±9.7^{a} (41.7)	66.7±3.8^{ab} (54.8)
Melia azedarach	Methanol	40.0±3.6^{a} (39.2)	57.8±19.8^{a} (49.9)	66.7±15.4^{a} (56.3)	94.5±7.7^{a} (79.4)
	Acetone	31.1±13.5^{a} (32.4)	46.7±13.9^{a} (42.8)	73.3±16.8^{a} (60.9)	91.3±4.4^{ab} (74.2)
Murraya koenigii	Methanol	35.5±9.7^{a} (36.2)	53.3±3.9^{a} (46.9)	66.7±13.3^{a} (55.4)	75.6±5.9^{ab} (60.6)
	Acetone	26.7±6.7^{a} (30.8)	42.2±21.2^{a} (35.2)	63.3±17.4^{a} (55.2)	73.3±13.3^{ab} (63.5)
Pongamia pinnata	Methanol	44.4±18.2^{a} (41.6)	62.2±14.6^{a} (52.5)	77.8±12.4^{a} (65.3)	81.1±8.9^{ab} (66.3)
	Acetone	31.1±5.9^{a} (33.7)	37.8±2.2^{a} (37.9)	60.0±25.2^{a} (55.4)	82.3±2.2^{ab} (65.2)
Vitex negundo	Methanol	42.2±17.4^{a} (39.9)	62.2±9.7^{a} (52.4)	68.9±5.9^{a} (56.3)	73.3±6.7^{ab} (59.2)
	Acetone	31.1±11.1^{a} (33.3)	37.8±11.1^{a} (37.7)	40.0±7.7^{a} (39.1)	68.9±9.7^{ab} (56.8)
Control	Distilled water	0.0b (0.8)	0.0b (0.8)	0.0b (0.80)	0.0c (0.8)

Values given in parenthesis are arcsine transformed values. All values are mean ± SD of three replicates of 30 insects in each replicate.
Values followed by the same alphabets are not significantly different at $p<0.05$ (DMRT)

The LD_{50} value of different medicinal plant extracts against the *S. litura* ranged from 223.48 to 482.63 ppm irrespective of the treatments. A lower LD_{50} value was observed in the treatments with *P. pinnata* (223.48 ppm) followed by *V. negundo* (260.10 ppm), *M. koenigii* (283.25 ppm) and *M. azedarach* (313.42 ppm) in methanolic extract. Deepthy *et al.* (2010) observed that methanolic extracts was found to be superior in causing maximum mortality and growth inhibitory action of *S. litura.* In general, LD_{50} value is lower with the methanolic extracts compared to the acetone extracts.

It was concluded that the methanolic extracts of various medicinal plants were found to possess insecticidal and growth inhibition of *S. litura.* In particular, *M. azaderach* followed by *P. pinnata* was proved to be superior in causing higher larval mortality of *S. litura* under controlled condition.

Table 2 Probit analysis of medicinal plant extracts against *Spodoptera litura*

Name of medicinal plant	Extract	*Heterogeneity ($\chi 2$)	Regression Equation	LD_{50} (ppm)
Adhatoda vasica	Methanol	0.457	Y = -3.369 + 1.487 x	423.0
	Acetone	0.353	Y = -7.552 + 2.217 x	458.7
Calotropis gigantean	Methanol	1.096	Y= -2.404 + 1.304 x	474.2
	Acetone	0.353	Y = -7.552 + 2.217 x	458.7
Melia azedarach	Methanol	3.652	Y = -10.093 + 0.2.746 x	313.4
	Acetone	0.248	Y = -11.501 + 2.970 x	356.2
Murraya koenigii	Methanol	0.034	Y = -5.729 + 1.967 x	283.3
	Acetone	0.504	Y = -7.806 + 2.253 x	482.6
Pongamia pinnata	Methanol	0.169	Y = -4.882 + 1.847 x	223.5
	Acetone	0.697	Y = -7.967 + 2.306 x	418.5
Vitex negundo	Methanol	0.624	Y = -2.429 + 1.371 x	260.1
	Acetone	0.634	Y = -7.427 + 2.204 x	435.2

Y=Probit kill; LD50= Concentration to give 50 per cent mortality.*All data were found to be significant at 5% level

REFERENCES

Al-Mehmadi and Al-Khalaf 2010. Larvicidal and histological effects of *Melia azedarach* extract on *Culex quinquefasciatus* Say larvae (Diptera: Culicidae). *Journal of King Saud University (Science)*, **22**: 77-85.

Carpinella M C, Defago M T, Valladares G and Sara P 2003. Antifeedant and insecticide properties of a limonoid from *Melia azedarach* (Meliaceae) with potential use for pest management. *Journal of Agricultural and Food Chemistry*, **51**: 369-374.

Choudhary J S, Srivastava C and Walia S 2014. Screening for antifeedant activity of *Gymnema sylvestris* leaf extracts against *Spodoptera litura* F. (Lepidoptera: Noctuidae). *The Bioscan*, **9**(2): 633-638.

Deepthy K B, Sheela M K, Sosamma J, Estelitta S and Thomas J 2010. Insecticidal and growth inhibitory action of *Vitex negundo* Linn. against Asian army worm, *Spodoptera litura* Fab. *Journal of Biopesticides*, **3**(1): 289-295.

Defago M T, Mangeaud A, Bensovsky V, Trillo C, Carpinella C, Palacios S and Valladares G 2009. *Melia azedarach* extracts: a potential tool for insect pest management. *In: Recent Progress in Medicinal Plants,* Vol. 23, Phytopharmacology and Therapeutic Values, Singh V V K and Govil J N (Eds.), Studium Press LLC, Houston, Texas, pp.17-33.

Govindan K, Gunasekaran K, Kuttalam S and Aiswariya K 2010. Laboratory evaluation of transgenic Bt cotton and non Bt cotton plant parts against third instar larvae of *Spodoptera litura* (Fab.) (Noctuidae: Lepidoptera). *Journal of Biopesticides,* **3**(2): 432-436.

Khanna G V, Kannairan K, Rajakumar G, Rahuman A A and Santoshkumar T 2011. Biolarvicidal compound gymnemagenol isolated from leaf extract of miracle fruit plant, *Gymnema sylvestre* (Retz) Schult against malaria and filariasis vectors. *Parasitology Research*, **109**: 1373-1386.

Kumar V, Chandrasekar K and Sidhu O P 2006. Efficacy of karanjin and different extracts of *Pongamia pinnata* against selected insect pests. *Journal of Entomological Research,* **30**(2): 103-108.

Prathibhav D, Ashok A H and Holihosur S N 2010. Screening of soxhlet extract of *Pongamia pinnata* for insecticidal properties against the polyphagous pest *Spodoptera litura* F. *Asian Journal of Microbiology, Biotechnology & Environmental Sciences*, **12**(2): 347-352.

Rao G V R, Wightman J A and Ranga R D V 1993. World review of the natural enemies and diseases of *Spodoptera litura* (F.) (Lepidoptera: Noctuidae). *Insect Science and its Applications*, **14**: 273-284.

Sentilkumar N, Murugesan S, Vijayalakshmi K B, Monisha M, Suresh Babu D, Lakshmi Devi R and Manivachakam P 2012. Insecticidal properties of certain flora based on ethanobotanical records against teak defoliator, *H. purea* Cramer. *European Journal of Experimental Biology*, **2**(3): 513-519.

Travis L M and Ken M 2012. Evaluation of *Melia azedarach* as a botanical pesticide against beet armyworm (*Spodoptera exigua*). *ARPN Journal of Agricultural and Biological Science*, **7**(11): 962-967.

Venkataiah M, Anil Kumar B and Sreedhar Chauhan 2015. Efficacy of newer insecticides against *Spodoptera litura* in groundnut (*Arachis hypogaea* L.). *Journal of Oilseeds Research*, **32**(2): 152-154.

OBITUARY

Dr. Mangina Venkateswara Rao
(1928-2016)

Renowned agricultural scientist and one of the key persons in India's 'Green Revolution', Padma Shri Dr. M. V. Rao, passed away on 8th March, 2016 in Hyderabad. He was 88 years and is survived by his wife, a son and two daughters.

Born on June 21, 1928 at Perupalem in West Godavari district of Andhra Pradesh, Dr. Rao joined the Indian Agriculture Research Institute (IARI) in 1956 as an Assistant Wheat Breeder, after completing his master's degree from Purdue University, United States. He became the Coordinator of the All-India Wheat Improvement Project in 1971.

In the company of Nobel laureate Dr. Norman E. Borlaug, Dr. M. S. Swaminathan, Shri C. Subramanian and many others who ushered in the Green Revolution during the early 1960s, Dr. Rao was involved in testing and identifying the best varieties of wheat from Mexico which were grown in the country and changed the agriculture scenario forever.

During a long career, Dr. Rao rose to the highest posts in agriculture. He was asked by the then Prime Minister, Shri Rajiv Gandhi to Head the Technology Mission on Oilseeds (one of the four technology missions) and was appointed as Special Director General (Technology Mission on Oilseeds), ICAR in 1986 which helped the country to attain self-sufficiency in oilseed production. Post-retirement, he has been selected as Agriculture Expert by World Bank in 1990. He served as Vice-Chancellor of the Acharya NG Ranga Agriculture University (1991-97).

Dr. M.V. Rao, was the first President of Indian Society of Oilseeds Research (ISOR) and guided the activities of the Society during 1983 to 1990 and 2006 to 2009. In his honour, ISOR initiated "Dr. M.V. Rao Lecture Series" from 2013. As chairman RAC (2007-2010), he guided the research programmes of IIOR.

As Vice-President of the National Academy of Agricultural Sciences (2000-2003), Dr. Rao played an important role on several committees, especially chairing the Committee on the New National Seed Policy. He has served as a member of the Board of Directors of the International Rice Research Institute (IRRI) and as member of the Wheat Advisory Committee of the Food and Agricultural Organisation (FAO).

Ironically for Dr. M.V. Rao, the golden jubilee celebrations of the Green Revolution held in New Delhi in November 2015, turned out to be his last big engagement. He was felicitated by Shri Radha Mohan Singh, Hon'ble Agricultural Minister, GOI and his 30-minute address to the galaxy of scientists drew wide applause.

A recipient of the Norman Borlaug Award and the Linker's Award, Dr. Rao was honoured with the Padma Shri by Government of India.

Dr. M.S. Swaminathan, in his condolence message, said "Dr. Rao's contributions to the food security of our country were truly monumental".

The staff of IIOR and members of ISOR deeply mourn his death and earnestly pray the Almighty that, the departed soul may rest in peace.

JOURNAL OF OILSEEDS RESEARCH

GUIDELINES TO AUTHORS

The Journal of Oilseeds Research is published quarterly. The following types of material are considered for publication on meeting the style and requirements of the journal (details in July, 2010 issue).

1. **Articles on original research completed,** not exceeding 4000 words (up to 15 typed pages, including references, tables, figures, etc.) should be exclusive for the journal. They should present a connected picture of the investigation and should not be split into parts. Complete information of Ph.D thesis should preferably be given in one article.
2. **Short Communication**, not more than 1300 words (total 5 typed pages), which deal with (I) research results that are complete but do not warrant comprehensive treatment, (ii) descriptions of new material or improved techniques or equipment, with supporting data, and (iii) a part of thesis or study. Such notes require no headed sections.
3. **Critical Research Review Articles**, showing lacunae in research and suggesting possible lines of future work. These are mostly invited from eminent scientists.
4. The research article or note submitted for publication should have a direct bearing on agricultural production or open up new grounds for productive research. Articles on oilseeds research, economics, demonstrations, social sciences, extension, etc., are also considered. Basic type of articles and notes relating to investigation in a narrow specialized branch of a discipline may not form an appropriate material for this journal, nor do the articles of theoretical nature, or those of local importance, repetitive, based on old data, with no positive significance.
5. Author should note: (a) period (years) of conducting the experiment must be indicated, (b) article should preferably be submitted soon after completion of experiment, (c) articles on genetics and plant breeding and on plant crops should be based on data of minimum two years, (d) contribution involving a former or present student must clarify that it is not based/based on complete M.Sc. Thesis, or complete or a part of the Ph.D thesis, indicating its year of submission and (e) Article Certificate must be signed by all the authors and must contain subscription numbers of authors.
6. **Title** should be short, specific and information. It should be phrased to identify the content of the article and include the nature of the study and the technical approach, essential for key-word indexing and information retrieval.
7. **A Short Title** not exceeding 35 letters should also be provided for running headlines.
8. **By-line** should contain, in addition to the names and initials of the authors, the place (organization) where research was conducted. Change of address should be given as a footnote, e-mail ID and correspondence address separately.
9. **Abstract**, written in complete sentences, should not have more than 150 words. It should contain a very brief account of the materials, methods, results, discussion and conclusion, so that the reader need not refer to the article except for details. It should not have reference to literature, illustrations and tables.
10. **Introduction** part should be brief and limited to the statement of the problem or the aim and scope of the experiment. The review of recent literature should be pertinent to the problem. Key words of the article should be given in the beginning.
11. Relevant details should be given of the **Materials and Methods** including experimental design and the techniques used. Where the methods are well known, citation of the standard work in sufficient. Mean results with the relevant standard errors should be presented rather than detailed data. The statistical methods used should be clearly indicated.
12. **Results and Discussion** should be combined, to avoid repetition.
13. The results should be supported by brief but adequate tables or graphic or pictorial materials wherever necessary. Self-explanatory tables should be typed on separate sheets, with appropriate titles.
14. The tables should fit in the normal layout of the page in portrait style. All weights and measurement must be in SI (metric) unit. Tables and illustrations (up to 20% of text) should not reproduce the same data.
15. The discussion should relate to the limitations or advantages of the author's experiment in comparison with the work of others. All recent relevant literature should be discussed critically.
16. Line-drawings should be clearly drawn (7 inch or 17 cm width) in black waterproof ink on smooth, tough paper, minor points of style should be noted carefully. Photographs should be large, unmounted, glossy prints of good quality. They should be clear and relevant to the subject. Colour photographs may be sent for better identification and legibility of different parts of the object. All figures should have legends (types). Original artwork should accompany 2 copies. Repetition in graphic and tabular matter should be avoided.
17. For citing **References** a recent issue or the present journal may be referred, ensuring that all the references cited in the text are referred in the end under References section of the article. Each citation should have the name(s) of the author(s), initials (without full stops, but comma after each full name), year of publication (with full stop), full title of the article (with full stop), name of the journal (in italics with comma but without abbreviations), volume number (in bold), preferably the issue (within parentheses and colon) and complete page range (not merely the first page and full stop). Complete name of publisher and place of publication of books should be given in case of books. For proceedings or other publications complete details should be given.
18. All articles are sent to referees for scrutiny and authors should meet criticism by improving the article, indicating the modifications made (in separate sheet, 2 copies).
19. Articles should be **Typewritten** in MS Word format in Times New Roman font with 12 font size in double line spaced throughout (including byline, abstract, references and tables) on white, durable A-4 size paper with one inch margins on all sides. The hard copy of the Articles should be sent in triplicate after checking typographical errors. **It is mandatary to send soft copy of the article in neatly packed CD and/or by E-mail on: editorisor@gmail.com. Articles not sent by CD or E-mail will take longer time to consider for its publication.**
20. For **writing,** authors are requested to consult the recent issue of **Journal of Oilseeds Research**, either this issue or the immediate past issue. The language and spellings are followed as per British style, but not in American style.
21. **Proof Correction** - Author(s) should be prepared to make necessary corrections or modifications in their article in accordance with the remarks/suggestions of the referee of the article. The decision of the Referee and/or Indian Society of Oilseeds Research is final in this regard. No arguments or clarifications are entertained in any manner at any stage.
22. While submitting the article(s), please ensure that all the authors are life/annual members of the ISOR.