THE INDIAN SOCIETY OF OILSEEDS RESEARCH

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

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The National Academy of Agricultural Sciences has enhanced the rating of the *Journal of Oilseeds Research* to **3.97**

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

JOURNAL OF OILSEEDS RESEARCH

Previous Issue : Vol. **31**, No. 2, pp.95-193

Vol. **32**, No. 1 June, 2015

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Safe sesame (*Sesamum indicum* L.) production : Perspectives, practices and challenges

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(Received: March, 2015; Revised: May, 2015; Accepted: June, 2015)

ABSTRACT

Sesame seed is a reservoir of nutritional components with numerous beneficial effects for health promotion in humans. In order to complement efforts to boost sesame production and thereby enhancing economic returns to sesame growers through its supply to meet the growing demand in domestic as well as in international market, there is an urgent need to address an important issue i.e., safe sesame production. Here, we have adopted two approaches - aspects and dimensions - to analyze perspectives of safe sesame, with the objective of achieving comprehensive understanding of various issues and considerations related to safe sesame production and its human consumption. Apart from two dimensions - human health and trade -, there are mainly two aspects of sesame being considered safe. The first aspect is concerned with how safe is sesame seed or oil for human consumption in terms of its nutritional components including the absence of anti-nutritional factors. The second is regarding the absence of chemicals, infectious pathogens and other contaminants that may pose threat to human health. In this paper, we have analyzed the available literature, related to safe sesame production, in the light of eight considerations: (1) Human nutrition, (2) Meteorology, (3) Genotype, (4) Technology, (5) Crop management, (6) Plant health management, (7) Harvest and post-harvest handling and (8) Challenges.

Keywords: Challenges, International trade, Prospects, Safe production, Sesame

Sesame (*Sesamum indicum* L.) belonging to the order tubiflorae, family Pedaliaceae, is an herbaceous annual species cultivated for its edible seed, oil and flavorsome value. It is also known as gingelly, til, benne seed and popularly as 'Queen of Oilseeds' due to its stabilized keeping quality contributed by high degree of resistance to oxidation and rancidity (Bedigian and Harlan, 1986).

Sesame is believed to have been originated in India, where maximum variability in genetic resources is present (Bhat *et al.,* 1999). India is a major exporter to number of countries and has earned the foreign exchange of ₹2800 crore (Ranganatha, 2014). The uniform, lustrous, white and bold seed, free from insect pests and pesticide residue, with low free fatty acid (<2%), low oxalic acid (<1%) and high lignan content (>830 mg/100 g seed), is preferred for export. In the recent past, the international demand and market for sesame have witnessed substantial growth. In order to complement efforts to boost sesame production and thereby enhancing economic returns to sesame growers through its supply to meet the growing demand in domestic as well as in international market, there is an urgent need to address an important matter of concern i.e., safe sesame.

PERSPECTIVES

Here, we have adopted two approaches - aspects and dimensions - to analyze perspectives of safe sesame, with the objective of achieving comprehensive understanding of various issues and considerations related to safe sesame production and its human consumption.

Aspects of safe sesame: There are two main aspects of sesame being considered safe for human consumption. The first is concerned with how safe is sesame seed or oil for human consumption in terms of its nutritional components including absence of anti-nutritional factors. The second is regarding the absence of chemicals, infectious pathogens and other contaminants posing threat to human health. However, both the aspects, altogether, are influenced by methods of cultivation, harvesting, processing, storage and handling. While the first aspect is internal to the biological value of the product, primarily influenced by sesame genotype; the second aspect is concerned with the human activities reflected in the practices of cultivation, harvesting, processing, storage and handling.

Dimensions of safe sesame: Safety considerations need to be pursued from the perspectives not only of human nutrition and health, but also of trade. In other words, a particular type of sesame as a commodity, produced with a particular method, may actually be good for human-health and nutrition, yet may not be preferred by consumers. Then, such commodity becomes not acceptable from trade point-of-view, ultimately leading to the farmers at loss. Therefore, trade-dimension of safe sesame is also considered important in addition to the health-dimension.

In order to make relevant and scientific information available at one place for the benefit of all the stake-holders; including farmers, traders, policy-makers, certification/ regulatory agencies, enforcement agency, consumer fora, etc., so that they become well equipped to deal with concerned issues related to the safe sesame; we have analyzed available literature in the light of eight considerations: (1) Human nutrition, (2) Meteorology, (3) Genotype, (4) Technology, (5) Crop management, (6) Plant health management, (7) Harvest and post-harvest handling, and (8) Challenges. In this paper, we have attempted to discuss perspectives, provide such a comprehensive form of information on practices, which hither to is not available, and further discuss the challenges for safe sesame production.

HUMAN NUTRITION CONSIDERATIONS

Sesame seed is a reservoir of nutritional components with numerous beneficial effects for health promotion in humans (Pathak *et al*., 2014). Availability of valuable information on superior nutraceutical, pharmacological, traditional and industrial value of sesame seed with respect to its bioactive components, will strongly promote the use of sesame seeds/oil in the daily-diet, world-wide (Pathak *et al*., 2014). Availability of safe sesame further helps in this process. Sesame seed and oil vary (Table 2) with respect to their functional components.

Sesame seed: Sesame seeds are considered valuable food as they enhance the diet with the pleasing aroma and flavor, and offer nutritional and physiological benefits. The seeds have special significance for human nutrition on account of its high content of sulphur amino acids and phytosterols (El-Adawy and Mansour, 2005). The seed is high in protein, vitamin B1 and dietary fiber; apart from being an excellent source of phosphorous, iron, magnesium calcium, manganese, copper and zinc (Table 2). In addition to these important nutrients, sesame seeds contain antioxidants, lignans, tocopherols, phytosterols, phytates and PUFA. While majority of them play nutritional role, some are also anti-nutritional.

Sesame oil: Sesame seed contains 48-55% (Table 1) of high quality oil which is rich (Table 2) in polyunsaturated fatty acids (PUFA), mainly linolenic acid, oleic acid, palmitic and stearic acid, with trace amount of linolenic acid (Kamal-Eldin *et al*., 1992). The oil has natural antioxidants, sesamin, sesamolin and tocopherol homologues (Brar and Ahuja, 1979). The antioxidative agents; sesamin, sesamolin, sesamol, their glucosylated forms sesaminol glucosides; and tocopherol make the oil very stable and therefore it has a long shelf life (Chung, 2004; Suja *et al*., 2004). Thus, these bioactive components, along with numerous health benefits, enhance the stability and keeping quality of sesame oil.

Defatted sesame meal: Defatted sesame meal/cake is a rich source of protein, carbohydrate, mineral nutrients (Table 2) and phyates.

The detailed biological functions of various bioactive components present in sesame are discussed below.

Antioxidants: Lignans present in sesame seed provide an innate non-enzymatic antioxidant defense mechanism (Suja *et al*., 2004) against reactive oxygen species. They are responsible for enhancing antioxidant activity of vitamin E (Ghafoorunissa *et al*., 2004) in lipid peroxidation systems. Antioxidant and anti-carcinogenic activities of sesame seed further expand sesame applications in health food products for liver and heart protection and tumor prevention (Cheng *et al*., 2006). Antioxidant activity plays a major role in the prevention of degenerative diseases such as cancer (Yokota *et al*., 2007), cardiovascular diseases (Visavadiya and Narasimhacharya, 2008), atherosclerosis and the process of ageing, as they play role in lowering of cholesterol levels, increasing of hepatic fatty acid oxidation enzymes (Ashakumary *et al*., 1999) and antihypertensive effects (Lee *et al*., 2004; Nakano *et al*., 2008).

Lignans: Based on their solubility, lignans present in sesame may be grouped into two categories, *viz*., oil soluble lignans and glycosylated water soluble lignans. Sesamin, sesamolin, sesaminol, sesamolinol and pinoresinol are the oil-soluble lignans. The glycosylated-lignans are sesaminol triglucoside, pinoresinol-triglucoside, sesaminol-monoglucoside, pinoresinol-monoglucoside, and two isomers of pinoresinol- and sesaminol- diglucoside (Moazzami *et al*., 2006; Katsuzaki *et al*., 1994; Katsuzaki *et al*., 1994).

Major lignans in the sesame seed are sesamin, sesamolin and sesaminol (Budowski and Markley, 1951; Osawa *et al*., 1985). They possess the unique property of helping in lowering of blood lipids (Hirata *et al*., 1996). The other important properties (Fig. 1) are: lowering of arachidonic acid levels (Shimizu *et al*., 1991), cholesterol levels through simultaneous inhibition of absorption and synthesis of cholesterol (Hirose *et al*., 1991), anti-inflammatory function (Hsu *et al*., 2005) and immunomodulatory activities.

According to reports available on sesamin and sesamolin contents of sesame genotypes, the highest is reported in core collection from China with an average value of 8.54 mg/g for sesamin and sesamolin (Wang *et al*., 2012) followed by Indian sesame with 2.45 mg/g for sesamin and 1.10 mg/g for sesamolin (Pathak *et al*., 2014). Moazzami *et al*. (2006) reported that Indian sesame accessions had higher sesamin (1.63 mg/g seed) and sesamolin (1.01 mg/ g seed) than that of US accessions.

Table 1 Proximate composition of sesame seed

Constituent	Composition %
Moisture	6-7
Proteins	20-28
Oil	48-55
Sugars	14-16
Fiber content	6-8
Minerals	5-7

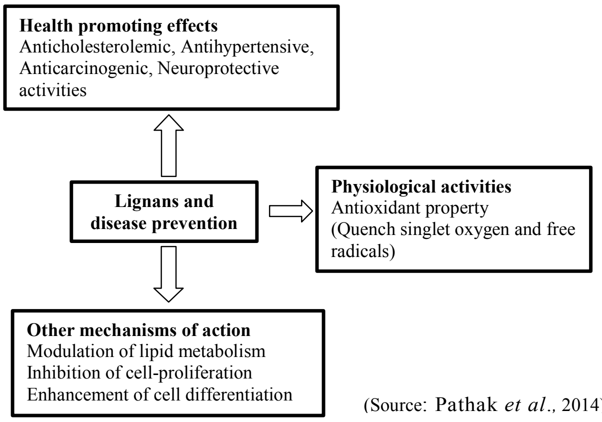
(Source: Pathak *et al*., 2014)

Table 2 Variation in the contents of functional components in sesame seed and oil

Bioactive Components	Name of Component	Quantity		Reference
		Sesame Seed (mg/g seed)	Sesame Oil (mg/g)	
Lignans	Sesamin	8.80	6.20	Moazzami *et al.,*
	Sesamolin	4.50	2.45	2006 Hemalatha and
	Sesamol	1.20	-	Ghafoorunisa, 2004
	Sesaminol	1.40	0.01	
Tocopherol	α-tocopherol	-	-	Kamal-Eldin and
	Β-tocopherol	-	-	Appelqvist, 1996
	γ-tocopherol	$800\mu g\ g^{-1}$	0.68	
	Õ-tocopherol	-	-	
Polyunsaturated Fatty acids	Palmitic acid (16:1)	9.4%	14.45%	Uzun *et al*., 2008
	Oleic acid (18:1)	39.1%	50.54%	
	Linoleic acid (18:2)	40%	45.50%	
	Linolenic acid (18:3)	0.46%	0.85%	
Phytosterols	Β-sitosterol	3.35	2.63	Normen *et al*., 2007
	Campesterol	1.00	1.35	
	Stigmasterol	0.37	0.47	
	Δ^5-avenasterol	-	0.82	
	Sitostanol	-	0.04	
	Campestanol	-	0.02	
	Ergosterol	-	-	
	Total phytosterols	4.72	5.33	
Phytates	Phytic acid	5.18%(defatted sesame meal)		De Boland *et al*., 1975
Minerals	Ca	4.21	-	
	Fe	0.06	-	
	Zn	0.03	-	
	P	4.45	-	
	K	3.85	-	
	Na	0.08	-	
	Mg	2.21	-	
	Cu	0.41	-	
	Mn	0.02	-	

(Source: Pathak *et al*., 2014)

Tocopherols: Tocochromanols are called amphipathic molecules in the sense that lipophilic isoprenoid side chain is associated with membrane lipids and the polar chromanol ring is exposed to membrane surface. The metabolic fate and biological activities of tocols are governed by their structural forms. Based on molecular structure, various isoforms of tocopherols are found in nature. While all isoforms possess lipid antioxidant activity, α-tocopherol possesses the highest vitamin E activity in mammals (Bramley *et al*., 2006; Herbers, 2003). Because of its ability to break radical-chain in membranes and lipoproteins, as well as in foods (Kamal-Eldin and Appelqvist, 1996), α-tocopherol is found to reduce the risk of cardiovascular diseases and of certain types of cancer (Burton and Traber, 1990).



(Source: Pathak *et al.*, 2014)

The major tocopherol in sesame seed is γ-tocopherol, with α- and δ-tocopherols being present in smaller amounts (Williamson *et al.*, 2008; Hemalatha and Ghafoorunissa, 2004). Gamma-tocopherol is reported to be more potent than α-tocopherol in decreasing platelet aggregation, oxidation of low density lipid (LDL) and delaying of intra-arterial thrombus formation (Li *et al.*, 1991; Saldeen *et al.*, 1999). The amount of γ-tocopherol in sesame ranges from 468.5 to 517.9 mg/kg lipid and 490-680 mg/kg in case of sesame oil (Kamal-Eldin and Appelqvist, 1994b), with α- and δ-tocopherols being present at low levels (Yoshida *et al.*, 2007). Species-level variations reported are 210-320, 750 and 800 mg/kg sesame oil in *Sesamum alatum, S. angustifolium* and *S. latifolium,* respectively (Kamal-Eldin and Appelqvist, 1994b). Williamson *et al.* (2008) reported that α-, δ- and γ-tocopherol varied in the range of 0.034-0.175, 0.44-3.05 and 56.9-99.3 μg/g seed, respectively, among US accessions. The results reviewed represent a large variation for γ-tocopherol content thereby offering scope for genetic improvement.

Phytosterols: Phytosterols are bioactive compounds that have a chemical structure very similar to cholesterol but, when present in sufficient amounts in the diet, reduce cholesterol level in the blood, enhance the immune response, and decrease the risk of certain cancers (Pathak *et al.*, 2014). These tri-terpenes exhibit, in animals and humans, a number of biological activities, *viz*., anti-inflammatory (Bouic, 2002), anti-bacterial (Zhao, 2005), antioxidative (Van Rensburg, 2000) and anti-cancerous (Awad *et al.*, 2000). Different groups of phytosterols include sitosterol, campesterol, stigmasterol, Δ^5-avenasterol, sitostanol and campestanol. Of these, β-sitosterol is the predominant phytosterol in sesame oil, followed by campesterol and stigmasterol, the content of which ranges from 231.7 to 305.2 mg/100 g sesame seed (Pathak *et al.*, 2014). The beneficial effects of phytosterols are so dramatic that they have been extracted from soybean, corn and pine tree oil and added to processed foods, eg., "butter", which are then labeled as cholesterol-lowering "foods". Sesame seeds have been reported to contain the highest (400-413 mg/100 g) phytosterol content (Mohamed and Awatif, 1998). They reported that brown sesame had higher phytosterol content than white one.

Phytates: Phytic acid is an important source of plant phosphorous. Its six reactive phosphate groups have a strong chelating ability to complex with proteins in addition to minerals, thereby contributing to anti-nutritional effects (Urbano *et al.*, 2000). Dietary phytates have attracted much interest because of their role in cancer prevention and hypocholesterolemic effect (Shamsuddin, 1995). The action of phytates is linked with the antioxidant effect by which it binds the excess free iron, thus preventing the formation of free radicals (Graf *et al.*, 1987). Sesame seed is a rich source of phytates and the defatted sesame meal contains 5.18%, compared with 1% in soybean meal and 1.5% in isolated soybean protein (De Boland *et al.*, 1975). The high content of phytic acid and oxalic acid in sesame seed hinders the use of sesame protein as food (Johnson *et al.*, 1979). Hence, there is a need and scope to develop sesame genotypes with low phytic and oxalic acids.

Polyunsaturated fatty acids (PUFA): High levels of monounsaturated (MUFA) and PUFA add to the quality of oil for human consumption. The PUFA have anti-inflammatory, anti-thrombotic, anti-arrhythmic, hypolipidemic and vasodilatory properties. Moreover, high levels of linoleic acid reduce the blood cholesterol and play a vital role in preventing atherosclerosis (Simopoulos, 1999). Since the demand for beneficial PUFA has increased drastically, increasing efforts are being made to find plant sources of PUFA that are economical and sustainable. The fatty acids of sesame oil consist mainly of linoleic (35-50%) and oleic (35-50%) acids, with small amounts of palmitic (7-12%) and stearic (3.5-6%) acids and only trace amount of linolenic acids (Kamal-Eldin and Appelqvist, 1994a; Spencer *et al.*, 1976). Sesame oil used in combination with soybean oil enhances the nutritive value of the lipid and increases vitamin E activity (Namiki, 1995). Studies on unsaturated fatty acids by various researchers suggest that Indian sesame germplasm has high genetic variability with respect to fatty acid composition (Uzun *et al.*, 2008). This large variation at inter-and intra-specific level offers interesting future prospects (Mondal *et al.*, 2010).

Economic uses of sesame: The knowledge of type of use of the sesame is important in dealing with safe sesame related issues. This helps not only the grower and the end-user, but also the traders, processors and policy makers (Ranganatha *et al.*, 2013). Economic uses of sesame are numerous, both in the present as well as in the ancient past. This is another reason for its rightly termed sobriquet "Queen of oilseeds". Table 3 summarizes the uses and activities of various bioactive components of sesame. Various economic uses of sesame, spanning different applications in the form of seeds, oils, extracts, agents, etc., are discussed under the following broad headings.

Table 3 Uses and activities of various bioactive components of sesame

Use and activity	Bioactive components of sesame
Nutraceutical	
Anti-oxidant and providing hepato protection	Lecithin
Cancer preventive	Myristic acid
Tumor prevention, cardio protective	Fiber and Sesame oil
Anti-oxidant property	Sesamin and Sesamolin
Inhibition of cholesterol production	Lecithin and lignans
Skin softener	Sesame oil
Pharmaceutical	
Drug vehicle and laxative	Sesame oil
Hypoglycemic activity	Flavonoids
Inhibition of malignant melanoma	Linoleate in triglyceride form
Anti-bacterial mouthwash	Sesame oil
Industrial	
Anti-fungal	Chlorosesamone
Bactericidal and Insecticidal	Sesamin and Sesamolin
Cosmetics	Myristic acid
Bio-diesel	Sesame oil
Traditional	
Intestine lubrication	Sesame oil
Relieve constipation	Sesamin
Intestinal deworming	Sesamin, Sesamolin

(Source: Pathak *et al*., 2014)

Pharmaceutical uses: Sesame seed and oil possess immense pharmaceutical applications and have played a prominent role in Chinese and Indian systems of medicine. Sesame oil has burn-healing effects (Ang *et al*., 2001); when rubbed on the skin, it soothes minor burn or sunburn, as well as helps in the healing process. The sesame oil is an ideal massage oil due to its excellent emollient properties. When applied topically, it aids in healing the chronic diseases of the skin. In India, it has been used as an antibacterial mouthwash, to relieve anxiety and insomnia and in the treatment of blurred vision, dizziness and headache (Annussek, 2001). The sesame oil is a natural antibacterial for common skin pathogens such as Staphylococcus and Streptococcus as well as for common skin fungi such as athlete's foot fungus (Pathak *et al*., 2014).

Nutraceutical uses: The potentials of sesame to be used for nutraceutical purposes are needed to be exploited as discussed in the subsequent section on challenges.

Industrial uses: Several industrial uses have been identified for sesame (Table 3). Industrial usage entails thorough processing of sesame seed/oil. African people use sesame flowers to prepare perfumes and cologne. Myristic acid is used as an ingredient in cosmetics. Sesamin has bactericidal and insecticidal activities and also acts as an antioxidant, which can inhibit the absorption and the production of cholesterol in the liver. It is used as a synergist for pyrethrum insecticides. Sesame oil is used as a solvent, oleaginous vehicle for drugs and skin softener in producing margarine, high value soap, pharmaceuticals, paints and lubricants (Morris, 2002). Chlorosesamone obtained from roots of sesame has antifungal activity (Hasan *et al*., 2000). Biodiesel production from sesame oil, by its trans-esterification with methanol in the presence of NaOH as a catalyst, has been reported by Ahmad *et al.* (2010). They also investigated that the environmental performance of sesame biodiesel was superior to that of mineral diesel. This study supports the production of biodiesel from sesame seed oil as a viable alternative to the diesel fuel. However, high-value sesame oil is not to be promoted as biodiesel, as this place should go for the other low-value oils. Therefore, safe sesame production is a way to promote sesame oils as safe commodity for human consumption.

Traditional uses: Sesame seeds are used for traditional purpose since ancient times. Sesame seeds are used in the Hindu culture as a "symbol of immortality" and its oil is used widely in prayers and rituals performed during death of an individual. "Butter of the Middle East" *tahini*, a smooth creamy paste made up of toasted-hulled-ground sesame seeds, is a traditional ingredient in Middle Eastern cooking. The nutritious seed cake is used as animal feed and is also ground into sesame flour and added to health foods

(Bedigian, 2011; Pathak *et al*., 2014). South Indian cuisine depends upon sesame oil for cooking. In China, it was the only cooking oil revered until the quite recent past. Sesame seed benefits the body as a whole; especially the liver, kidney, spleen and stomach. Its high oil content not only lubricates the intestines, but nourishes all the internal viscera. It is also known to blacken the hair, especially the black sesame. Hence, it is applied to white hair, habitual constipation and insufficient lactation. Sesame oil is also helpful in treating intestinal worms such as ascaris, tapeworm, etc. (Pathak *et al*., 2014).

Value addition in sesame: In order to improve the economic value of sesame and thereby benefiting sesame growers, value added products of sesame oil and meal with following properties needs to be developed. Scientific research and standard practices in terms of sesame genetic improvement, food processing-including oil extraction, grading, packaging- and labeling needs to be followed on mission mode approach to boost sesame production. This indirectly motivates all stake holders to promote safe sesame production practices.

Low free fatty acids (FFA): To help the farmers in fetching better market price, sesame with <2% FFA needs to be developed, as low (i.e., <2%) FFA is considered the best for human consumption. White seeded varieties of sesame from Gujarat (0.5-1.2%), Rajasthan (0.75-1.5%) and Maharashtra (1.0-2.0%) contain low FFA, which are considered to give a good quality oil (Pathak *et al*., 2014). The FFA in sesame seeds from coastal Andhra Pradesh, Odisha, Tamil Nadu and Chhattisgarh are comparatively high, ranging from 2.0% to 4.0% (Pathak *et al*., 2014). Therefore, low FFA is a favorable consideration in sesame value addition.

High lignans (sesamin, sesamolin) and tocopherols: As discussed earlier, these are responsible for improving quality and shelf life of the oil. Sesame seed with high lignan and tocopherol content is very important in terms of health promotion and thereby preventing free-radical-related diseases. Therefore, development of sesame with high lignan and tocopherol contents is of utmost importance for enhancing oil quality and boosting sesame oil production there-through.

Low anti-nutritional factors: Anti-nutritional factors, i.e., oxalic and phytic acids (Pathak *et al*., 2014) present in sesame seed coat, necessitate dehulling leading to loss of mineral-rich seed coat (22.8 g/100 g). The presence of oxalic acid (14.3 g/100 g) and phytic acid (in traces) in the seed coat renders calcium and phosphorus non-available to the body and imparts unpleasant taste. Therefore, the nutritional value and taste of the sesame seed must be improved further and the necessity of dehulling must be reduced through the development of varieties with low anti-nutritional factors, i.e., oxalic and phytic acids. Thereby, large quantities of calcium and phosphorus, present in the seed coat, are made available to the human body. Such value-added sesame will be preferred and priced higher in western countries. This factor enhances the nutrition dimension of safe sesame.

Table 4 Target enzymatic sites for genetic engineering of sesame oil

Target oil	Advantage	Approach
High sesamin	Increased antioxidant, antiproliferative activity	Over-express sesamin synthase
High sesamolin	Increased antioxidant, antitumor, antithrombic activity	Over-express sesamin synthase
High γ-tocopherol	High antioxidant, antitumor and hypocholestrolemic action	Over-express Tocopherol cyclase
High α-tocopherol	Increase anticancerous activity	Over-express γ-tocopherol methyltransferase
High oleate	Increase oil stability, pharmaceuticals, cosmetics, soaps	Down-regulate oleoyl-ACP desaturase
High linoleate or linoleneate	Improve nutraceutical value, cosmetics, paints	Over-express ? 12 and ? 15 desaturases
High β-sitosterol	Improve antioxidative, anticancerous, cholesterol lowering effects	Over-express sterol 24C methyltransferase
Low phytic acid	Anticancer activity, cholesterol lowering effects	Down regulate Myoinositol 1-phosphate synthase

(Source: Pathak *et al*., 2014)

METEOROLOGICAL CONSIDERATIONS

Agro-climatic conditions play indirect - but a very important - role in producing safe sesame. Conditions adverse to pest-diseases, for instance, are helpful for safe sesame production, for there is no need to use chemical measures of control. To the same effect, conditions favoring crop over weeds may require no weeding or weedicide application, thereby reducing the production cost. Also, meteorological conditions influence biological value of the product including seed size, oil content and other consumer-preference-related traits. Thus, meteorological considerations are important for safe sesame production, thereby making sesame safe not only for human-health but also for trade.

Discussed here are various meteorological considerations from the perspective not only of safe sesame but also of its productivity/yield.

Warmth: Germination of seed is negatively affected when temperature falls below 18°C, while sesame requires constant high temperature. The optimum range for growth, blossoms and capsule ripeness is 24-30°C. Pollination and formation of capsules are adversely affected, due to heat wave periods above 40°C. In regions visited by strong and hot winds, the plants form smaller seeds with lower oil content. For these reasons, sesame is cultivated as in summer in cooler regions and in winter crop in warm climes. Sesame is frost-susceptible. Depending on the climate, sesame can be cultivated at altitudes upto 1200 m in India (Arnon, 1972; Augstburger *et al*., 2000).

Water: Rainfall of 300-600 mm, optimally spread during vegetation period, is conducive for obtaining good yield. Arnon (1972) explains optimum distribution as: 35% before the first cusps are formed, 45% during the main blossoming period, 20% during the ripening period and drought, if possible, during harvesting. Being highly susceptible to water-logging, sesame crop can thrive only during moderate rainfall, or, when irrigation is carefully controlled, in drier regions. Because of its tap root system, sesame is drought resistant and, therefore, gives good harvest even when the only stored soil water is available.

Soil: While sesame can be cultivated on any type of soil, for realizing the yield potential of genotype and agronomic management practices, it requires well-drained, loose, fertile and sandy alluvial soils having pH between 5.4 and 6.7. Very low pH has a drastic effect on growth, whereas some varieties can tolerate up to pH 8.0 (Augstburger *et al*., 2000). As it is highly sensitive to high soil moisture content, sandy soils are preferred over heavy soils especially for cultivation under irrigated conditions, or during summer rain spells. Sloping ground is not suitable for sesame cultivation, for its slow early development coupled with requirement of weed-free seed bed fail to conserve soil against erosion. Water-logged soils, saline soils and shallow soils (<35 cm with impermeable subsoils) are to be excluded.

Wind: Tall varieties should be avoided in the regions encountering winds during the harvesting stage. Because sesame stem is hollow in the centre, hedges to protect plant against wind, if necessary, is helpful in protecting sesame crop from wind-driven lodging (Augstburger *et al*., 2000).

Day length: Because sesame is a short-day plant, there exists genotypes that are unaffected by day length. However, long period of sunshine favors sesame growth, development and reproduction (Augstburger *et al*., 2000).

GENOTYPIC CONSIDERATIONS

The quality consideration and consumer preference influence the breeding objectives. The requirements for confectionery market and the oil mills are totally different. The seed size, shape, coat texture, color and sweet taste are important and crucial for confectionary types, increasing globally with the growing health concern. However, these characters are not so important for oil industry. In India, white seeded sesame is preferred for export as well as for domestic use in northern plains and plateau region. Whereas, brown or black seeded are preferred by domestic consumers in east coast and black seeded in south coastal region.

The potentials of sesame have been amply demonstrated in tropical Venezuela (Mazzani, 1985) and South Korea, where sesame is a high input crop (Kang, 1994): similarly, in case of summer production areas in India (Sharma, 1994) and China (Zhao, 1994). Non-shattering cultivars are needed in case of harvesting using combined harvester in developed countries and moderate types are adjustable elsewhere (Ashri, 1998; Bedigian, 2010). Desirable physiological characters are photo- and thermo-insensitivity; improved harvest index; higher efficiency in nutrient uptake; tolerance to water-logging, drought, salinity and abiotic stresses; fertilizers and/or irrigation responses; and, high and stable seed yield under a wide range of environments (Rajan, 1981). Ranganatha *et al*. (2012b) have reviewed the selected released varieties of India (Table 5) and the situations for which they are recommended. Further, discussed in the following are genotypic considerations for various situations from the perspective of safe sesame.

Plant types for input intensive agriculture: The agro-morphological features of the plant types for input intensive agriculture (Ranganatha, 2014) are as follows: (a) Short duration (75-85 days), (b) Dwarf plant types, (c) Photo- and thermo-insensitivity, (d) Higher response to added inputs and irrigation, (e) Short inter-nodal length and higher number of effective capsules, (f) Perfect synchrony in maturity, and (g) High harvest index. The present day local type is a total misfit for input intensive agriculture due to poor response to higher levels of management. In the non-traditional areas, input intensive agriculture cultivars like RT-125, RT-127, TKG-21, TKG-22, TKG-55, Madhavi and HT-2 are the appropriate choice to the farmers. Selection of appropriate types for *kharif*, winter and summer seasons in different agro-climatic regions is helpful for enhancing the productivity. Hence, popularization of these ideal plant types is the pre-requisite for achieving a breakthrough in sesame productivity, along with safe sesame production, in different agro-production situations.

Table 5 Selected released varieties of sesame in India

Variety	Year of Release	Days to Maturity	Oil content (%)	Average Yield	Salient Features, Recommended Areas
TMV-3	1948	80-82	48-50	600-650	Black seed, Rainfed and irrigated areas of Tamil Nadu and Karnataka
TMV (Sv)-7	2009	85-90	50-52	750-850	Tamil Nadu, Andhra Pradesh, Karnataka, Cosmopolitan variety suited for all seasons, brown seed
T-4	1960	85-90	48-51	600-650	White seed, For alluvial soils of Uttar Pradesh
Amrit	2006	80-85	43-46	750-850	Light brown seed, *kharif* rainfed , *rabi*, summer irrigated, Andhra Pradesh , Tamil Nadu, Chhattisgarh, West Bengal and Madhya Pradesh
TC-25	1978	80-85	50-53	750-800	White seed, Punjab, Vidarbha region (MS), Madhya Pradesh and Rajasthan
RT-351	2010	85-90	48-50	750-800	Rajasthan, Gujrat, UP, Maharashtra, Haryana, Punjab, Himachal Pradesh, Karnataka and Jammu & Kashmir.
Gujarat Til-2	1994	88-92	48-52	750-800	White seed, Gujarat
E-8	1989	95-100	47-50	550-600	Creamy white seed, Northern Karnataka
Thilathara	2006	84-88	48-50	600-650	Blackish brown seed, Kharif, Onattukara region of Kerala Summer rice fallows
JLT-408	2010	80-85	51-53	700-800	White seed, *kharif*, Assured rainfall zone of Khandesh and adjoining areas of Vidharba, Marathwada region
Madhavi	1978	75-80	46-48	650-700	Light brown seed, Andhra Pradesh
Hima	2006	80-85	75-80	700-750	Shiny white seed, Late *kharif, rabi* and semi-*rabi*, Andhra Pradesh
TKG-22	1995	82-85	50-54	600-700	White seed, Eastern Uttar Pradesh, Madhya Pradesh, Bihar, Orissa, West Bengal & North East states
GT10	2002	88-92	48-52	750-800	Black seed, recommended for Gujarat, tolerant to powdery mildew
Pragati	2002	85-90	48-52	700-750	White seeded, tolerant to powdery mildew and phytophthora, recommended for Uttar Pradesh
Savithri	2008	84-88	48-50	800-1000	Light brown seed recommended for West Bengal.
HT2	2012	85-90	48-50	700-750	White seed, recommended for Haryana, Punjab, Jammu & Kashmir and Himachal Pradesh

(Source: Ranganatha *et al*., 2012b)

Plant types for stress intensive agriculture: The essential features of the plant types recommended (Ranganatha, 2014) for stress intensive agriculture are as follows: (a) Medium/long duration (90-105 days), however very late types are undesirable; (b) Branching types, 2-4 branches; (c) High degree of tolerance to leaf spots, powdery mildew and moderate tolerance to phyllody; (d) Moderate tolerance to antigastra and gall fly; (e) Better adaptability and high regenerative growth after moisture stress; (f) Fairly good tolerance to waterlogging; (g) Medium tall plant type; (h) Less number of immature capsules; and (i) Fairly good synchrony in maturity. In the traditional areas in India, cultivars like Phule til-1, TC-289, JT-7, Gauri, Rajeshwari, DSS-9, CO-1 and new types with introgression of local germplasm are recommended. The straight derivatives of exotic types should be advocated only after testing for their adaptability. Hence, indigenously bred stocks, possessing these features are choice to the farmers.

Biotic stresses: Sesame suffers from various diseases caused by fungi, bacteria, phytoplasma and virus. The integrated disease management (IDM) is structured to use resistant varieties, cultural practices, disease surveillance and need based control measures. Different degree of host plant resistance to various diseases (Table 6) was reviewed by Ranganatha *et al*. (2012b). Wild sesamum species have shown resistance to insect-pests and diseases (Parani *et al*., 1996; Ashri, 1998). *S. malabaricum* has been reported to be resistant to shoot webber, powdery mildew and phyllody. Resistance to phyllody and phytophthora blight has also been reported in *S. alatum* and *S. radiatum*. As varietal replacement helps providing a spatial and temporal discontinuity against the pathogen, use of resistant varieties has been the main approach. The use of resistant varieties is the cheapest and effective means of controlling diseases (Lee *et al.*, 1985) without application of chemicals. Growing such biotic tolerant/resistant varieties goes a long way in promoting safe sesame crop management practices, for it requires no, or minimum, pesticide/insecticide application (Ranganatha, 2014).

Table 6 Host plant resistance against major diseases

Disease	Causal organism	Status of resistance
Stem and root rot	*Macrophomina phaseolina*	Tolerance in cultivated and resistance in wild species
Phytophthora blight	*Phytophthora parasitica*	Tolerance in cultivated and resistance in wild species
Alternaria leaf blight	*Alternaria sesami*	Tolerance in cultivated and resistance in wild species
Phyllody	*Phytoplasma*	Tolerance in cultivated and resistance in wild species
Wilt	*Fuarium oxysporum*	Resistance in wild species
Cercospora leaf spot	*Cercospora sesami*	Tolerance in cultivated and resistance in wild species
Powdery mildew	*Leveillula taurica*	Tolerance in cultivated and resistance in wild species
Bacterial leaf spot	*Pseudomonas syringae*	Genetic variation reported
Bacterial blight	*Xanthomonas campestris*	Genetic variation reported
Leaf curl	Tobacco mosaic virus	Unknown

(Source: Ranganatha *et al*., 2012b)

Abiotic stresses: Sesame faces various stresses such as water-logging, fluctuations in temperature, photoperiod, salt and drought (Ranganatha, 2014). The climatic factors such as precipitation and humidity, and soil factors influence the growth. Sesame is considered to be more drought resistant than many other crops. However, during the plant establishment phase it is susceptible to moisture stress. Varieties having low water evaporation rates in the conditions of high temperature were tolerant to water stress (Ranganatha, 2014). A comparison of dehiscent and indehiscent types showed that water conductance under irrigated conditions in dehiscent types was higher than in indehiscent types. Thus, there were greater leaf water deficits in shattering than in non-shattering types due to faster transportation in hot weather. Single stem types are reported to have more rapid root elongation than branching types, but root spread in branching types is greater. The root/shoot ratio is generally higher in dry region types. Therefore, root depth and elongation rate, rather than root/shoot ratio must be used as selection criteria. Among the wild species, angustifolium is drought resistant, as it shows high percent of capsule set during dry season. The adaptive features of this species are fleshy roots, small linear leaves, large number of stomata located only at the adaxial surface, and hairiness. This species has the potential of donating valuable genes for drought resistance.

Sesame is highly sensitive to water-logging. However, some varieties show tolerance to considerable extent (Ranganatha *et al.,* 2012b). The resistance has been reported in some wild types and some varieties from Venezuela. Sesame is susceptible to salt concentration. However, variability for salinity tolerance among cultivars has been reported (Ranganatha, 2014). Sesame variety TMV-1 has been found to be tolerant even to sea water. Thus, there is a scope for breeding varieties suitable for high salt concentrations. Sesame has been reported to be sensitive to boron. Phosphorus concentration was found to alter the salt tolerance. The studies should be expedited to understand the basis of stress tolerance, which helps in integrated approach towards developing stress tolerant plants. While developing salt-tolerant sesame, salt accumulation in the sesame seed should be studied from the perspective of safe sesame.

Quality improvement: This is important from nutrition- and trade-dimensions of safe sesame, for healthy composition is always considered by consumers and, therefore, traders. The oil content and fatty acid composition are the important components for quality breeding (Were *et al*., 2006). Oil content generally ranges from 35 to 50%, with oil in most of the commercial cultivars hovering around 50%. Sesame oil primarily comprises oleic acid, linoleic acid, palmatic acid and stearic acid. Genotypic variation was observed for the proportion of fatty acids, but, in general, oleic acid and linoleic acids account for a predominant proportion (Lee *et al.*, 1984; Ashri, 1998; Bedigian, 2010). With the growing health consciousness, the international demand and export of sesame are continuously increasing (Ashri, 1998; Bedigian, 2010). Therefore, the improved varieties containing oxalic acid below 1%, *viz*., HT-1, Pragati, TC-25, Phule Til-1, JLT-7, Rajeshwari, DS-1, GT-1, TKG-55 and AKT-101 are recommended. The varieties with less than 2% FFA content, *viz*., Hima, T-3, Vinayak, Shekhar, RT-125, N-8, T-78, JLT-26, GT-1, T-4 and AKT-101 are considered of good quality. White seeded sesame from drier area of Gujarat (0.5-1.2%), Rajasthan (0.75-1.5%) and Maharashtra (1.0-2.0%) contains low FFA, conforms to the norms of good quality. Varieties of sesame containing lignans over 830mg/100g of seed are preferred in the international market.

Evaluation of Vietnamese and Combodian collections revealed oil content of 47.2 to 55.6% and mean oleic acid of 37.65%, linoleic acid of 45.67% in the germplasm (Pham, 2011). Were *et al.* (2006) reported oleic acid of 31.6 to 41.9% and linoleic acid of 42.9 to 53.9% in the genetic stocks. Uzun and Cagirgan (2009) identified molecular markers linked to determinate growth habit in sesame. Genotypic variation for fatty acid composition and oil content was noticed in the determinate and indeterminate types of sesame (Uzun and Cagirgan, 2009). Further, suggested that indeterminate type accumulated higher oil content than determinate type.

The varieties recommended for various states (Table 7), and specific situation/ purpose (Table 8) are presented here.

Table 7 Varieties recommended for different states

Name of State	Varieties
Gujarat	Guj-Til-1, Guj-Til-2, Purva-1, GT-10
Madhya Pradesh	JT-7, N-32, TKG-21, TKG-22, TKG-55, JTS-8, RT-54, Uma
Rajasthan	RT-46, RT-54, RT-103, RT-125, RT-127, Pratap
Maharashtra	Phule Til-1, N-8, Tapi, Padma, T-85, AKT-64, AKT-101
Uttar Pradesh	T-4, T-12, T-13, T-78, Sekhar, Pragti
Tamil Nadu	Co-1, TMV-3, TMV-4, TMV-5, TMV-6,TSS-6, VRI-1, Paiyur-1
West Bengal	Tilottoma and Rama
Orissa	Vinayak, Kanaka, Kalika, Uma, Usha, Nirmala, Prachi
Andhra Pradesh	Gouri, Madhavi, Rajeshvari, Varaha (YLM-1), Gautam (YLM-2), Swetha, Chandan
Kerala	Kayamkulam-1, Kayamkulam-2, Soma, Surya, Thilothama, Thilothara
Karnataka	E-8 and DS-1
Punjab	Punjab Til-1, TC-25 and TC-289
Bihar	B-67 and Krishna
Haryana	Haryana Til-1
Himachal Pradesh	Brijeshwari
J & K	RT 46
NEH region	TKG-21 and TKG-22

[Source: Sesame manual at http://agmarknet.nic.in]

Table 8 Important varieties for specific situation/purpose

Salient features	Variety
White bold seeded, export quality	Nirmala, Gujarat Til-2, JTS-8, HT-1, Tapi and Phule Til-1
Black seeded for domestic/ medicinal use	TMV-3, CO-1 and GT-10
High oil content	TKG-21, JT-27, TKG-22, Gautam, E-8, Kayamkulam-1 Tilothama, and TSS-6
Suitable for semi-*rabi*	N-8, AKT-101
Suitable for summer	TMV-4, Uma, Rama, Gouri, RT-54, TKG-21 and TKG-22
Non-shattering habit	Uma
Suitable for heavy soils	Pratap
For lowland and upland rice fallow	Soma, Surya and Thilothama
Phytophthora blight	TKG-22
Bacterial and Cercospora leaf spots	TKG-21

[Source: Sesame manual at http://agmarknet.nic.in]

TECHNOLOGICAL CONSIDERATIONS

Exploitation of hybrid vigour in sesame: Hybrid vigour, also called heterosis, ensures the exploitation of benefit of traits governed by various types of gene interactions. If hybrid-vigour is studied and exploited for breaking yield-barrier, it would greatly benefit the farmers, thereby creating a scenario that leads to increasing sesame area, influencing regulatory policy formulations, regulated and commercial cultivation of sesame – all these encourage development and deployment of safe sesame production practices. In this perspective, opportunities and challenges in exploitation of hybrid vigour in sesame is discussed.

Genetics of heterosis: Although sesame is largely self-pollinated, substantial levels of heterosis have been reported for certain hybrid combinations from various countries. High yield of hybrid, than those of the better parent have been reported by Murthy (1975), Osman and Yermanos (1982), Yermanos (1984), Osman (1989), Zhan *et al*. (1990), Tu (1993), Murthy (1994), Ashri (1998), Sumathi and Muralidharn (2009) and Bedigian (2010). Zhao (1994) reported that there was residual heterosis in F_2. Generally, high levels of heterosis was noticed, when the parents of hybrids were from divergent origins. There were also marked differences in the F_1 hybrid vigour between reciprocals (Ray and Sen, 1992; Tu, 1993), suggesting the involvement of the cytoplasmic component. General and specific combining ability were assessed in different hybrid combinations by various authors; their relative impact varied. Some researchers considered additive gene action to be more important (Ibrahim *et al*., 1983; Dharmalingam and Ramanathan, 1993; Inrie, 1995), while others considered the non-additive components to be more important (Imrie, 1995; Quijada and Layrisse, 1995). The impact of additive vs. non-additive genes is expected to vary from one hybrid combination to the other.

However, in order to exploit hybrid-vigour, there is a need to develop hybrid technologies, *viz*., (a) Development of genetic male sterile line; (b) Development of cytoplasmic genetic male sterile line; (c) Manual emasculation and pollination; and (d) Gametocidal application.

Development of genetic male sterile line: Several sources of genetic male sterility are reported in sesame (Ashari, 1998; Bedigian, 2010). Male sterility in sesame was reviewed by Yermanos and Osman (1981), Osman (1985), Ashri (1998) and Bedigian (2010). Male sterility is expressed under homozygous recessive conditions (msms) and such lines are maintained by crossing with heterozygous (Msms) male fertile plants. The genetic male sterility alleles in sesame were originated as a spontaneous mutation in Venezuela (Mazzani *et al*., 1981). Gao *et al*. (1992) reported that in msms plants, the non-vacuolated microspores break down at the tetrad stage. Breeding lines containing male sterility (ms) allele were developed by Yermanos (1984). Male sterility trait, reported in a line of Venezuela, has been introgressed into the lines adapted to diverse conditions; e.g. California (Yermanos and Osman, 1981) and China (Wang *et al*., 1993; Wang *et al*., 1995; Tu *et al*., 1995). This male sterility gene has been exploited for the production of hybrids in China. However, stable genetic male sterile lines for commercial exploitation in hybrid seed production is yet to be developed in India.

Development of cytoplasmic genetic male sterile line: Development of cytoplasmic genetic male sterile line is a stable means for production of hybrid. The crossing between *S. malabaricum* and *S. indicum* followed by genomic substitution of *S. indicum* resulted in development of CGMS lines (Prabhakaran *et al*., 1996; Bhuyan and Sharma, 2003). Through the substitution of nuclear genomes, CGMS lines were developed. Identification of suitable pollen parent for exploitation of heterosis for producing superior hybrid is essential. Male sterility has been noticed in the cross of *S. malabaricum* x *S. indicum*, however not in the reciprocal cross (Thangavelu, 1994a), suggesting that inter specific crosses may produce cytoplasmic genetic male sterility. However, the stable CGMS system is yet to be developed.

Manual emasculation and pollination: The flower of sesame is campanulate, i.e., bell-shaped, with 2-3 cm long corolla having five epipetalous stamens, enabling easier emasculation through the removal of petals. The anther dehisces depending upon season and location (Ranganatha *et al*., 2012b). The viability of the anther is shorter (24 hrs) than that of stigma (>48 hrs). Floral biology is such that out crossing percent ranges between 5 and 15 per cent. However, a split corolla line is reported to have high out-crossing to the tune of 70%. Due to long flowering duration and high pollen density, single healthy male flower can pollinate 3-4 female flowers. High number of seeds per capsule (40-60) and low seed rate makes manual hybrid production a viable option. As the emasculated female line does not have any pollen, and therefore, the insect activity is minimal in female line, hand pollination system becomes easy for production of hybrid seeds. However, other school of thought considers manual production of hybrid to be a laborious, time consuming and uneconomical (Ranganatha, 2014).

Gametocidal application: Because manual emasculation of female line is time consuming, the use of gametocide is considered as an alternate means of emasculation. However, it has been observed that the application of gametocide adversely affects ovule fertility and many of the morphological traits, *viz*., plant height, number of branches, capsules/plant, seeds/capsule and seed yield of male-sterility-induced female plants. Application of sodium 2, 3-dichloro isobutyrate @ 1000 ppm at bud initiation stage followed by two sprays at 10 days interval was initially found effective. The application of Mandok @ 0.05 % at bud initiation followed by two sprays at ten days interval produced better pollen sterility in the female line without affecting ovule fertility. Chemical emasculation of sesame by growth regulators such as dalapon, FW 450 (2, 3 dichloro methyl propionic acid sodium salt) and sodium 2, 3-dichloropropionate was reviewed by Osman (1985). In China, Zhao (1994) reported that the gametocides caused hypertrophy of the tapetal cells with FW450. It is, therefore, important that while selecting gametocide types and dosages, their effect on ovule fertility and plant morphology should be kept in mind (Sudhir Kumar and Reddy, 2005). The best time for application is just after Pollen Mother Cell (PMC) formation and this treatment is not applicable for indeterminate lines. However, more research is needed to be expedited to invent effective gametocides suitable for their application in commercial hybrid seed production.

Hybrid seed production technology: Four flowers of female parent can be pollinated by a single male flower. The process of dusting is attended between 6 and 9 AM. During this period, dusting of 800-1000 flowers could be completed. The care must be taken to emasculate and pollinate all the flowers produced on a particular day. The left over flowers that missed emasculation must be removed. The percent of capsule set is as high as 80 (Manivannan and Ganesan, 1993).

Issues related to hybrid seed production: In view of the difficulties encountered in producing hybrid seed with the available genetic male sterility, F_2 hybrids with residual heterosis were proposed in China (Zhao, 1994), but this approach was not adopted due to non-uniformity and the reduced vigour. Use of the split corolla mutant, which reduces selfing as the maternal line, is an alternate approach for the production of hybrid seed. If the crossing blocks are in isolated areas from other flowering plants around, insect pollinators will produce a high percent of out-crossed seed. Even if the cross pollination rate is only 50%, the yield increase will be considerable, provided the parents have high combining ability. An advantage of this system is that the split corolla female parent can be maintained by selfing (Ranganatha *et al*., 2012b).

Genetic engineering of sesame oil: Vegetable oils may sometimes lack the properties best suited for their intended use. For instance, they could have undesirable nutritional attributes such as the presence of anti-nutritional factors or a high proportion of saturated fatty acids (Pathak *et al*., 2014), in comparison to the more acceptable unsaturated forms. Such deficient oil must be modified to attain the desired properties. Modification of vegetable oils is conventionally done by chemical processes, such as partial hydrogenation, fractionation, etc. (Timms *et al*., 2005). These processing methods, however, are expensive and sometimes yield undesirable products in the edible oils. Development of crop varieties producing oils with high quality with better market value presents a better alternative to chemical modification of vegetable oils. One of the methods to achieve the above target is domestication of wild plants that accumulate oil with characteristics of interest. However, it takes a long time in breeding for the cultivars to adapt to cultivation and huge efforts are required to domesticate and develop cultivars of high nutritional value. In sesame, attempts are being made to modify the antioxidant bio-active components by means of conventional breeding to meet various consumer demands (Pathak *et al*., 2014). Though the technique is successful, conventional breeding relies on naturally occurring variation within a species or genus, and is limited to cross-compatible taxa. Current research effort is directed toward creating oils having high levels of nutritional components by genetic engineering. This approach is superior to previous researches owing to its precision and applicability across taxa. By using molecular techniques, it is possible to modify specific seed oil quality while keeping the rest of the genetic background of the plant unchanged. The major lignans and tocopherols should be targeted for genetic modification in sesame. Enhancement of these components would lead to increase in stability and keeping quality of oil. Biotechnology offers the best opportunity for transferring high antioxidant ability and nutritional composition from wild to cultivated species. A detailed knowledge of the metabolic pathways, involved in the biosynthesis of antioxidative compounds, is a prerequisite for genetic engineering of bioactive components (Pathak *et al*., 2014). Table 4 shows target enzymatic steps, which could be modulated by genetic engineering, to alter the seed fatty acids, lignan and tocopherol profile, leading to accumulation of nutritionally superior oil in sesame. Moreover, down-regulation of the gene encoding synthesis of phytic acid would enable low phytic acid production thereby enabling bioavailability of minerals. Using various modification strategies, it is possible to vary the specific properties of different bioactive components. Considering that conventional sesame oil is beneficial to human health, it seems appropriate that further improvement of quality should focus on producing oils with new nutraceutical, pharmaceutical, dietary and cosmetic uses that would embrace the known advantageous properties of the oil (Pathak *et al*., 2014). While doing so, scientific information and data are needed to be generated on safe limits of various components altered by modifications so that they help producing sesame, safe for various uses including human consumption.

CROP MANAGEMENT CONSIDERATIONS

One of the major inputs to safe sesame production comes from the crop management. Discussed in the following are cultural, mechanical, chemical and biological practices that can be followed for an effective management of nutrients, weeds, diseases and pests, leading to the safe sesame production.

Common cultural practices: Timely sowing, field sanitation, crop rotation, deep ploughing of fields during summer, destruction of alternate host plants, eradication of weeds and volunteer sesame plants help safe sesame production (Ranganatha *et al*., 2011b). Pre-monsoon deep ploughing (two/three times) helps to expose the hibernating pupae to sunlight and predatory birds. Planting of sorghum/maize/bajra in 4 rows all around sesame crop provides for guard/barrier crop. The use of healthy, certified and weed-seed-free seeds is of great help in achieving safe sesame production.

Integrated nutrient management (INM): Deep-ploughing in summer helps break hard pan and thereby facilitates rain water absorption and deep root-penetration. Application of manures and fertilizers need to be practiced based on soil test values following integrated nutrient management approach. Well decomposed farm-yard-manure (FYM) @ 5 to 10 t or vermicompost @ 2.5 to 5 t/ha must be incorporated during the last preparatory cultivation. Soil must be treated with *Azotobactor* or *Azospirillium* culture @ 600 g/ha. Fertilizer requirements are: N-P-K @ 30-60-40 kg/ha, at the time of sowing, for the rainfed crop; and, N-P-K @ 40-60-40 kg/ha at the time of sowing followed by 30 kg/ha as top dressing, at 30-35daysafter sowing, in case of irrigated crop. Sulphur @ 50 kg/ha helps to increase the yield, if soils are deficient in sulphur. Placement of fertilizer at seeding using seed drills is more effective than broadcast application.

In order to achieve the higher seed yield, the farmers must increase the dose of organic manures, *viz*., FYM from 5 to 10 t/ha; compost from 3 to 5 t/ha; oilcakes from 0.5 to 1 t/ha; rock phosphate from 0.5 to 1 t/ha and gypsum from 1 to 2 q/ha, based on the soil fertility and targeted yield, and considering the availability. Further, on long-term basis, green manuring, bone meal, elemental sulphur and wood ash must be used for maximizing organic production. It is important to avoid the partially decomposed FYM/Compost, for it may contain weed-seeds and, therefore, may infest the field with weeds.

Weeds: At the time of field preparation, the field should be cultivated to destroy the weeds already grown in the field. Boundary and bunds of the field should be kept free from weeds. Sowing in lines is followed to facilitate inter-culture operations. Stale seed bed technique helps to control early germinating weeds. The use of straw mulch helps to control the weed growth and to conserve the soil moisture. Sesame is sensitive to weed competition during the first 15 to 45 days after sowing. A minimum of two weedings/intercultivations, one at 15 days after sowing and the other at 35 days after sowing, are required to keep the field relatively weed-free. Row-seeded crop facilitates the use of blade harrows for inter-cultivation. Left-over weeds must be removed after the harvest of crop to prevent the spread of weed-seeds.

Strategic diversification: Strategic diversification helps non-chemical measure of controlling weeds, pests and diseases while ensuring maximization of economic returns. Thus, such practices are useful in safe sesame production.

Crop rotation: To avoid weed proliferation, sesame should not be cultivated directly following a fallow period. Previous crop must be with a few demands from the soil. For it loosens the soil with its tap root system, providing a dense network of roots in the upper layer, sesame is also a good preliminary crop. Because of its short vegetation period, tolerance to drought and ability to use stored moisture, sesame is well-suited as second crop also. The typical crop rotation partners for sesame include cotton, grain legumes (peanuts, soya, mung, urd bean, red gram, variety of beans, etc.), maize, and rice (Augstburger *et al*., 2000).

The following are some of the examples at global level. Turkey: Chickpea-wheat (or barley)-sesame; Uganda: Cotton-sesame-maize+beans-fallow; and, South Brazil: green fertilizers with white lupins/vetch/oats or field beans, as second crop during winter, and maize, soya or sesame in rotation (Weiss, 2000), during summer.

Intercrop: In different parts of the world, sesame is grown as a part of mixed crop with cotton, maize, sorghum, millet, peanuts, soya, or phaseolus species. Land equivalent ratio (LER) is never-the-less higher (Weiss, 2000).

Intercrop with perennials: Cultivation between the rows with cashew, agro-forest trees, and coconut palms; contour-line planting with pineapple; or, legume hedges between the strips helps to prevent the soil erosion and thereby reduces the loss of nutrients, organic substances and soil acidification, ultimately helping to improve the yield (Weiss, 2000).

Bee-keeping: It is simple, yet rewarding, to keep bees during the main pollination period, for it helps increasing the yield up to 21% (Rao *et al*., 1980).

PLANT HEALTH MANAGEMENT CONSIDERATIONS

Adoption of non-chemical approach (Hegde, 2005) in sesame health management, to control disease and pest, contributes significantly in safe sesame production. These approaches address trade and health dimensions of safe sesame. Even though the following practices are commonly followed among farmers, our aim is to collate and analyze them from the perspective of safe sesame. Where ever feasible and economical, chemical control methods are also discussed keeping in mind their residual effects reported by other researchers. The point here is that preferably non-chemical methods supplemented by chemical methods, not compromising the health and trade dimensions of safe sesame, make it a prudent combination of integrated pest management (IPM) for safe sesame production.

Application of bio-pesticides: Bio-insecticides are a group of insecticides that are derived from biological origin like plants, microbes, insects, lower amphibians, etc. They act only on target organisms like pest which cause widespread damage to plants and crops without affecting other spheres of life like grazing mammals, birds, human, etc. They also reduce major environmental hazards caused by chemical pesticides (Das *et al*., 2007). They possess the following general features (Das *et al*., 2007): a narrow target range and a specific mode of action, slow acting but high effectiveness, relatively critical application times, suppression rather than elimination of pest population, limited field persistence, short shelf-life and being safe to human and the environment.

Soil borne and foliar diseases: Rising of African marigold nursery 15 days prior to sowing and ensuring of proper spacing help controlling many pests and diseases (Augstburger *et al*., 2000).

Non-chemical control: Application of neem cake @ 200 kg/ha, seed treatment with *Trichoderma viride* @ 4 g/kg of seed or neem seed kernel extract (NSKE) 4%, conservation of natural enemies through ecological engineering and augmentative release of natural enemies, and spraying of neem oil @ 5 ml/l as foliar sprays (Augstburger *et al*., 2000) help the plant health management.

Cultural control: Soil amendment with farm yard manure @ 5 t/acre is helpful in reducing the incidence of the disease, powdery mildew. Bower system (maintain gapping) of cropping reduces the disease incidence. Avoidance of planting overlapping crops in adjacent area. Crop rotations, *viz*., sesame-maize-cabbage, okra-sesame-maize, maize-sesame-maize and sesame-finger millet-eggplant are reported to be effective in reducing disease incidence. Crop rotation with non-host crops, particularly with rice, not only helps reduction of disease incidents but also in providing good drainage. Destruction of crop debris, removal of alternate weed hosts, providing irrigation at critical stages of the crop, and avoiding of water-logging and of water-stress during flowering stage help controlling pests and diseases. Avoidance of chemical spray when 1-2 larval parasitoids are observed helps to enhance parasitic activity.

Seed treatment: Treatment with Trichoderma @ 4 g/kg of seed, *Pseudomonas fluorescens* @ 2 g/kg seed or *Bacillus subtilis* @ 2 g/kg seed, and Neem seed kernel extract (NSKE) 5% (Augstburger *et al*., 2000) help controlling soil borne pathogens.

Mechanical practices: Mechanical practices, such as collection and destruction of disease-infected and insect-infested plant parts, eggs and early stage larvae; hand-picking during the early stages of crop of the older-larvae, gregarious caterpillars and the cocoons that are found on stem and destroying of them in kerosene-mixed water; the installation of yellow sticky traps @ 10-15 trap/ha, light trap @ 1-3/ha and operating them between 6 PM and 10 pm; installation of pheromone traps @ 10-13/ha with the replacement of lures with fresh ones after every 2-3 weeks for monitoring adult moth activity; and, the provision of bird perches @ 50/ha to encourage predatory birds such as king crow, common mynah, (Das *et al*., 2007; Augstburger *et al*., 2000) etc., complements in production of safe sesame; for there is no, or little, application of chemical control measures.

ECO-FRIENDLY DISEASE MANAGEMENT

Phyllody: Phyllody (Phytoplasma) is a serious and wide spread disease in sesame. The phyllody is transmitted by the insect vector *Orosius albicinctus,* making all floral parts transformed into green leafy structures. In severe condition, the entire inflorescence is replaced by short twisted leaves closely arranged on a stem with short internodes and abundant abnormal branches causing witches broom like appearance of plants. In addition to common cultural, mechanical and biological practices, intercropping of sesamum + redgram (6:1) and spraying of neem oil @ 50 ml/l for vector (leafhopper) control is helpful in managing the phyllody. The tolerant varieties are TKG 21, RT-125 and RT-103. Inter-cropping of sesame + pigeonpea (1:1) is helpful for the management of Phyllody.

Stem and root rot: Another important disease is stem and root rot (*Macrophomina phaseolina / Rhizoctonia bataticola*), in which stem becomes black at ground level and then extends upwards rupturing the stem. Black dots appear on the infected stem and the roots will become brittle. In disease infected plants, capsules turn black, which open prematurely exposing shriveled seed. The tolerant varieties are RT-46, RT-125, MT-75, TKG-22 and Nirmala. Inter-cropping of sesame + mothbean (1:1 or 2:1) is helpful for controlling stem and root rot.

***Cercospora* leaf spot**: *Cercospora* leaf spot occurs in epiphytotic form reducing the seed yield severely. Starting with appearance of small, angular brown leaf spot, it spreads, under favorable conditions, to leaf petiole, stem and capsules; forming linear dark colored lesions. Inter-cropping of sesame + pearl millet (3:1) is helpful for controlling *Cercospora* disease.

Powdery mildew: Powdery mildew appears at any stage, flowering to capsule formation, forming small patches of white powder on upper side and occasionally on lower surface of leaves. The tolerant varieties are Swetha Til, RT-127 and MT-75.

Phytophthora blight: Phytophthora blight produces initial symptoms of water soaked spots on leaves and stem. The spots are brown in the beginning which later turns to black. It can attack at all the stages of the crop. Phytophthora tolerant varieties are MT-75, TKG-22 and TKG-55. Inter-cropping of sesame + pearl millet (3:1) is helpful for controlling Phythopthora disease.

Alternaria leaf spot: Alternaria leaf spot affects the plants at all stages and produce small dark brown water soaked, round to irregular lesions with concentric rings. Inter-cropping of sesame + pearl millet (3:1) is helpful for controlling Alternaria disease.

Integrated approach: The seed or soil treatment with biocontrol agent is gaining importance in the management of soil- and seed-borne diseases. Seed treatment with *Trichoderma viride/Bacillus subtilis* @ 4 g/kg of seed helps to control all the soil/seed borne pathogens. Soil application of biocontrol agents like *Trichoderma viride* or *Pseudomonas fluorescence* @ 2.5 kg/ha. Cultural practices, recommended for disease management, such as crop rotation, deep summer ploughing, good drainage, destruction of crop residues, alternate hosts, roguing of diseased plants and growing of tolerant varieties must be followed meticulously, for all these supports safe sesame production.

ECOFRIENDLY INSECT-PEST MANAGEMENT

Leaf roller and gall fly: Leaf roller (*Antigastra catalaunalis*) and gall fly (*Asphondylia sesami*) are serious pests on sesame. Leaf roller/ capsule borer is the most serious pest. The active period for this pest is July to October. In the early stage of crop, caterpillars feed on tender leaves. At flowering, larvae feed inside the flowers and on capsules; larvae feed on developing seed boring into capsule. Gall fly is another important pest. Clear humid weather is conducive for its multiplication. Maggots feed inside the floral buds, making it fail to develop. Apart from common cultural, mechanical and biological practices, discussed earlier, spraying of quinalphos 25% EC or carbaryl 10% DP helps in the management of the pests. Residues of quinalphos are found in soil up to 8 days and in plant material up to 3 days (Aktar *et al*., 2008). Carbaryl residual effect in the field is observed up to 22 days (Rehman *et al*., 1999). Therefore, sesame seeds and oil are safe, for they are free from quinalphos and carbaryl contamination. The tolerant varieties are: RT-46, RT-54, RT-103, RT-125, RT-127, TKG-21, TKG-55, TKG-22, Usha, SwetaTil, Tapi, Krishna, N-32, JTS-8, MT-75, Hima and SI-250, for *Antigastra catalaunalis;* and RT-46, Swetha Til, RT-103, OMT-26, RT-127, Hima and RT-125, for gall fly. Intercropping with mung bean, urd bean, moth bean, cowpea, pigeonpea and pearl millet is helpful for managing *A. catalaunalis;* and with mungbean, pearl millet and groundnut, for gall fly.

Linseed bud fly: Linseed bud fly (*Dasineura sesami*) is also an important pest of sesame. Maggots feed inside the floral bud leading to formation of gall like structure that does not develop in to flower/capsule. The affected buds wither and drop off. The tolerant varieties are MT-175 and Shekhar.

Leafhopper: Leafhopper (*Orosius albicinctus*) is a serious pest for it transmits phyllody. Nymphs and adults suck the sap of tender parts and transmit the disease. Apart from common cultural, mechanical and biological practices, the usual practice is to spray oxydemeton-methyl 25% EC or Dimethoate 30 EC. But it is not safe as their residues last as long as 2 years. Therefore, natural method of control is recommended. There's a product called "Ecobran" that only affects grasshoppers and their close relatives. It doesn't affect other insects or birds (www.ecobran.com). Ecobran uses carbaryl, an organophosphate. Inter-cropping with redgram helps the management of sesame leaf hopper.

Hawk moth: Til hawk moth (*Acherontia styx*) is a minor pest on sesame. Common cultural, mechanical and biological practices and deep-ploughing to expose the pupae for predation by insectivorous birds followed by hand-picking (collection) and destruction of caterpillars helps to manage this pest.

Bihar hairy caterpillar: Bihar hairy Caterpillar (*Spilarctia obliqua*) is a minor pest on sesame. In addition to common cultural, mechanical and biological practices, single irrigation, given to avoid prolonged mid-season drought, helps to prevent pre-harvest infestation. The trenches of 1 inch depth dug in the middle of the field help to kill the larvae in pits.

Pod bug: Pod bug (*Elasmolomus sordidus*) is another minor pest on sesame. Measures to control other pests take care of this.

Integrated approach: Destruction of crop debris and use of light traps are helpful to monitor populations. Cultural practices helpful for minimizing the pest-infestation are crop rotation, deep summer ploughing, good drainage and use of tolerant varieties. Two sprays of NSKE 3% or neem oil 5% or mahua oil 2% are effective biopesticide to control leaf roller/capsule borer, pod bug, bud-fly and leafhopper. If insect population is not coming down then third spray of NSKE or neem oil alternating with the chemicals may be followed. Apart from conserving native natural enemy populations which are mortality factors for pest management, there must be releasing of larval parasites, *viz., Bracon hebator, Bracon geichi* and Trathala flavo-orbitalis; and predators, *viz., Cantheconidia furcellata,* for managing *A. catalaunalis;* Larval parasites, *viz., Eurytoma dentipectus* and *Bracon hebetor*, for gall fly; and bioagents, *viz., Trichogramma* spp., *Apanteles achorantiae* (larval parasite) and *Zygobothria sp*., for Til hawk moth. The use of fungal entomopathogens, *viz., Beauveria bassiana* @ 10g/1, *Metarrhizum ansiopliae* @ 10g/l and *Bacillus thuringiensis* @ 2g/l is also an effective measure against *A. catalaunalis.*

HARVEST AND POST HARVEST CONSIDERATIONS

Safe practices to be followed during harvesting, packaging, storage, processing, and handling, contribute significantly towards trading sesame as safe commodity for human consumption. In consumer- and, therefore, trade-perspectives, absence of chemicals, heavy metals, infectious pathogens and any other contaminants in sesame, or any other commodity in general, is considered safe. This concern can be addressed in two ways; first, ensuring absence of such contaminants, and second, meeting the regulatory requirements of maximum residue limits (MRLs) standards set by national and international regulatory body (e.g., sanitary and phyto-sanitary measures set by WTO and the food standards set in codex alimentarius of FAO-WHO). In order to prevent the presence, or to keep below the MRLs, of chemicals, heavy metals, infectious pathogens and any other contaminants in sesame seeds and oils, the safe practices must be adopted at the sites of harvesting, storage, processing and handling to ensure that products meet the safety standards.

Harvesting: Timely harvesting ensures optimum quality and consumer acceptance. The harvesting of the sesame must be done at its physiological maturity, for delayed harvesting may result in shattering of seeds. The physiological maturity is ascertained when the following changes are observed: the lower most capsule turned brown and began to pop open, the stem turned yellow, the leaves started falling-off, blossoming has finished and leaves turned yellow. Uniform maturity is an important genotypic feature that not only minimizes harvesting cost but also the yield losses. Sesame is generally harvested by hand, dried in field and threshed and cleaned manually (Ranganatha *et al*., 2011a). Therefore, care must be taken to maintain hygiene of the highest degree to prevent contamination with infectious microorganisms from sources such as hands of persons, soil and cloths, or canvas, deployed for drying and threshing. Hands of the harvesting persons must be kept hygienic, harvested plants must be placed on clean canvas, or sturdy clothes, spreaded in the field, and allowed for drying for 4-5 days in the open sun. The sheaves must be stacked in the open; one above the other, in circular fashion, with the stem pointing out and the top portion pointing inside. The sheaves must be small (diameter of 15 cm) and be positioned on the cloth or canvas spread in the field so that sun can shine down directly on to the capsules (Weiss, 2000). In this way, apart from achieving easier threshing and the minimum loss, the drying through better heat and air circulation helps the avoiding of fungal infection.

For the mechanized harvesting, drying, and threshing, the above-points are to be kept in mind while developing and deploying appropriate machineries — to help produce the safe sesame seeds/oil. In uniformly maturing genotypes, single harvesting is enough; otherwise 2-3 harvestings are required.

In the first shaking, 75% of the seeds fall off. Drying of the plants in the sun for 2-3 more days and shaking of the plants once again ensure that all the mature seeds fall off. Winnowing the seeds and drying in the sun for 3-5 days with intermittent stirring, once in 3 hours, helps to achieve uniform drying. Collected seeds must be stored in gunny bags. Utmost care must be taken to clean clothes/bags/ containers/equipments used in harvesting, threshing and processing. Harvesting during adverse weather conditions must be avoided.

Packaging: Packaging provides physical protection against contamination, damage or handling losses during transportation. The produce is handled many times between production and consumption. Hence, it plays an important role in marketing of produce. More care is to be taken in packaging of Sesame seed meant for export. Appropriate packaging materials, labels and label-information should be used (http://agmarknet.nic.in /amrscheme/4.% 20Manual-Sesame-Draft.htm#ANNEXURE- V).

Safe and scientific storage of sesame: Stabilization of prices by balancing demand and supply necessitates storage. Condition of storage should protect the quality of seed from deterioration (Ranganatha, 2014). Storage provides protection against weather, moisture, insects, micro-organisms, rats, birds and any type of infestation and contamination. Therefore, the method of storage plays a very important role in supplying the safe sesame. In India, for AGMARK certification, the following requirements must be followed for safe and scientific storage (http://agmarknet. nic.in/amrscheme/4.%20Manual-Sesame- Draft.htm# ANNEXURE- V). The relevant information is reviewed here from the perspective of ensuring safe sesame at storage level.

Selection of site: The storage structure must be located on a raised well-drained site. The site must be protected from humidity (moisture), excess heat, insects, and rodents. It must not be exposed to the bad weather conditions and must be easily accessible.

Storage structure: The storage structure must be selected according to quantity to be stored. Sufficient space must be provided between two stacks for proper aeration.

Cleaning and fumigation: The storage structure must be properly cleaned and there should be no left-over seeds, cracks, holes and crevices in structure. The structure must be fumigated before storage.

Drying and cleaning: The seed must be properly dried and cleaned to avoid quality deterioration before storage.

*Cleanliness of bag***s**: Only new and dry gunny bags must be used for storage.

Separate storage of new and old stock: The new and old stocks must be stored separately to check the infestation and to maintain the hygienic condition.

Use of dunnage: The bags of sesame seeds must be kept on the wooden crates or bamboo mats along with a cover of polythene sheet to avoid the absorption of moisture.

Proper aeration: There must be proper aeration during the clean-weather-condition. Aeration must be avoided during the rainy season.

Cleaning of vehicles: The vehicles that are used for the transportation of sesame seed must be cleaned with the disinfectants to avoid infestation.

Regular inspection: To maintain proper health and hygiene of stock, regular inspection of stored seed is essential.

Management of storage pests: Discussed here are the storage pest management practices that are safe for trade purposes, for they are recommended by 'AGMARK' (http://agmarknet.nic.in/amrscheme/4.% 20Manual-Sesame-Draft.htm#ANNEXURE-V) certification agency. Regarding each of the storage pests, the nature of damage and the control measures are discussed from the view point of ensuring the safe sesame while controlling the storage pests.

Rice moth (Corcyra cephelonica): Larvae contaminate the seed with dense webbing, excreta and hairs making whole seeds bound into lumps. The control measures are: careful sanitation to avoid stored pests -- dispose of heavily infested seeds in wrapped, strong, plastic bags or in sealed containers --, maintenance of optimum moisture content (not >5%) for it is critical in preventing the development of storage pests, avoidance of storing broken seeds for the long period, and dusting with an inert-substance such as attapulgite-based clay dust (ABCD), to minimize storage insect problems.

Rice weevil (Sitophilus oryzae): Adults and larvae both bore in to seeds and feed on the seeds. Control measures are same as those for rice moth.

Turmeric powder and essential oil of mint, mentha species, can also be used to control the storage pests.

Rodents: Rodents eat whole and broken seeds, spilling more seeds than they consume. Rodents also cause contamination with their hair, urine and feces, which deteriorate the quality of sesame and cause many diseases, like cholera, ringworm, rabbies, etc., to human upon consuming such contaminated sesame. Prevention, before damaging sesame bags, alone ensures safe sesame as it is impossible to reverse the contamination already occurred. Further, rodent prevention provides for a great deal in ensuring safe sesame, for it keeps the product free from infectious microorganisms, otherwise-which it is unsafe as rodent, being close relative of human, harbors most of the infectious pathogens of man. If rodents are noticed, immediate inspection to find damaged sesame bags should be undertaken after killing all the rats in the store room. Different types of rat cages which are available in the market can be used. Rats caught in the cage can be killed by dipping in the water. Anti-coagulant pesticide like zinc phosphide can be mixed with food stuff used as bait. Keeping baits for a week is recommended as it helps both monitoring and controlling. Tablets of aluminium phosphide must be placed in each hole / burrow and the holes must be plugged with the mud mixture to make it airtight, thereby killing all the rodents in the burrow by fumigation. Following this, the burrows should be plugged completely to prevent re-occupation. Burrow inspection and destruction carried out before storing sesame is a good preventive measure. The rats can be controlled by lemon verbena.

CHALLENGES

The need for promoting nutraceutical uses of sesame: The future of functional foods depends upon the unequivocal demonstration of their efficacy in promoting health (Pathak *et al*., 2014). The bioactive components such as sesamin, sesamolin and tocopherols (Table 3) found in sesame seed need to be accurately quantified and safe limits needs to be standardized. Food-chain of human consumption needs to be enriched with these compounds using safe sesame having such bioactive components developed through conventional plant breeding and agronomic practices along with application of molecular techniques. For economic gain in international and national market, monitoring and regulation of trading safe sesame as functional food needs a comprehensive, health- and trade- promoting policy frame-work apart from development of cost effective and universal reference-analytical techniques. Also, there is a need to develop superior sesame genotypes with the enhanced level of various bioactive compounds.

The need for transition from organic farming to safe and sustainable farming: Two famous books, "One Straw Revolution", by Masanobu Foukuoka, and "Oruvarathayude Bonus" (bonus of fertility), by Dayal, form the starting ground for discussion on sustainable agriculture synonymous with organic farming. Sustainable agriculture integrates three major goals: (1) environmental health, (2) economic profitability, and (3) socio-economic sustainability. Sustainability rests on the principle that we must meet the needs of the present without compromising the ability of future generations to meet their own needs (Joseph, 2006). Organic farming, in its traditional sense, does not allow the use of chemicals for plant health management. However, the use of organic substances, for promoting the plant growth and development, and for managing the plant health, was in vogue. The basic premises for such a practice was that while organic substances are safe, chemical substances are hazardous to the environment and human health. In the sense of safe and sustainable farming that is relevant today, how-long the toxicity of a particular substance, irrespective of its organic/inorganic origin, persists in the environment and plant parts, must be considered while deciding whether, or not, to use it in the plant health management. The emphasized is that because something is of biological or natural origin, we cannot accept it unless its deleterious effect is ruled out beyond reasonable doubt; similarly, because something is artificially or industrially produced, its benefit need not be ignored unless its harmful effect is proved. Thus, the deployment of substances that do not affect the environment and health of consumers is wiser to be allowed to be used, if it otherwise ensures safe sesame production. The barriers of low-output and limited-resource-capacity of natural inputs that are inherent in the traditional sense of organic farming cannot be overcome unless there is a transition from organic farming to safe farming that can meet the growing demand for sesame in the international as well as the domestic market. However, scientific data and policy framework need to be expedited so that the farmers and consumers have a harmonized understanding as to which are the safe substances to be used in plant health management during the course of safe sesame production.

The need for promoting mechanized harvesting: Majority of the sesame is harvested manually in the world. In some genotypes, the seeds abscise from the placenta and in others they are attached. The original placenta attachment discovered in Venezuela in 1956 was very fragile. Yermanos (1984) felt that it was too weak to provide shatter resistance. This character had been incorporated into Kinman lines and was present in S03 and S07. Through crossing, lines with different placenta-attachment-governing genes followed by selection process, the placenta attachment has been strengthened enough to hold the seed. The lines primarily from Thailand, Myanmar and China have a hole in the membrane in the lower part of the capsule. In working towards capsule split to expose the membrane, this lower hole can allow the seed to exit. This character of a hole at the bottom has been exploited. The plant characters suitable for mechanized harvesting are height of plant, distance of the first capsule from the ground level, the type of branching, and lodging resistance (Ranganatha *et al*., 2012b). The possibility of using existing general harvester, or the development sesame specific harvester, is needed to explored to promote mechanized harvesting; for it minimizes the risk of contamination with infectious pathogens and thereby helps safe sesame production.

The need for policy to harness the potentials of transgenic technology: There are several serious insect-pests and diseases on sesame. The use of pest and/or disease resistant cultivars undoubtedly complements the safe and sustainable farming including even organic farming; for it requires no application of pesticides in whatever form, i.e., neither chemical nor organic. The pest and disease resistant cultivars can be developed in two ways: the conventional breeding and transgenic technology. However, the conventional breeding technology depends on the genetic variations limited to the species/genus level, whereas transgenic technology has been developed to overcome this limitation. While any technology should be tested, for ruling out its deleterious effect on health and environment, before accepting it, the current public perception of transgenic technology has created a kind of stigma without concerning the merits of it. The public aversion to transgenic technology has created such a magnanimous impact and penetrating-effect that such stigma is getting echoed even in scientific literature. For instance, while Shashidhara *et al.* (2007) reports and appreciates the potentials of transgenic in sesame improvement in their article, the title was "Development of transgenic sesame is detrimental to Indian economy". The reason stated in the article is not scientific but is only based on public perception. The public opinion, perception and views about transgenic technology are needed to be made realistic and founded on scientific considerations. This is possible only through government policy support. Therefore, there is an urgent need for public policy and regulatory mechanism founded on scientific principles to help farmers harnessing the potentials of transgenic technology in safe sesame production.

The need for the national food safety standards specific to sesame: There are no sesame-specific national food safety standards in India with respect to maximum residue level (MRL) of pesticides, heavy metals and other contaminants permissible in sesame seed/oil. However, there are legislations which govern the trading-standards of sesame for the AGMARK certification purpose (http://agmarknet.nic.in/ amrscheme/ 4.%20Manual- Sesame-Draft.htm). AGMARK is a certification mark employed on agricultural products in India, assuring that they conform to a set of standards approved by the Directorate of Marketing and Inspection, an agency of the Government of India. The AGMARK is legally enforced in India by the Agricultural Produce Act of 1937 (amended in 1986). The other legislation is the Prevention of Food Adulteration Act, 1954 that provides for the grade specifications for sesame. Under the provisions of this legislation, maximum permissible limit is 0.1 mg/kg each for Lead (Pb) and Arsenical (As). There is a caveat, mentioned therein, that in the event of conflict and contradictions, codex standards prevail over national standards. Therefore, there is a need for developing the national food standards specific to sesame to enable the uniform practice of safe sesame production and trading.

The need for international food safety standards specific to sesame: Protecting the purity of food supply has been a function of governments for centuries. Food regulations in different countries are often conflicting and contradictory. Conflicting nature of food regulations may be an obstacle to trade and may therefore affect the global distribution of nutritionally valuable food. Therefore, experts at the first meeting of the joint FAO/WHO expert committee on nutrition suggested that FAO and WHO should study these problems more closely (FAO/WHO, 1950). As a result, Codex Alimentarius Commission (CAC) was instituted in 1961 by FAO-WHO joint action. The Codex Alimentarius is recognized by the world trade organization (WTO) as an international reference document for the resolution of disputes concerning food safety and consumer protection. Its name is derived from the Codex Alimentarius Austriacus, meaning book of food in Latin. Currently the CAC has 186 codex members comprised of 185 member countries and 1 member organization (EU) and 229 codex observers comprised of 52 inter-governmental organizations (IGOs), 161 non-governmental organizations (NGOs) and 16 UN agencies. India is member since 1964 (Codex, http://www.codexalimentarius.org/members-observers/members/en/?no_cache=1). CAC sets codex standards for food safety and documents them in codex alimentarius. The Codex Alimentarius is a collection of internationally recognized standards, codes of practice, guidelines and other recommendations relating to foods, food production and food safety.

The codex framework for developing food safety standards: Codex committee develops codex standards applying risk analysis and relying on scientific advice. FAO/WHO organizes expert bodies which provide independent advice to Codex committee. These bodies also give direct advice to Member Governments. There are three FAO/WHO expert committees: One each on food additives, pesticide residues and on microbiological risk assessment. Risk analysis is fundamental to the scientific basis of Codex food safety standards. Member countries can request, access and contribute data to this process. It is due to its scientific basis that Codex texts are considered by WTO as the international reference for food safety standards (http://www.codexalimentarius.org/scientific-basis/en/). Currently, there are no data on maximum residue level (MRL) information in the codex text on sesame seed/oil, neither crude nor edible. Therefore, sesame producing member countries need to sensitize CAC on necessity to develop codex standards for sesame, codex code OC 0700. Once the CAC is pressed into action, it calls for the experts and data from the sesame producing member countries. The scientific information and data related to MRLs of food additives, pesticide residues and microbial risk assessment that is researched and submitted in the prescribed format gets discussed in the respective FAO/WHO expert meeting. If passed, they get published in the codex text and become adopted with effect from the date specified therein.

The sanitary and phytosanitary (SPS) measures: The sanitary and phytosanitary (SPS) measures are an integral part of export trade as per agreement made under GATT, 1994. The SPS agreement applies to all the sanitary and phytosanitary measures that may directly or indirectly affect international trade. Sanitary measures relate to human and animal health and phytosanitary measures to plant life/health. SPS measures are applied in four situations for the protection of human, animal or plant health. They are: (a) Risks arising from the entry, establishment or spread of pests, diseases, disease-carrying organisms or disease causing organisms; (b) Risks coming from additives, contaminants, toning or disease causing organisms in foods, beverages or feedstuffs; (c) Risks arising from diseases carried by animals; plants or products thereof or from the entry, establishment or spread of pests, and (d) Prevention or limitation of damage caused by the entry, establishment or spread of pests.

The consequences of SPS standards violations are: (i) import ban (total/partial), generally applied when there is a significant rate of risk about a hazard; (ii) non-grant of import permits due to non-compliance of predetermined specifications, as technical specifications are the most widely applied measures; and (iii) non-grant of permits of import upon non-compliance of information requirements (labelling requirements, control on voluntary claims and inappropriate labelling).

CONCLUSIONS

The International demand for sesame is continuously growing every year due to its increasing usage in food articles and pharmaceuticals. The quality to suit the preference of consumers and maintenance of export standards will continue to be important. Currently, pesticide-residue-free, white-seeded sesame is preferred in the international market. To remain a leading country in sesame production and export, the efforts should be intensified to develop and promote the safe sesame production technology. While undertaking safe sesame production, the following advice (Ranganatha *et al*., 2011a) needs to be followed. The Practices that are to be followed are: observation of the proper field sanitation by removing infested plants and by keeping the area free from weeds; learning to identify the insect/disease pests that cause damage to sesame; the practice of crop rotation by planting appropriate crops in the next season; the use of disease- and pest-resistant/tolerant varieties; the use of plant extracts and other homemade solutions, along with the standard procedures for their preparation and application, to control pests and diseases; the produce must be properly dried and stored in an airtight container protected from the direct sunlight and moisture; and, the maintenance of hygiene of the highest degree must to ensure the safe sesame seed/oil. The Practices that are to be strictly avoided are: the use of banned pesticides during the cultivation/storage; intercropping/ mix-cropping of sesame with high pesticide consuming crops like cotton, to avoid the possible drift of pesticides; harvesting and mixing together of different color types; the use of cow dung paste on '*Kachha*' threshing floors; and, the allowing of cattle/stray animals to enter the threshing floor/market yard.

Safe sesame production practices are needs of the hour for the nation from trade, nutrition and health point of view. There are feasible and economical practices that can be adopted for safe sesame production. But, if approached in isolation, such practices can leads to prevalence of conflict and contradictions thereby adversely affecting the global distribution of nutritionally valuable sesame. Holistic and comprehensive approaches are needed to be expedited by of all the concerned stake holders including traders, farmers, processing industry, policy makers, enforcement agency, certification agency, non-governmental organizations, inter-governmental organizations, etc. Formulation of national and international standards specific to sesame helps all stake holders to gear up their efforts and strategies in a harmonized way to ensure safe sesame production.

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Review Article

Development of new sources of male sterility in sunflower (*Helianthus annuus* L.) : Limitations and opportunities

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(Received: November, 2014; Revised: May, 2015; Accepted: June, 2015)

ABSTRACT

Cytopasmic male sterility (CMS) is a reasonably common characteristic of higher plants. The discovery of a stable source of CMS was the first step towards the practical use of heterosis in sunflower. The second step was the discovery of fertility restoration gene(s). The first CMS (CMS89) in sunflower was reported in descendants of an interspecific hybrid between *Helianthus petiolaris* Nutt. and cultivated sunflower (the variety Armavirskiy-9345). Although CMS89 or its derivatives are used to produce all commercial sunflower hybrids, more than 72 additional sources of sunflower CMS have been described by various scientists. Male sterility may have multiple causes. It can result from adverse growth conditions, from diseases, or from mutations. In this paper, CMS sources obtained by different methods like hybridization (both intraspecific and interspecific crosses), mutagenesis, chemical and spontaneous occurrence of male sterility as well as limitations and opportunities of diverse CMS sources in sunflower were discussed.

Keywords: Cytoplasmic male sterility, Intraspecific, Interspecific, Mutagenesis, Sunflower

Cytoplasmic male sterility (CMS) was established to exist in many plant species but its application was limited to a small number of them because of the level of scientific knowledge in the field of CMS and the available differences between the existent systems of CMS fertility restoration. The reasons for these differences and for the appearance of new CMS have not been clarified yet (Christov, 2003). To provide answers to these questions, suitable cultivated plants, in which many CMS sources had been identified, have to be investigated. Hybrid breeding leading to high yielding F_1 plants require an efficient and complete control of pollination. Based on its origin, CMS is classified as autoplasmic or alloplasmic. Autoplasmic CMS refers to the cases where CMS has arisen within the species as a result of mutational changes in the cytoplasm. Alloplasmic male sterility arises from interspecific, intergeneric and occasionally intraspecific crosses due to incompatibility between nucleus and cytoplasm. Both types of CMS have been identified in sunflower. CMS in sunflower is most frequently alloplasmatic. Term alloplasmic was coined by Pearson (1981) who uses it to describe male sterility resulting from interspecific and intergeneric crosses. Up to now hybrid production in sunflower has relied on one source of cytoplasmic male sterility, the so called PET-1 cytoplasm, which has been obtained by an interspecific cross between *Helianthus petiolaris* and *Helianthus annuus* (Leclercq, 1969). The identification of additional CMS sources has been an important objective to broaden genetic diversity in cultivated sunflower. Altogether, more than 72 CMS sources have been described in the genus *Helianthus* (Serieys, 2002). Although CMS89 or its derivatives are used to produce all commercial sunflower hybrids (Friedt, 1992) because of stability of PET-1 source over a wide range of environments and seasons and easy availability of fertility restorer gene(s) for the same. On the other hand the lack of corresponding maintainer and restorer lines for available diverse CMS sources. Therefore, these male sterile sources have not been used in commercial hybrid breeding although they might offer the chance to broaden the genetic basis in order to reduce the potential risk of vulnerability by pathogens.

Due to its importance for hybrid breeding the searching of new CMS sources is continue and many CMS sources have been produced either by different interspecific crosses involving *H. argophyllus* (ARG-1), *H. neglectus* (NEG-1), *H. exilis* (EXI-2), *H. anomalus* (ANO-1) and two subspecies of *H. praecox* (PRR-1, PRH-1), or by mutagenesis of two maintainer lines for the PET-1 cytoplasm (MUT-1, MUT-2). The CMS ANN-10 was appeared by spontaneous mutation. In addition to the continuing search for new cytoplasmic male sterility sources, identification and use of new restorer lines is essential to know the fertility restoration on new CMS sources and also to diversify the genetic base of the hybrids for increased hybrid vigour, adaptation and resistance to pest and diseases. The new CMS source obtained in a new way enriches the knowledge of the origin and differences between the CMS sources and casts light on the whole system of CMS fertility restoration. In this paper, the results of investigation of interspecific, intraspecific, spontaneous mutation and CMS sources derived through mutagenesis are presented and also mentioned limitations and opportunities of new CMS sources in heterosis breeding.

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TYPES OF CMS IN SUNFLOWER

Genetic male sterility: Genetic male sterility in sunflower controlled by a single recessive gene (Kuptosv, 1935; Gundaev, 1965; Leclercq, 1966; Putt and Heiser, 1966; Vranceanu, 1967; Vilichko, 1989). Evolving hybrids using genetic male sterility was developed by Vranceanu (1970) in Romania. Inheritance studies have indicated that the genetic male sterility in sunflower is due to a monogenic recessive gene closely linked with the green seedling colour (Leclercq, 1970; Vranceanu, 1970). The number of genes determining this trait differs (ms1 to ms5, Vranceanu, 1970; ms6 to ms9, Jan, 1992). Hybrid seed production cost was high in view of the labour requirement to remove fertile plants. Due to this reason today this method is not utilized for commercial seed production.

Cytoplasmic male sterility: CMS is usually defined as "maternally inherited deficiency in producing viable pollen" and the mitochondria are responsible for this trait. This definition leads us to call CMS any mitochondrial mutation which impairs the proper functioning of mitochondria, leading to male sterility. The male-sterile line is maintained by crossing with a maintainer line (B line) carrying the same nuclear genome as the MS line but with normal fertile cytoplasm. The discovery of a stable source of CMS was the first step towards the practical use of heterosis in sunflower. The second step was the discovery of fertility restoration by Kinman (1970). The first CMS (CMS89) in sunflower was reported by Leclercq (1969) in descendants of an interspecific hybrid between *Helianthus petiolaris* Nutt. and cultivated sunflower (the variety Armavirskiy-9345).

Developing new CMS sources in sunflower: Need of originating new CMS sources are to improve sunflower productivity to break the yield barrier through development of improved hybrids. Frequent use of the same sterile cytoplasm increases the genetic vulnerability of the present sunflower hybrids to diseases and pests. In order to minimize such a risk, new sources of cytoplasmic male sterility are essential to increase the genetic diversity of the commercial hybrids. Inspite of the fact that new CMS sources continue to be discovered (Serieys, 2002), there are hardly any reports of their utilization for commercial hybrid production. Diverse CMS sources help to understand the molecular basis of male sterility and provide opportunities to improve the oil content, oil quality, seed yield, ideal plant type and resistant to biotic and abiotic stresses. The diversification of CMS sources may also be useful to optimize the utilization of genetic resources in breeding programs by “changing” the restorer status of an inbred line (i.e. a restorer genotype of one cytoplasm may be a male sterility maintainer of a second one). The detailed information on origin, FAO code along with references of different cytoplasmic male sterilities in sunflower (Serieys, 1996) is described in Table 1.

CMS sources derived by intra-specific hybridization: Anaschenko *et al.* (1974) discovered new source of CMS by crossing *Helianthus annuus* ssp. *lenticularis* and *Helianthus annuus* ssp. *annuus* and named it as CMS KI-70. This was later designated as ANL-1 and commonly referred to in literature as the Kuban source of CMS. In the same year another source ANL-3 was also reported. Heiser (1982) found a new CMS source in a cross between *Helianthus annuus* ssp. *lenticularis* and *Helianthus annuus* (Commander). Male sterility character was incorporated to the genetic background of RHA-265 which is a restorer of PET-1 and thus giving a new source Indiana 1 (CMS I) designated as ANL-2. Vranceanu *et al.* (1986) reported a new source in a cross *H. annuus* ssp. *texanus* x cultivated sunflower. The new source was designated as ANT-1 or FUNDULEA-1.

CMS sources derived by inter-specific hybridization: CMS frequently arises from interspecific crosses. There are a few successful examples of CMS created by such crosses in sunflower. More than half of the new CMS sources have been developed by inter-specific hybridization. Vulpe (1972) found a new source RIG-1 from the inter-specific cross between a wild perennial hexaploid *H. rigidus* and the cultivated *H. annuus.* Leclercq (1974) found a new source of CMS, again in a cross *H. petiolaris* x *H. annuus.* This source differed from the classic CMS PET-1 for fertility restoration. Whelan (1980) reported a new source of CMS by inter-specific substitution of the nucleus of *H. annuus* cv. Saturn into the cytoplasm of *H. petiolaris.* This new source was *H. giganteus* and *H. maximiliani* through 3-way cross. PET-3 source of CMS was reported by Leclercq (1983) again by employing *H. petiolaris* as the female parent in the cross. Serieys (1984) found large number of CMS sources by crossing wild annual species with the cultivated sunflower. The first source discovered came from *H. petiolaris* ssp. *fallax.* This source was named as CMS PF (PEF-1). The second source came from *H. bolanderi* and was named as CMS BOL (BOL-1). Serieys and Vincourt (1987) reported two new sources produced by crossing *H. exilis, H. niveus* ssp. *canescens* with the *H. annuus* and the new sources were registered as EXI-1 and NIC-1. Anashchenko (1974) discovered the new CMS source CMS-KU-70. Whelan and Dorell (1980) and Whelan (1981) also reported another CMS sources (CMG-3 and CMG-2). Christov (1990a, 1990b, 1991, 1992) and Christov *et al.* (1993) reported many new CMS sources (ARG-1, ARG-2, ARG-3, RIG-2, PET-4, PRH-1, PRR-1 and DEB-1) by using different wild species like *H. argophyllus, H. petiolaris, H. rigidus, H. praecox* and *H. debilis* in inter-specific hybridization. Some restorers of PET-1 appeared to be restorers for ARG-1 and ARG-2 suggesting that these could be utilized in heterosis breeding programmes. In a study conducted by Serieys (1994) on new CMS sources ANL-1, EXI-2, NEG-1, PEP-1 and PRP-1, it was observed that all these new sources were different from one another and also from classical CMS PET-1.

Table 1 Overview of the investigated CMS sources

Name	Origin	FAO code	Reference
Spontaneously occurring CMS sources			
H. annuus 367	ANN1	*H. annuus* wild	Serieys and Vincourt, 1987
H. annuus 517	ANN2	*H. annuus* wild	Serieys and Vincourt, 1987
H. annuus 519	ANN3	*H. annuus* wild	Serieys and Vincourt, 1987
H. annuus 521	ANN4	*H. annuus* wild	Serieys and Vincourt, 1987
NS-ANN-81	ANN5	*H. annuus* wild	Skoric, 1988
NS-ANN-2	ANN6	*H. annuus* wild	Skoric, 1987
-	ANN7	*H. annuus* wild	Jan, 1988
-	ANN8	*H. annuus* wild	Jan, 1988
-	ANN9	*H. annuus* wild	Jan, 1988
AN-67	ANN10	*H. annuus*	Christov, 1992
AN-58	ANN11	*H. annuus*	Christov, 1994
AN-2-91	ANN12	*H. annuus*	Christov, 1991
AN-2-92	ANN13	*H. annuus*	Christov, 1992
Intraspecific crosses			
Kouban	ANL1	*H. annuus lenticularis*	Anashchenko *et al*., 1974
Indiana1	ANL2	*H. annuus lenticularis*	Heiser, 1982
VIRR 126	ANL3	*H. lenticularis*	Anashchenko, 1974
Fundulea 1	ANT1	*H. annuus texanus*	Vranceanu *et al*., 1986a
Interspecific crosses			
Anomalus	ANO1	*H. anomalus*	Serieys and Vincourt, 1987
Argophyllus	ARG1	*H. argophyllus*	Christov, 1990
Argophyllus	ARG2	*H. argophyllus*	Christov, 1990
Argophyllus	ARG3	*H. argophyllus*	Christov, 1992
Bolanderi	BOL1	*H. bolanderi*	Serieys and Vincourt, 1987
Exilis	EXI1	*H. exilis*	Serieys and Vincourt, 1987
Exilis	EXI2	*H. exilis*	Serieys, 1991
CMG2	GIG1	*H. giganteus*	Whelan, 1981
CMG3	MAX1	*H. maximiliani*	Whelan and Dedio, 1980
Neglectus	NEG1	*H. neglectus*	Serieys and Vincourt, 1987
Fallax	PEF1	*H. petiolaris* ssp. *fallax*	Serieys and Vincourt, 1987
PET/PET	PEP1	*H. petiolaris* ssp. *petiolaris*	Serieys and Vincourt, 1987
Petiolaris	PET1	*H. petiolaris*	Leclercq, 1969
CMG1	PET2	*H. petiolaris*	Whelan and Dedio, 1980
Petiolaris Bis	PET3	*H. petiolaris*	Leclercq, 1983
PET34	PET4	*H. petiolaris*	Christov, 1991
PHIR 27	PRH1	*H. praecox* ssp. *hirsutus*	Christov, 1993
PRUN 29	PRR1	*H. praecox* ssp. *runyonii*	Christov, 1993
Vulpe	RIG1	*H. rigidus*	Vulpe, 1972
DV10	DEB-1	*H. debilis*	Christov, 1994
Praecox	PRP1	*H. praecox ssp. praecox*	Serieys, 1994
EXI2	EXI-2	*H. exilis*	Serieys, 1994
Induced by mutagenesis			
HEMUS	MUT1	Irradiation of "Hemus"	Christov, 1993
PEREDOVIK	MUT2	Sonification of "Peredovik"	Christov, 1993
STRP555-1	MUT-3	Streptomycin treatment of HA89 seeds	Jan and Rutger, 1988

Spontaneously occurring cytoplasmic male sterility: Some new CMS sources were found to have originated directly in ecotypes of wild *H. annuus* adding diversity to the CMS sources. Serieys (1984) found four sources directly in ecotypes of wild *H. annuus* and later named as ANN-1, ANN-2, ANN-3 and ANN-4. Two more new sources ANN-7 and ANN-8 were discovered which appeared as spontaneous mutations in the wild *H. annuus* (Jan, 1995). Marinkovie and Miller (1995) found another sources from wild sunflower population and designated it as ANN-5. This showed high stability under different conditions.

CMS sources derived through mutagenesis: Jan and Rutger (1988) studied the effectiveness of mitomycin C and streptomycin in inducing CMS in cultivated sunflower. It was revealed that streptomycin was more effective than mitomycin C for inducing CMS mutations and the induced CMS mutants could be used readily for hybrid seed production without altering current fertility restoration system and could provide alternative male sterile system. They discovered new source STRP-555 by treating HA-89 seeds with streptomycin. Christov *et al.* (1993) reported two more CMS mutants in Peredovik and Hemus which were developed by sonification of Peredovik and irradiation of Hemus, respectively. Anashchenko (1977) concluded that the most important effects of physical and chemical mutagenesis are the production of a large number of recessive genes and cytoplasmic mutations.

Chemically induced male sterility system: Benzotriazole ($C_6H_5N_3$) to be quite effective in inducing complete pollen sterility in sunflower and double treatment with 1.0% benzotriazole can be effectively used at commercial scale (Tripathi and Singh, 2013). All the concentrations (1.5% & 2.0%) and treatments induced 100% pollen sterility, except single treatment of 1.0% benzotriazole, which induced 97.0% pollen sterility. Sterility induced by benzotriazole was of permanent nature and persistent throughout the flowering period. It act as an inhibitor of microspore development, and thus, causing male sterility in plants. It was also found to be a suitable chemical hybridizing agent for some other crops like Brassica juncea (Chauhan and Kinoshita, 1982), *Vicia faba* (Shivana and Sawahney, 1997), *Datura alba* (Chauhan and Agnihotri, 2005), *Capsicum annum, Gossypium arboreum* and *Raphanus sativus* (Singh and Chauhan, 2001).

Hormonal induced male sterility: Male sterility has also been induced in sunflower crop by the use of gibberellic acid (Piquemal, 1970; Miller and Fick, 1978). Chemical emasculation by use of gibberellic acid was originally shown by Schuster (1961) to be effective in causing male sterility, and it was extensively used in producing test crosses between inbred lines and various tester parents (Anashchenko, 1972; Skoric, 1988). However, inbred lines may show different responses to gibberellic acid requiring higher or lower concentrations and earlier or later application times (Piquemal, 1970). But there are various negative effects such as incomplete male sterility, reduced female sterility and stem elongation have been associated with the use of gibberellic acid, depending on concentration and timing of application (Miller, 1987).

Limitations of available diverse CMS sources : In sunflower more than 72 new CMS sources of different origin have been reported. Stability of CMS lines with reference to its sterility nature over a wide range of seasons or situations is one of the important pre-requisite before its wider practical use. However, these sources have not been exploited commercially in breeding programme because of the instability of diverse CMS sources over different range of environments and seasons (Seetharam and Satyanarayana, 1980; Seetharam and Virupakshappa, 1993; Kumar *et al.,* 1993; Rajanna *et al.,* 1998), majority of the restorers of the classical source CMS F failed to restore fertility in the new CMS sources (lack of effective fertility restorers) (Devasenamma and Vishnuvardhan Reddy, 2000; Reddy *et al.,* 2008; Rukminidevi *et al.,* 2006; Sujatha and Vishnuvardhan Reddy, 2008; Abdul Gafoor, 1997) and restorer genes have not been reported for the other sources either because of the CMS were not still clearly studied or genes are very rare in the available *Helianthus* germplasm (Serieys, 1994). Earlier studies by Havekes *et al.* (1991), Virupakshappa *et al.* (1991, 1992), Virupakshappa and Jayarame Gowda (1996) and Ravi Kumar *et al.* (1994) have also reported less abundance and rarity of fertility restorers for the new CMS sources including CMS I (*H. lenticularis*) and CMS PF (*H. fallax*). However, several sources have negative effects on seed yield and other plant and seed characteristics (Petrov, 1992; Serieys, 1992; Havekes *et al.,* 1991).

OPPORTUNITIES

There are many reports stressing the need for CMS diversification not only for superior economic traits but also a means of checking vulnerability of hybrids to diseases (Fleming, 1972; Gracen and Grogan, 1974; Kumar *et al.,* 1983; Kruleves *et al.,* 1988; Davidenko *et al.,* 1988; Mangat and Virk, 1993; Gill, 1993). The range for disease score was much wider for CMS F (PET-1) compared to CMS PF (*H. fallax*) and CMS I (*H. lenticularis*). Rajanna (1995) studied hybrids of three CMS sources CMS F, CMS PF and CMS I to downey mildew in sunflower and noticed that the three CMS differs considerably for disease reaction. The hybrids of CMS PF were free from downey mildew, while the hybrids in the background of CMS F revealed susceptibility while, Puttaranga Swamy (1997) found CMS I tolerant to Alternaria leaf spot. Rajanna (1995) indicated that hybrids derived from cytoplasmic background of CMS I ranked first followed by CMS F and CMS PF for achene yield, oil yield and oil content. Abdul Gafoor (1997) reported that CMS PF hybrids showed superiority over CMS F hybrids for oil content. Many researchers (Baldini *et al*., 1991; Matvienko, 1989; Serieys, 1996, 1999) confirm the positive or negative influence of cytoplasm type. The positive effect on oil content was also reported (Serieys, 1992). The hybrids developed based on new CMS sources (FMS and IMS) recorded significantly higher oil content compared to corresponding hybrids based on classical source (Meena, unpublished). The hybrids, based on ANL1, ANL2, MAX1, PEF1, PET2 and ANN4, showed good agronomic performance for plant height, days to flowering, maturity and oil content (Horn and Friedt, 1997). However, in case of seed oil content the CMS source from *H. lenticularis* showed superiority over the classical cytoplasm by producing hybrids with significantly higher oil content. Therefore, these new male sterility sources can replace the classical source with added advantage.

CONCLUSION

Successful diversification of CMS systems demands considerable efforts by way of identifying suitable maintainer and restorer lines besides assessing the stability of male sterility under varied agro climates. In the past, several workers have made attempts to identify fertility restorers to new sources of CMS but with limited success. There is a need for new CMS lines with several desirable attributes like dwarfness, early maturity, good seed yield and oil content coupled with diverse cytoplasm are expected which could make a significant dent in development of superior hybrids with better heterosis and stability. The CMS base exploited in the sunflower breeding programmes is narrow and there is an urgent need for widening the CMS base for enhancing the productivity and production of sunflower. The utilization of different cytoplasmic backgrounds in hybrid development will improve general variability of the sunflower and lessen the threat of epiphytotics.

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Path coefficient analysis of seed yield in Indian mustard [*Brassica juncea* (L.) Czern. & Coss.] under drought

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(Received: June, 2014; Revised: October, 2014; Accepted: March, 2015)

ABSTRACT

The present investigation was carried out to assess the components of seed yield under drought stress using path coefficient analysis. Twenty two genotypes of Indian mustard were grown in a Randomized Complete Block Design with three replications during *rabi*, 2007-08. Analysis of variance indicated presence of variability in the experimental genotypes for seed yield and other morpho-physiological characters except main shoot length, harvest index, protein content, SLW at 35 days after sowing (DAS) and seed: husk ratio. Seed yield/plant was positively and significantly correlated at both phenotypic and genotypic levels with days to maturity, plant height, primary branches/plant, secondary branches/plant, siliquae on main shoot, LAI, CGR and biological yield/plant. Seed yield/plant had negative genotypic correlations of moderate strength with transpiration quotient at 35 and 75 DAS indicating its positive relationship with water use efficiency. The RGR during 35-75 DAS followed by RGR between 75 and 95 DAS exerted the highest direct positive effects on seed yield. Biological yield/plant, SLW at 75 DAS, TDM at 75 and 95 DAS, SCMR at 35 DAS, siliquae on main shoot, days to maturity and siliqua length also had substantial positive direct effects. The characters under study explained about 96.5% and 100% variability in the seed yield at phenotypic and genotypic level, respectively. Dry matter production, early growth and development of the crop are important under drought due to continuous decline in available soil moisture. Since LAI, LGR, CGR, RGR and NAR are the functions of dry matter production and/or leaf area, therefore, selection on the basis of high biological yield and large LAI at 50% flowering should be quite effective in improving seed yield under drought. An increase in LAI might increase radiation load resulting in to high transpiration. Therefore, genotypes having high LAI with erect leaves and low TQ should be accorded priority in the selection programme.

Keywords: Correlations, Indian mustard, Path analysis, Physiological parameters, Seed yield

Seed yield like in other crops, in Indian mustard [*Brassica juncea* (L.) Czern. & Coss.] too, is the result of additive and multiplicative interactive effects of various agro-morphological and physiological processes reflected in yield components. Seed yield *per se* doesn't have genes and largely influenced by components characters such as branches/plant, seeds/siliqua, siliqua length, main shoot length and 1000-seed weight (Meena *et al.,* 2006; Singh *et al.,* 2006; Brar *et al.,* 2007 and Misra *et al.,* 2007). Path coefficient analysis (Wright, 1921) is an effective mean to find out the direct and indirect effects of various components on a dependent variable like seed yield. Although a large number of studies have been carried out dealing with correlations and component analysis under irrigated conditions in Indian mustard but such studies under drought stress are limited (Mondal and Khajura, 2000 and Tyagi and Chauhan, 2003). Further, information on cause and effect analysis involving physiological characters which determine growth and development of the plant and consequently, the seed yield is scanty. In view of the aforesaid, the present investigation was undertaken with the objective to have information on direct and indirect effects of morpho-physiological characters on seed yield under drought.

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MATERIALS AND METHODS

The material for the present investigation comprised 18 advanced breeding lines and 4 varieties of Indian mustard [*Brassica juncea* (L.) Czern. & Coss.] grown in a Randomized Complete Block Design with three replications under rainfed conditions during *rabi,* 2007-08 using only pre-sowing irrigation. There were 4 rows of 4 meter length for each entry in a block. The row spacing was 30 cm and plant spacing within a row was maintained at 10 cm by thinning. A fertilizer dose of 40:20:20 kg/ha ($N:P_2O_5:K_2O$) was applied at the time of sowing. Soil moisture content was recorded from the time of sowing till maturity at an interval of 15 days at 3 depths (15, 30 and 60 cm) using gravimetric method. The soil samples were dried in an oven at 75±2°C for at least 72 hrs till constant weight was achieved. The soil moisture content was expressed in percentage on wet basis. Days to maturity were computed on plot basis. At the time of harvest, 10 random competitive plants from each replication were taken from the two central rows to record seed yield/plant, yield components, biological yield/plant and harvest index. To study different growth parameters, the plant samples from 50 cm running row length were harvested above ground level at 35,75 and 95 days after sowing (DAS). The shoot and leaves were separated and leaf area was recorded. Plant samples (shoot and leaves) were dried separately in an oven at 65±2°C for at least 72 hours till constant weight was achieved. The samples were weighed using an electronic balance and drymatter of leaves, shoot as well as shoot + leaves was expressed in g/m^2. For recording photosynthesis, transpiration and SPAD chlorophyll meter readings (SCMR), 3^{rd} and 4^{th} fully expanded leaf from the top was used from three randomly selected plants in each replication. Growth parameters were computed using leaf area and dry weight of leaves as well as total dry matter as per the methods of Radford (1967). Photosynthesis and transpiration rate were measured with the help of portable photosynthesis system (CIRAS-2). Transpiration quotient (TQ), ratio of transpiration and photosynthesis were expressed as mmoles/μ mole. The SCMR measurements were obtained from the SPAD chlorophyll meter. The character means for each replication were subjected to analysis of variance according to the procedure outlined by Panse and Sukhatme (1967). Phenotypic and genotypic correlation coefficients of seed yield (effect) with various yield related and physiological characters (causes) were partitioned in to direct and indirect effects by path coefficient analysis as suggested by Wright (1921) and elaborated by Dewey and Lu (1959). Residual factor was also included in the causal system, representing all other factors not included in the analysis, which might affect the end product i.e., seed yield. There was steady and rapid decline in soil moisture content at all the three soil depths from the time of sowing up to 65 days after sowing (DAS) coinciding with 50% flowering in majority of the genotypes. Thereafter, the moisture content stabilized and showed gradual decline. The reduction in soil moisture content from 65 DAS till the time of harvest was only 1.6% at 15 cm, 0.6% at 30 cm and 1.4% at 60 cm.

RESULTS AND DISCUSSION

Analysis of variance revealed high and significant genotypic differences for days to maturity, plant height, siliquae on main shoot, siliqua length, 1000-seed weight, seed yield/plant and oil content. The genotypic differences were significant for primary branches/plant, secondary branches/plant, seeds/siliqua and biological yield/plant. Highly significant genotypic differences were observed for leaf area index and total drymatter at 35, 75 and 95 DAS. However, TQ and SCMR showed highly significant genotypic differences at 35 and 75 DAS. The specific leaf weight had highly significant genotypic differences at 75 and 95 DAS. The genotypic differences were also highly significant for leaf area ratio, leaf growth rate, crop growth rate, relative growth rate and net assimilation rate during 35-75 and 75-95 DAS.

Genotypic correlations for seed yield and other morpho-physiological characters were invariably higher than phenotypic correlations. The results of the present study were in agreement with earlier studies of Kumar *et al.* (1999) but contradictory to those of Kardam and Singh (2005) who observed higher phenotypic correlations than genotypic correlations. Correlation coefficients of seed yield with other characters at phenotypic and genotypic level were partitioned into direct and indirect effect considering seed yield as dependent variable (effect) and the other characters as independent variables (cause). The direct and indirect effects were classified as low (< 0.2), moderate (0.20-0.30) and high (> 0.30).

Significant and positive association of seed yield with days to maturity (r = 0.539**) appeared to be due to low direct (0.137) and its indirect positive effects through biological yield (0.384), RGR during 35-75 DAS (0.200) and TDM at 95 DAS (0.104). Nevertheless positive effects were partly neutralized by low negative indirect effects via RGR during 75-95 DAS, LAI, CGR, NAR, TQ and SCMR (Table 1). High positive indirect effects of plant height through biological yield (0.567) and low indirect effects through siliquae on main shoot and RGR during 35-75 DAS were mainly responsible for the built up of positive correlation between plant height and seed yield (r = 0.751**). The positive and significant relationship of primary and secondary branches/plant with seed yield could be due to their high and positive indirect effects through biological yield. Positive and significant association of seed yield (r = 0.762**) with siliquae on main shoot was due to low positive direct (0.143) and its high indirect effects through biological yield (0.561). Positive and significant association of biological yield/plant with seed yield/plant was because of its high positive direct (0.732) and positive indirect effects of low magnitude via RGR during 35-75 DAS (0.124) and siliquae on main shoot (0.112). Oil content had low direct and indirect effects in both directions, hence no association with seed yield. Seed yield was positively and significantly correlated with LAI at 35 (r = 0.458) and 75 DAS (r = 0.515) due to their positive indirect effects of high magnitude through biological yield (Table 1). The other physiological characters like SLW at 75 DAS, TDM at 35, 75 and 95 DAS had low to moderate direct effects but their indirect effects through most of the characters except biological yield were low to very low and in both directions resulting into cancellation of one another and thus no significant correlations of these characters with seed yield.

The built-up of significant and positive correlation of seed yield with CGR (35-75 DAS) was due to positive indirect effects of high magnitude through biological yield (0.385) and RGR during 35-75 DAS (0.300). The correlation was slightly reduced by high negative indirect effects through

RGR during 75-95 DAS (-0.341). CGR during 75-95 DAS had high negative direct effects on seed yield, which were off-shot, by high (0.310) indirect positive effects through RGR during 75-95 DAS, therefore, no relationship with seed yield was observed. Relative growth rate (35-75 DAS) exerted high positive direct effect on seed yield and moderate positive indirect effect through biological yield which were cancelled, by high negative indirect effects via RGR between 75-95 DAS and low indirect effect through NAR during 35-75 DAS. Net assimilation rate (35-75 DAS) had negative direct effect (-0.256) and indirect effect via RGR (75-95 DAS), which were neutralized, by positive indirect effects through CGR (75-95 DAS) and RGR (35-75 DAS) resulting into non-significant association. Similar trend of relationship was observed for NAR during 75-95 DAS and seed yield.

Days to maturity had positive direct effect of moderate magnitude (0.208). Its high positive association with seed yield was mainly through positive high indirect effects via RGR during 35-75 DAS (0.973) and LAI at 75 DAS (0.456) as well as moderate positive effects through biological yield/plant (0.259) and TQ at 35 DAS (0.237). High positive relationship between seed yield and plant height (r = 0.956) was mainly because of high effects via LAI at 75 DAS (0.624), RGR during 35-75 DAS (0.948) and TQ at 35 DAS.

High positive correlation of branches/plant with seed yield was due to moderate positive indirect effects through plant height, biological yield, RGR during 35-75 DAS, TQ at 35 DAS (Table 1). High positive association of secondary branches/plant with seed yield (r = 0.799) was the result of its high direct (0.328) and indirect effects through LAI at 75 DAS (0.493) and RGR during 35-75 DAS (0.505). The magnitude of correlation was reduced by high negative indirect effects via TDM at 75 DAS, CGR during 35-75 DAS and RGR during 75-95 DAS.

Siliquae on main shoot had low positive direct effect on seed yield but its association was high because of positive high indirect effects via secondary branches/plant, LAI at 75 DAS, RGR during 35-75 DAS and TQ at 35 DAS. Direct positive and high effect of siliqua length coupled with high indirect effects through RGR during 35-75 DAS along with moderate positive indirect effects via NAR during 75-95 DAS and TQ at 35 DAS were responsible for building positive association between siliqua length and seed yield (Table 1). Biological yield had very high correlation with seed yield (r = 0.998) due to very high positive indirect effect through RGR during 35-75 DAS (1.081) and high direct effect (0.301), high positive indirect effect via LAI at 75 DAS (0.614) and TQ at 35 DAS (0.302).

Leaf area index at 35 DAS had low direct effect on seed yield but its high indirect effects via RGR during 35-75 DAS (0.654), LAI at 75 DAS (0.432), siliquae on main shoot (0.354) and biological yield (0.307) were responsible for building its high positive correlation with seed yield. LAI at 75 DAS exerted high direct effect on seed yield besides its high indirect effects via RGR during 35-75 DAS (0.735). It's low to moderate but positive indirect effects through majority of the component characters compensated the high negative indirect effects of LAI at 75 DAS. Leaf area index at 95 DAS had moderate negative direct and indirect effects but very high (0.904) positive indirect effects via RGR during 35-75 DAS besides moderate effects via TQ at 35 DAS and LAI at 75 DAS were responsible for building positive association of LAI at 95 DAS with seed yield. In spite of its low negative direct effect, LGR (35-75 DAS) had very high positive association with seed yield because of its high positive indirect effects through RGR during 35-75 DAS and LAI at 75 DAS along with NAR during 75-95 DAS and biological yield. Negative association of moderate strength between SLW at 75 DAS and seed yield was primarily because of very high indirect effect via RGR during 35-75 DAS (Table 2).

Moderate negative direct effect of SLW at 95 DAS was also associated with high indirect effect (-0.768) through RGR during 35-75 DAS and responsible for low negative association of SLW at 95 DAS and seed yield. Positive effects of total drymatter/m^2 at 35 DAS through secondary branches/plant, biological yield, LAI at 75 DAS, RGR during 35-75 DAS and NAR during 75-95 DAS resulted in to a positive association between seed yield and TDM at 35 DAS (Table 2).

Positive indirect effects of TDM at 95 DAS through RGR during 35-75 DAS, TQ at 35 DAS, LAI at 75 DAS, biological yield, secondary branches/plant and days to maturity appeared to be responsible for building up positive association of TDM at 95 DAS with seed yield. Crop growth rate during 35-75 DAS though had high negative (-0.562) direct as well as indirect effects via RGR during 75-95 DAS (-0.566) but its association with seed yield was positive and significant because of very high (1.271) positive indirect effect via RGR during 35-75 DAS and high effect via LAI at 75 DAS (0.522). Positive association of seed yield and RGR during 35-75 DAS could be because of very high direct, high indirect effects through TQ at 35 DAS and LAI at 75 DAS. RGR during 75-95 DAS affected seed yield positively and directly (0.754) but its negative association with seed yield was due to low but negative indirect effects via most of the characters (Table 3).

Negative and high direct effect of NAR during 75-95 DAS and its high negative indirect effect via RGR during 35-75 DAS contributed to the building of its negative association with seed yield. TQ at 35 DAS had high negative direct effect (-0.492) and negative very high (-0.862) indirect effects through RGR during 35-75 DAS contributing to the negative relationship with seed yield. Negative association between TQ at 75 DAS with seed yield was also due to high negative indirect effects via TQ at 35 DAS (-0.425) and

RGR during 35-75 DAS (-0.456) but its direct effect on seed yield was high and positive. Negative indirect effects of SCMR at 35 DAS through 14 characters neutralized its high positive direct and indirect effects via other characters resulting into negative association (Table 3).

Seed yield/plant was positively and significantly correlated at both phenotypic and genotypic levels with days to maturity, plant height, primary branches/plant, secondary branches/plant, siliquae on main shoot and biological yield/plant. Lodhi *et al.* (2014) have reported positive and significant association of seed yield with primary branches, secondary branches, main shoot length and seeds per siliqua. Yadava *et al.* (2011) also reported significant positive association between number of secondary branches and seed yield. The LAI and CGR had positive correlations with seed yield. Reddy (1991) also reported positive and significant association of seed yield and LAI. Path coefficient analysis indicated substantial positive direct effects of biological yield/plant, RGR during 35-75 and 75-95 DAS, SLW at 75 DAS, TDM at 75 and 95 DAS, SCMR at 35 DAS, siliquae on main shoot, days to maturity and siliqua length. High positive effects of days to maturity on seed yield were also reported by Mondal and Khajura (2000). In the present study plant height, primary branches and secondary branches/plant though had low direct effects but considerable moderate to high positive indirect effects via biological yield/plant and RGR between 35-75 DAS. The results of the present study suggested that days to maturity, plant height, primary branches and secondary branches/plant were in realizing higher seed yield.

Net assimilation rate (35-75 DAS), CGR (75-95 DAS) and LGR (75-95 DAS) exhibited substantial but negative direct effects on seed yield. The positive correlations of most of the morpho-physiological characters with seed yield were mainly due to high to moderate indirect effects via biological yield/plant and RGR during 35-75 and 75-95 DAS apart from their low to moderate direct effects. The relative growth rate between 35 and 75 DAS followed by RGR during 75-95 DAS exerted the highest direct positive effects on seed yield at genotypic level. The positive direct as well as indirect effects of RGR were, in general, high and responsible for building positive association with seed yield. TQ at 35 DAS and CGR during 35-75 DAS had negative and moderate direct effects. The positive and high genetic associations of plant height, days to maturity, primary branches/plant, secondary branches/plant, siliquae on main shoot, biological yield/plant and LGR during 35-75 DAS with seed yield were due to their high and positive indirect effects through RGR during 35-75 DAS and LAI at 75 DAS. The characters under study explained about 96.5% and 100% variability in the seed yield at phenotypic and genotypic level, respectively.

Table 1 Direct (underlined) and indirect effects of 32 characters on seed yield in Indian mustard under drought stress

Character	DM	PH	PB	SB	SMS	SL	S/ S	SW	BY	OC	LAI			LAR		LGR	
											35 DAS	75 DAS	95 DAS	35-75 DAS	75-95 DAS	35-75 DAS	75-95 DAS
DM	0.137	-0.036	0.015	0.017	0.066	0.019	0.001	-0.006	0.384	0.004	0.008	-0.038	-0.005	0.001	-0.001	0.039	0.004
	0.208	**0.115**	**0.050**	**0.144**	**0.059**	**0.062**	**0.006**	**0.010**	**0.259**	**0.013**	**0.019**	**0.456**	**-0.175**	**0.001**	**-0.016**	**-0.020**	**0.000**
PH	0.082	-0.061	0.032	0.038	0.120	0.031	-0.002	-0.003	0.567	-0.002	0.019	-0.041	-0.002	0.028	-0.002	0.013	-0.043
	0.138	**0.174**	**0.114**	**0.345**	**0.118**	**0.014**	**0.009**	**0.004**	**0.292**	**0.016**	**0.060**	**0.624**	**-0.050**	**0.028**	**-0.067**	**-0.017**	**-0.024**
PB	0.022	-0.020	0.094	0.062	0.053	0.013	-0.009	-0.001	0.381	0.014	0.011	-0.024	-0.000	0.021	-0.001	0.016	-0.038
	0.122	**0.235**	**0.085**	**0.150**	**0.120**	**0.060**	**-0.005**	**0.004**	**0.266**	**0.003**	**0.042**	**0.402**	**-0.021**	**0.031**	**-0.010**	**-0.005**	**-0.016**
SB	0.024	-0.023	0.060	0.098	0.085	0.009	-0.005	0.001	0.491	0.006	0.019	-0.026	0.000	0.016	-0.001	0.018	-0.051
	0.092	**0.184**	**0.039**	**0.328**	**0.138**	**0.023**	**0.003**	**-0.004**	**0.263**	**0.003**	**0.063**	**0.493**	**0.022**	**0.019**	**-0.042**	**-0.013**	**-0.030**
SMS	0.063	-0.051	0.035	0.058	0.143	0.007	-0.004	-0.002	0.561	0.005	0.020	-0.030	-0.001	0.025	-0.003	0.005	-0.040
	0.093	**0.156**	**0.078**	**0.343**	**0.131**	**-0.033**	**0.014**	**-0.002**	**0.222**	**0.019**	**0.064**	**0.416**	**-0.007**	**0.023**	**-0.107**	**-0.010**	**-0.022**
SL	0.022	-0.016	0.011	0.007	0.009	0.117	-0.007	-0.007	0.192	-0.004	0.005	-0.011	-0.004	0.002	-0.002	0.002	0.029
	0.038	**0.007**	**0.015**	**0.022**	**-0.013**	**0.341**	**-0.006**	**0.017**	**0.106**	**0.014**	**0.016**	**0.187**	**-0.173**	**0.005**	**-0.049**	**-0.005**	**0.010**
S/S	-0.003	-0.003	0.025	0.014	0.015	0.025	-0.033	-0.005	0.122	0.003	-0.005	0.004	-0.001	0.002	0.000	0.001	0.020
	-0.057	**-0.079**	**0.020**	**-0.042**	**-0.088**	**0.107**	**-0.020**	**0.008**	**-0.075**	**0.012**	**-0.019**	**-0.224**	**-0.040**	**-0.010**	**0.003**	**0.010**	**0.016**
SW	0.042	-0.011	0.005	-0.006	0.012	0.045	-0.009	-0.018	0.170	0.025	0.001	-0.006	-0.004	0.004	-0.002	0.010	0.033
	0.074	**0.026**	**0.011**	**-0.052**	**-0.008**	**0.203**	**-0.006**	**0.028**	**0.077**	**0.023**	**0.002**	**0.009**	**-0.117**	**-0.001**	**-0.054**	**-0.002**	**0.011**
BY	0.074	-0.048	0.050	0.067	0.112	0.032	-0.006	-0.004	0.714	0.005	0.017	-0.039	-0.004	0.021	-0.001	0.026	-0.028
	0.180	**0.169**	**0.075**	**0.287**	**0.097**	**0.120**	**0.005**	**0.007**	**0.301**	**0.014**	**0.059**	**0.614**	**-0.147**	**0.018**	**-0.046**	**-0.024**	**-0.017**
OC	-0.008	-0.002	-0.018	-0.008	-0.011	0.007	0.001	0.006	-0.054	-0.070	-0.008	-0.010	0.001	0.006	0.000	0.008	-0.012
	-0.065	**-0.070**	**-0.006**	**-0.026**	**-0.060**	**-0.116**	**0.006**	**-0.016**	**-0.105**	**-0.041**	**-0.015**	**0.259**	**0.027**	**0.019**	**0.041**	**-0.007**	**-0.009**

Character	SLW 75 DAS	SLW 95 DAS	TDM 35 DAS	TDM 75 DAS	TDM 95 DAS	CGR 35-75 DAS	CGR 75-95 DAS	RGR 35-75 DAS	RGR 75-95 DAS	NAR 35-75 DAS	NAR 75-95 DAS	TQ 35 DAS	TQ 75 DAS	SCMR 35 DAS	SCMR 75 DAS
DM	-0.104	0.002	-0.001	0.064	0.104	-0.055	-0.031	0.200	-0.134	-0.066	0.001	-0.026	0.013	-0.042	0.005
	-0.137	**0.085**	**0.023**	**-0.725**	**-0.076**	**-0.407**	**0.008**	**0.973**	**-0.234**	**0.065**	**0.107**	**0.237**	**-0.146**	**-0.156**	**0.009**
PH	-0.032	0.001	-0.010	0.051	0.066	-0.048	0.006	0.134	-0.185	0.047	0.002	-0.024	0.018	-0.059	0.010
	-0.083	**0.026**	**0.113**	**-0.797**	**-0.071**	**-0.416**	**-0.008**	**0.948**	**-0.442**	**-0.029**	**0.197**	**0.316**	**-0.284**	**-0.317**	**0.026**
PB	0.019	0.000	-0.014	0.011	0.020	-0.009	-0.007	-0.017	-0.051	0.077	0.001	-0.015	0.012	-0.033	-0.002
	0.026	**-0.017**	**0.068**	**-0.245**	**-0.021**	**-0.128**	**0.003**	**0.256**	**-0.203**	**-0.126**	**0.112**	**0.213**	**-0.202**	**-0.227**	**-0.007**
SB	-0.004	0.000	-0.014	0.031	0.036	-0.029	0.054	0.042	-0.122	0.034	0.001	-0.011	0.000	-0.022	0.004
	-0.036	**-0.016**	**0.149**	**-0.675**	**-0.044**	**-0.358**	**-0.027**	**0.505**	**-0.389**	**-0.055**	**0.132**	**0.190**	**-0.026**	**-0.141**	**0.011**
SMS	-0.019	0.001	-0.013	0.037	0.064	-0.039	-0.037	0.102	-0.142	0.042	0.001	-0.024	0.019	-0.031	0.008
	-0.073	**-0.021**	**0.126**	**-0.581**	**-0.070**	**-0.321**	**0.014**	**0.740**	**-0.317**	**-0.048**	**0.026**	**0.348**	**-0.301**	**-0.174**	**0.023**
SL	-0.029	0.003	-0.007	0.026	0.024	-0.026	0.036	0.102	-0.175	0.002	0.002	-0.028	0.025	-0.070	0.010
	-0.035	**0.145**	**0.031**	**-0.329**	**-0.016**	**-0.244**	**-0.015**	**0.709**	**-0.390**	**0.012**	**0.222**	**0.256**	**-0.326**	**-0.297**	**0.020**
S/S	0.047	-0.001	0.004	-0.017	-0.038	0.007	0.052	-0.037	-0.027	0.016	0.001	0.006	-0.002	0.012	-0.011
	0.088	**-0.025**	**-0.070**	**0.361**	**0.054**	**0.118**	**-0.030**	**-0.130**	**-0.135**	**-0.015**	**0.054**	**-0.026**	**0.067**	**0.066**	**-0.032**
SW	-0.023	0.002	0.005	0.018	0.001	-0.028	0.053	0.157	-0.211	-0.027	0.003	-0.016	0.021	-0.017	0.000
	-0.026	**0.071**	**-0.028**	**-0.218**	**-0.003**	**-0.191**	**-0.015**	**0.769**	**-0.404**	**0.035**	**0.166**	**0.132**	**-0.225**	**-0.060**	**0.000**
BY	-0.038	0.001	-0.011	0.048	0.069	-0.048	-0.001	0.124	-0.167	0.023	0.002	-0.021	0.015	-0.035	0.004
	-0.113	**0.067**	**0.119**	**-0.928**	**-0.090**	**-0.482**	**-0.001**	**1.081**	**-0.454**	**-0.001**	**0.225**	**0.302**	**-0.235**	**-0.216**	**0.011**
OC	0.019	-0.001	0.003	-0.006	-0.002	0.003	0.008	-0.040	0.062	0.010	-0.001	0.012	-0.012	-0.003	-0.004
	0.042	**-0.062**	**0.022**	**0.144**	**0.007**	**0.091**	**-0.005**	**-0.535**	**0.216**	**-0.034**	**-0.027**	**-0.149**	**0.156**	**-0.008**	**-0.010**

DM - Days to maturity, PH - Plant height, PB - Primary branches, SB - Secondary branches, SMS - Siliquae on main shoot, SL - Siliqua length, S/S - Seeds/siliqua, SW - 1000-seed weight, BY - Biological yield, OC - Oil content, LAI - Leaf area index, LAR - Leaf area ratio, LGR - Leaf growth rate, SLW - Specific leaf weight, TDM - Total dry matter, CGR - Crop growth rate, RGR - Relative growth rate, NAR - Net assimilation rate, TQ - Transpiration quotient, SCMR - SPAD chlorophyll meter readings

Table 2 Direct (underlined) and indirect effects of 32 characters on seed yield in Indian mustard under drought stress

Character	DM	PH	PB	SB	SMS	SL	S/ S	SW	BY	OC	LAI 35 DAS	LAI 75 DAS	LAI 95 DAS	LAR 35-75 DAS	LAR 75-95 DAS	LGR 35-75 DAS	LGR 75-95 DAS
LAI 35DAS	0.030	-0.032	0.027	0.050	0.078	0.015	0.005	-0.001	0.335	0.016	0.037	-0.037	0.000	0.021	-0.002	0.009	-0.069
	0.067	**0.180**	**0.061**	**0.353**	**0.145**	**0.092**	**0.007**	**0.001**	**0.307**	**0.011**	**0.058**	**0.432**	**0.001**	**0.011**	**-0.069**	**-0.008**	**-0.021**
LAI 75 DAS	0.074	-0.036	0.032	0.036	0.061	0.019	0.002	-0.002	0.397	-0.010	0.019	-0.070	-0.003	0.028	0.000	0.051	-0.068
	0.136	**0.156**	**0.049**	**0.232**	**0.079**	**0.092**	**0.007**	**0.000**	**0.265**	**-0.015**	**0.036**	**0.697**	**-0.088**	**0.019**	**-0.001**	**-0.021**	**-0.019**
LAI 95 DAS	0.076	-0.012	-0.002	0.004	0.016	0.048	-0.002	-0.007	0.283	0.004	0.001	-0.020	-0.010	-0.009	-0.001	0.031	0.074
	0.141	**0.034**	**0.007**	**-0.028**	**0.004**	**0.229**	**-0.003**	**0.013**	**0.171**	**0.004**	**0.000**	**0.239**	**-0.258**	**-0.010**	**-0.023**	**-0.017**	**0.018**
LAR 35-75 DAS	0.002	-0.023	0.027	0.021	0.048	0.003	-0.001	-0.001	0.206	-0.006	0.011	-0.027	0.001	0.072	-0.002	0.003	-0.066
	0.003	**0.097**	**0.053**	**0.126**	**0.061**	**0.032**	**0.004**	**-0.001**	**0.111**	**-0.016**	**0.013**	**0.263**	**0.052**	**0.050**	**-0.061**	**-0.002**	**-0.018**
LAR 75-95 DAS	-0.013	0.014	-0.007	-0.015	-0.048	-0.028	-0.002	0.004	-0.109	-0.004	-0.010	-0.002	0.001	-0.016	0.007	0.024	-0.012
	-0.018	**-0.065**	**-0.005**	**-0.076**	**-0.078**	**-0.093**	**0.000**	**-0.009**	**-0.077**	**-0.009**	**-0.022**	**-0.006**	**0.033**	**-0.017**	**0.180**	**-0.010**	**-0.004**
LGR 35-75 DAS	0.061	-0.009	0.018	0.020	0.008	0.003	0.000	-0.002	0.212	-0.006	0.004	-0.041	-0.004	0.002	0.002	0.087	-0.034
	0.176	**0.126**	**0.020**	**0.182**	**0.055**	**0.074**	**0.009**	**0.002**	**0.303**	**-0.012**	**0.019**	**0.620**	**-0.184**	**0.003**	**0.074**	**-0.023**	**-0.009**
LGR 75-95 DAS	-0.004	-0.019	0.026	0.036	0.042	-0.025	0.005	0.004	0.144	-0.006	0.018	-0.035	0.005	0.035	0.001	0.021	-0.137
	-0.001	**0.122**	**0.040**	**0.289**	**0.087**	**-0.097**	**0.010**	**-0.010**	**0.156**	**-0.011**	**0.036**	**0.395**	**0.140**	**0.026**	**0.022**	**-0.006**	**-0.033**
SLW 75 DAS	-0.079	0.011	0.010	-0.002	-0.015	-0.019	-0.009	0.002	-0.149	-0.007	-0.007	0.030	0.005	0.010	0.000	-0.037	-0.009
	-0.158	**-0.081**	**0.012**	**-0.066**	**-0.053**	**-0.066**	**-0.010**	**-0.004**	**-0.189**	**-0.010**	**-0.012**	**-0.351**	**0.164**	**0.010**	**0.008**	**0.017**	**-0.002**
SLW 95 DAS	-0.032	0.007	0.003	-0.004	-0.011	-0.039	-0.002	0.004	-0.132	-0.011	-0.003	0.001	0.004	0.020	0.001	-0.009	-0.045
	-0.082	**-0.021**	**0.007**	**0.025**	**0.013**	**-0.229**	**-0.002**	**-0.009**	**-0.093**	**-0.012**	**-0.003**	**-0.026**	**0.146**	**0.023**	**0.016**	**0.007**	**-0.013**
TDM 35DAS	0.004	-0.016	0.034	0.035	0.045	0.022	0.003	0.002	0.193	0.005	0.022	-0.028	0.001	0.002	0.000	0.011	-0.058
	0.028	**0.114**	**0.033**	**0.281**	**0.096**	**0.061**	**0.008**	**-0.005**	**0.206**	**-0.005**	**0.050**	**0.390**	**0.001**	**0.007**	**-0.010**	**-0.012**	**-0.020**

Character	SLW 75 DAS	SLW 95 DAS	TDM 35 DAS	TDM 75 DAS	TDM 95 DAS	CGR 35-75 DAS	CGR 75-95 DAS	RGR 35-75 DAS	RGR 75-95 DAS	NAR 35-75 DAS	NAR 75-95 DAS	TQ 35 DAS	TQ 75 DAS	SCMR 35 DAS	SCMR 75 DAS
LAI 35DAS	-0.033	0.001	-0.024	0.058	0.065	-0.047	0.065	0.112	-0.230	0.052	0.002	-0.023	0.011	-0.048	0.013
	-0.038	**0.012**	**0.151**	**-0.708**	**-0.051**	**-0.375**	**-0.020**	**0.654**	**-0.455**	**-0.024**	**0.157**	**0.201**	**-0.118**	**-0.178**	**0.024**
LAI 75 DAS	-0.076	0.000	-0.016	0.077	0.088	-0.062	0.092	0.155	-0.205	0.017	0.004	-0.015	0.002	-0.091	0.016
	-0.091	**0.008**	**0.097**	**-0.815**	**-0.063**	**-0.421**	**-0.026**	**0.735**	**-0.353**	**0.003**	**0.233**	**0.113**	**-0.009**	**-0.314**	**0.028**
LAI 95 DAS	-0.097	0.003	0.003	0.044	0.103	-0.043	-0.104	0.192	-0.080	-0.102	0.001	-0.030	0.023	-0.013	0.002
	-0.114	**0.122**	**0.000**	**-0.526**	**-0.075**	**-0.298**	**0.029**	**0.904**	**-0.160**	**0.099**	**0.091**	**0.237**	**-0.249**	**-0.044**	**0.004**
LAR 35-75 DAS	0.025	-0.002	-0.001	-0.028	-0.008	0.002	-0.087	-0.029	0.028	0.194	0.000	-0.008	0.024	-0.088	0.018
	0.035	**-0.100**	**0.024**	**0.293**	**0.001**	**0.042**	**0.026**	**-0.160**	**0.044**	**-0.147**	**-0.035**	**0.086**	**-0.264**	**-0.330**	**0.034**
LAR 75-95 DAS	0.009	-0.001	0.001	0.000	-0.057	0.025	0.147	-0.148	0.132	-0.050	0.003	0.040	-0.033	0.046	-0.012
	0.008	**-0.020**	**-0.010**	**-0.014**	**0.035**	**0.182**	**-0.040**	**-0.625**	**0.210**	**0.051**	**0.160**	**-0.306**	**0.330**	**0.156**	**-0.020**
LGR 35-75 DAS	-0.078	0.001	-0.005	0.057	0.063	-0.038	0.066	0.112	-0.092	-0.074	0.003	0.003	-0.010	-0.016	0.003
	-0.127	**0.066**	**0.086**	**-0.931**	**-0.066**	**-0.409**	**-0.029**	**0.697**	**-0.293**	**0.078**	**0.311**	**-0.022**	**0.131**	**-0.078**	**0.008**
LGR 75-95 DAS	0.012	-0.002	-0.017	0.024	-0.007	-0.015	0.144	-0.034	-0.085	0.102	0.002	0.014	-0.015	-0.055	0.011
	0.012	**-0.085**	**0.104**	**-0.290**	**0.006**	**-0.113**	**-0.042**	**-0.154**	**-0.171**	**-0.086**	**0.136**	**-0.105**	**0.180**	**-0.201**	**0.020**
SLW 75 DAS	0.181	-0.002	0.001	-0.070	-0.122	0.052	0.057	-0.211	0.085	0.109	-0.001	0.026	-0.012	0.037	-0.009
	0.180	**-0.112**	**-0.029**	**0.768**	**0.086**	**0.400**	**-0.016**	**-0.934**	**0.165**	**-0.101**	**-0.073**	**-0.214**	**0.130**	**0.128**	**-0.016**
SLW 95 DAS	0.058	-0.007	0.003	-0.045	-0.027	0.031	-0.073	-0.140	0.186	0.098	-0.002	0.018	-0.016	-0.002	0.001
	0.093	**-0.217**	**-0.006**	**0.589**	**0.021**	**0.258**	**0.029**	**-0.768**	**0.376**	**-0.117**	**-0.191**	**-0.215**	**0.166**	**-0.001**	**0.002**
TDM 35DAS	-0.004	0.001	-0.040	0.040	0.035	-0.020	0.091	-0.047	-0.141	0.047	0.002	-0.005	-0.002	-0.012	0.000
	-0.030	**0.008**	**0.174**	**-0.593**	**-0.027**	**-0.260**	**-0.037**	**0.211**	**-0.358**	**-0.023**	**0.194**	**0.028**	**0.072**	**-0.056**	**-0.001**

DM - Days to maturity, PH - Plant height, PB - Primary branches, SB - Secondary branches, SMS - Siliquae on main shoot, SL - Siliqua length, S/S - Seeds/siliqua, SW - 1000-seed weight, BY - Biological yield, OC - Oil content, LAI - Leaf area index, LAR - Leaf area ratio, LGR - Leaf growth rate, SLW - Specific leaf weight, TDM - Total drymatter, CGR - Crop growth rate, RGR-Relative growth rate, NAR-Net assimilation rate, TQ- Transpiration quotient, SCMR-SPAD chlorophyll meter readings

Table 3 Direct (underlined) and indirect effects of 32 characters on seed yield in Indian mustard under drought stress

Character	DM	PH	PB	SB	SMS	SL	S/ S	SW	BY	OC	LAI 35 DAS	LAI 75 DAS	LAI 95 DAS	LAR 35-75 DAS	LAR 75-95 DAS	LGR 35-75 DAS	LGR 75-95 DAS
TDM 75DAS	0.076	-0.027	0.009	0.026	0.046	0.027	0.005	-0.003	0.301	0.003	0.019	-0.047	-0.004	-0.018	0.000	0.043	-0.029
	0.134	**0.123**	**0.018**	**0.196**	**0.068**	**0.099**	**0.007**	**0.005**	**0.247**	**0.005**	**0.036**	**0.503**	**-0.120**	**-0.013**	**0.002**	**-0.019**	**-0.009**
TDM 95 DAS	0.080	-0.022	0.011	0.019	0.051	0.016	0.007	0.000	0.276	0.001	0.013	-0.034	-0.006	-0.003	-0.002	0.030	0.006
	0.140	**0.109**	**0.016**	**0.128**	**0.081**	**0.047**	**0.010**	**0.001**	**0.241**	**0.002**	**0.026**	**0.389**	**-0.172**	**-0.001**	**-0.056**	**-0.014**	**0.002**
CGR 35-75 DAS	0.086	-0.033	0.009	0.033	0.064	0.035	0.003	-0.006	0.385	0.002	0.020	-0.049	-0.005	-0.001	-0.002	0.038	-0.023
	0.151	**0.129**	**0.019**	**0.209**	**0.075**	**0.148**	**0.004**	**0.010**	**0.258**	**0.007**	**0.039**	**0.522**	**-0.137**	**-0.004**	**-0.058**	**-0.017**	**-0.007**
CGR 75-95 DAS	0.010	0.001	0.002	-0.012	0.012	-0.010	0.004	0.002	0.002	0.001	-0.006	0.015	-0.002	0.015	-0.003	-0.013	0.046
	0.016	**-0.012**	**0.002**	**-0.078**	**0.017**	**-0.046**	**0.005**	**-0.004**	**-0.001**	**0.002**	**-0.010**	**-0.162**	**-0.068**	**0.012**	**-0.064**	**0.006**	**0.013**
RGR 35-75 DAS	0.078	-0.023	-0.004	0.012	0.041	0.034	0.003	-0.008	0.250	0.008	0.012	-0.031	-0.005	-0.006	-0.003	0.028	0.013
	0.147	**0.119**	**0.016**	**0.120**	**0.070**	**0.175**	**0.002**	**0.016**	**0.235**	**0.016**	**0.027**	**0.371**	**-0.169**	**-0.006**	**-0.081**	**-0.012**	**0.004**
RGR 75-95 DAS	-0.039	0.024	-0.010	-0.026	-0.043	-0.044	0.002	0.008	-0.254	-0.009	-0.018	0.031	0.002	0.004	0.002	-0.017	0.025
	-0.065	**-0.102**	**-0.023**	**-0.169**	**-0.055**	**-0.177**	**0.004**	**-0.015**	**-0.181**	**-0.012**	**-0.035**	**-0.326**	**0.055**	**0.003**	**0.050**	**0.009**	**0.008**
NAR 35-75 DAS	0.035	0.011	-0.028	-0.013	-0.023	-0.001	0.002	-0.002	-0.065	0.003	-0.008	0.005	-0.004	-0.055	0.001	0.025	0.055
	0.073	**-0.028**	**-0.058**	**-0.097**	**-0.034**	**0.023**	**0.002**	**0.005**	**-0.002**	**0.008**	**-0.008**	**0.013**	**-0.138**	**-0.040**	**0.050**	**-0.010**	**0.016**
NAR 75-95 DAS	-0.027	0.015	-0.011	-0.015	-0.011	-0.036	0.003	0.006	-0.201	-0.008	-0.012	0.034	0.002	0.000	-0.003	-0.036	0.035
	-0.048	**-0.073**	**-0.020**	**-0.093**	**-0.007**	**-0.163**	**0.002**	**-0.010**	**-0.145**	**-0.002**	**-0.020**	**-0.348**	**0.050**	**0.004**	**-0.062**	**0.016**	**0.010**
TQ 35 DAS	-0.051	0.021	-0.019	-0.015	-0.048	-0.046	-0.003	0.004	-0.214	-0.012	-0.012	0.015	0.004	-0.008	0.004	0.004	-0.026
	-0.100	**-0.112**	**-0.037**	**-0.127**	**-0.093**	**-0.177**	**-0.001**	**-0.008**	**-0.185**	**-0.012**	**-0.024**	**-0.160**	**0.125**	**-0.009**	**0.112**	**-0.001**	**-0.007**
TQ 75 DAS	-0.026	0.016	-0.017	0.000	-0.041	-0.043	-0.001	0.006	-0.159	-0.013	-0.006	0.002	0.003	-0.026	0.004	0.013	-0.031
	-0.049	**-0.080**	**-0.028**	**-0.013**	**-0.064**	**-0.179**	**-0.002**	**-0.010**	**-0.114**	**-0.010**	**-0.011**	**-0.010**	**0.103**	**-0.021**	**0.095**	**-0.005**	**-0.010**
SCMR 35 DAS	-0.033	0.021	-0.018	-0.013	-0.026	-0.048	-0.002	0.002	-0.145	0.001	-0.010	0.037	0.001	-0.037	0.002	-0.008	0.044
	-0.059	**-0.101**	**-0.035**	**-0.084**	**-0.042**	**-0.185**	**-0.002**	**-0.003**	**-0.119**	**0.001**	**-0.019**	**-0.399**	**0.021**	**-0.030**	**0.051**	**0.003**	**0.012**
SCMR 75 DAS	-0.014	0.013	0.004	-0.008	-0.026	-0.025	-0.008	0.000	-0.061	-0.006	-0.011	0.025	0.000	-0.029	0.002	-0.006	0.034
	-0.026	**-0.063**	**0.009**	**-0.048**	**-0.042**	**-0.093**	**-0.009**	**0.000**	**-0.046**	**-0.005**	**-0.019**	**-0.265**	**0.014**	**-0.023**	**0.049**	**0.003**	**0.009**

Character	SLW 75 DAS	SLW 95 DAS	TDM 35 DAS	TDM 75 DAS	TDM 95 DAS	CGR 35-75 DAS	CGR 75-95 DAS	RGR 35-75 DAS	RGR 75-95 DAS	NAR 35-75 DAS	NAR 75-95 DAS	TQ 35 DAS	TQ 75 DAS	SCMR 35 DAS	SCMR 75 DAS
TDM 75DAS	-0.110	0.003	-0.014	0.114	0.103	-0.078	0.175	0.262	-0.328	-0.132	0.004	-0.020	-0.003	-0.033	0.009
	-0.122	**0.113**	**0.091**	**-1.129**	**-0.067**	**-0.524**	**-0.046**	**1.102**	**-0.530**	**0.110**	**0.289**	**0.151**	**0.035**	**-0.109**	**0.015**
TDM 95 DAS	-0.124	0.001	-0.008	0.066	0.179	-0.054	-0.204	0.210	-0.031	-0.069	-0.001	-0.041	0.020	-0.039	0.012
	-0.137	**0.041**	**0.042**	**-0.667**	**-0.113**	**-0.384**	**0.053**	**0.935**	**-0.050**	**0.058**	**-0.060**	**0.309**	**-0.200**	**-0.128**	**0.018**
CGR 35-75 DAS	-0.108	0.003	-0.009	0.101	0.110	-0.088	0.111	0.300	-0.341	-0.090	0.003	-0.029	0.007	-0.058	0.013
	-0.128	**0.100**	**0.080**	**-1.053**	**-0.077**	**-0.562**	**-0.030**	**1.271**	**-0.566**	**0.084**	**0.225**	**0.237**	**-0.072**	**-0.201**	**0.023**
CGR 75-95 DAS	-0.024	-0.001	0.008	-0.046	0.085	0.023	-0.431	-0.031	0.309	0.063	-0.006	-0.028	0.031	-0.002	0.003
	-0.026	**-0.056**	**-0.058**	**0.470**	**-0.053**	**0.152**	**0.112**	**-0.100**	**0.512**	**-0.046**	**-0.371**	**0.208**	**-0.323**	**-0.005**	**0.005**
RGR 35-75 DAS	-0.108	0.003	0.005	0.085	0.106	-0.075	0.038	0.352	-0.309	-0.119	0.002	-0.035	0.019	-0.050	0.015
	-0.122	**0.120**	**0.027**	**-0.901**	**-0.076**	**-0.517**	**-0.008**	**1.382**	**-0.514**	**0.093**	**0.170**	**0.307**	**-0.205**	**-0.179**	**0.027**
RGR 75-95 DAS	0.033	-0.003	0.012	-0.080	-0.012	0.064	-0.285	-0.233	0.468	0.061	-0.005	0.010	0.000	0.033	-0.006
	0.039	**-0.108**	**-0.082**	**0.794**	**0.008**	**0.422**	**0.076**	**-0.942**	**0.754**	**-0.049**	**-0.359**	**-0.079**	**-0.012**	**0.111**	**-0.009**
NAR 35-75 DAS	-0.077	0.003	0.007	0.059	0.048	-0.031	0.106	0.164	-0.112	-0.256	0.002	-0.003	-0.010	0.057	-0.005
	-0.098	**0.137**	**-0.022**	**-0.675**	**-0.036**	**-0.256**	**-0.028**	**0.696**	**-0.198**	**0.184**	**0.144**	**0.026**	**0.132**	**0.217**	**-0.008**
NAR 75-95 DAS	0.026	-0.002	0.011	-0.067	0.027	0.040	-0.332	-0.111	0.334	0.060	-0.007	-0.014	0.011	0.025	-0.003
	0.028	**-0.089**	**-0.072**	**0.700**	**-0.015**	**0.271**	**0.089**	**-0.502**	**0.580**	**-0.057**	**-0.467**	**0.107**	**-0.135**	**0.082**	**-0.006**
TQ 35 DAS	0.067	-0.002	0.003	-0.031	-0.103	0.036	0.167	-0.176	0.064	0.011	0.001	0.071	-0.053	0.070	-0.018
	0.078	**-0.095**	**-0.010**	**0.347**	**0.071**	**0.270**	**-0.047**	**-0.862**	**0.121**	**-0.010**	**0.102**	**-0.492**	**0.538**	**0.235**	**-0.030**
TQ 75 DAS	0.032	-0.002	-0.001	0.006	-0.051	0.009	0.197	-0.098	0.001	-0.036	0.001	0.055	-0.068	0.056	-0.016
	0.037	**-0.058**	**0.020**	**-0.064**	**0.036**	**0.065**	**-0.058**	**-0.456**	**-0.015**	**0.039**	**0.101**	**-0.425**	**0.623**	**0.192**	**-0.028**
SCMR 35 DAS	0.039	0.000	0.003	-0.022	-0.041	0.030	0.004	-0.104	0.089	-0.085	-0.001	0.029	-0.022	0.171	-0.033
	0.042	**0.000**	**-0.018**	**0.224**	**0.026**	**0.206**	**-0.001**	**-0.452**	**0.152**	**0.073**	**-0.070**	**-0.211**	**0.218**	**0.548**	**-0.052**
SCMR 75 DAS	0.036	0.000	0.000	-0.023	-0.045	0.026	0.030	-0.115	0.057	-0.026	-0.001	0.028	-0.024	0.123	-0.046
	0.040	**0.005**	**0.003**	**0.231**	**0.029**	**0.179**	**-0.008**	**-0.506**	**0.096**	**0.021**	**-0.038**	**-0.204**	**0.239**	**0.395**	**-0.072**

Residual effect = 0.1879 at phenotypic and 0.000 at genotypic level, Underlined values indicate direct effects, value in light and bold face indicate effects at phenotypic and genotypic level. DM - Days to maturity, PH - Plant height, PB - Primary branches, SB - Secondary branches, SMS - Siliquae on main shoot, SL - Siliqua length, S/S - Seeds/siliqua, SW - 1000-seed weight, BY- Biological yield, OC - Oil content, LAI - Leaf area index, LAR - Leaf area ratio, LGR - Leaf growth rate, SLW - Specific leaf weight, TDM - Total dry matter, CGR - Crop growth rate, RGR - Relative growth rate, NAR - Net assimilation rate, TQ - Transpiration quotient, SCMR - SPAD chlorophyll meter readings

Considering the results of the present investigation it is concluded that donors with multiple determinants of yield like days to maturity, plant height, more primary and secondary branches/plant, and high biological yield/plant should be used in the breeding programme for genetic enhancement of seed yield. However, a balance has to be struck between plant height, days to maturity and seed yield because of their positive associations suggesting that late maturing and very tall genotypes would have high seed yield while early maturity is a desirable character under drought stress. Furthermore, studies should work out the optimum maturity duration and plant height under drought stress.

It also appears from the foregoing that dry matter production accompanied by early growth and development of the crop is important under drought stress. Since LAI, LGR, CGR, RGR and NAR are the functions of dry matter production and/or leaf area, therefore, selection on the basis of high TDM and large LAI at 50% flowering should be quite effective in improving seed yield under drought. Nevertheless, increased LAI might increase radiation load resulting in to high transpiration. Therefore, genotypes having high LAI with erect leaves and low TQ besides desirable yield components should be accorded priority in the selection programme.

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Identification and delineation of potential castor growing areas in different Agro-eco sub regions of India

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(Received: April, 2015; Revised: May, 2015; Accepted: June, 2015)

ABSTRACT

Castor (*Ricinus communis* L.) is one of the oldest cultivated crops in the world. Castor oil is having global importance specially in chemical industry because it is the only commercial source of a hydroxylated fatty acid. Castor also has tremendous future potential as an industrial oilseed crop because of its high seed oil content, unique fatty acid composition, potentially high oil yields, and ability to be grown under drought and saline conditions. Soils and prevailing climatic conditions across different Agro-Eco Sub Regions (AESR) of India were assessed and matched with crop requirement criteria to identify the potential castor growing areas. Potential castor growing areas comprise favourable soil depth (deep soils) with longer Length of Growing Period (LGP). Among the traditional castor growing areas, AESR 5.2, 7.3, 8.2 and 8.3 have potential to grow castor whereas in non-traditional castor growing areas, AESR 6.3, 6.2, 13.1, 15.4 and 17.1 are most potential for expanding castor cultivation. Relative yield and spread index of castor indicated that most of the potential areas identified in different AESRs fall in zone II and III, need special attention to increase productivity and area expansion programme. Site specific management strategies like selection of suitable variety matching with LGP and proper adoption of nutrient management will overcome the limitations observed in these zones.

Keywords: Castor, Crop growing environment, Land suitability, Length of growing period

Castor (*Ricinus communis* L.) is one of the ancient and important non-edible oilseed crops cultivated for centuries specifically for the oil found in its seed. Castor oil commonly comprises as much as 50-60% of the weight of the seed, making it one of the highest yielding oilseed crops (Weiss, 2000; Baldwin and Cossar, 2009). Cultivation of castor is largely confined to countries lying between 40° N and 40° S latitude. India blessed with ideal tropical conditions for castor crop and is one of the biggest producers of castor seed (62.4%) followed distantly by China (19.2%) and Brazil (12.7%) (DOD, 2012). The productivity of castor in India is also high as compared to other countries. In India, Gujarat ranks first both in area and production followed by Rajasthan, Telangana/Andhra Pradesh and Tamil Nadu. These five states alone contribute nearly 95% of the total area and production of castor (DOD, 2012). The oil content of the seed varies from 35-55% with the average of about 47%. The castor oil is widely used and has multiple applications in preparation of several industrial products *viz*., paints, varnishes, soaps, lubricants, pharmaceutical, textiles, nylon roap, etc.

Castor crop requires a moderately high temperature (20-26°C) with low humidity throughout the growing season to produce maximum yields. Castor is tolerant to drought and grows well in relatively dry and hot regions having a well distributed rainfall of 500-750 mm. Long and clear sunny days are desirable to produce higher yield. Extreme temperatures have a bearing on oil quality. At temperature of >35°C and below 15°C, oil and protein content gets reduced. It can be grown on almost all soils except heavy clays and those poorly drained and saline (Moshkin, 1986). Soils of slightly acid reaction (pH of 5.0-6.0) are preferred. The growth components *viz*., LAI and dry matter and seed yield of castor was increased significantly with increment in soil depth due to higher moisture and nutrient use efficiencies (Subba Reddy *et al.,* 2004). Satyavathi and Suryanarayan Reddy (2004) evaluated the soil-site suitability for six major crops in Telangana state and found that the major limiting factor for the growth of castor is soil pH (pH>7.5) which can be corrected by applying organic manures and gypsum.

In India, castor is grown under two contrasting environments *viz.,* irrigated intensive cultivation with high productivity in Gujarat and Rajasthan; and rainfed cultivation coupled with poor management and very low productivity in Andhra Pradesh, Karnataka, Tamil Nadu, Orissa, etc., which require location specific technologies. There exists a huge yield gap between Improved Technology (IT) and Farmers Practice (FP) of castor cultivation. This paper attempts to assess and identify suitable castor growing tracts based on prevailing soil and climatic conditions across castor growing

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areas in the country and identify production constraints to suggest measures for improved production and productivity and identify potential new areas for crop area expansion.

MATERIALS AND METHODS

District and state wise area, production and productivity data of castor crop was compiled from available sources (DOD, 2012). The soil information for castor growing districts were abstracted from state soil survey reports published by National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur under soil resource mapping project of the country (Challa *et al.,* 1995; Natarajan *et al.,* 1996; Reddy *et al.,* 1996; Sarkar *et al.,* 1995; Shivaprasad and Seghal, 1996; Sharma *et al.,* 1994; Haldar *et al.,* 1997; Shyampura and Seghal, 1995; Sen *et al.,* 1999; Singh *et al.,* 2003). Castor growing districts map was over laid on agro-ecological sub regions map prepared by NBSS&LUP (Seghal *et al.,* 1992) to arrive at length of growing period of castor in different growing tracts of the country (Fig. 1). Land suitability assessment was carried out following FAO guidelines (FAO, 1976) and soil-site suitability criteria were developed for castor (Table 1). These criteria were used to group the castor growing areas into highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N) based on kind and degree of limitations (Naidu *et al.,* 2006). The cultivars recommended for different regions were matched with length of growing period (LGP) of the area to know relative suitability of the variety for the region. Based on the secondary data, Relative Yield Index (RYI) and Relative Spread Index (RSI) were worked out as suggested by Kanwar (1972) to know the efficient districts for suggesting different strategies to improve the production of castor. RYI and RSI are calculated grouped into following four zones. Zone-I: High Yield and High spread (>90 RYI and >90 RSI), Zone-II: High yield and Low Spread (>90 RYI and <90 RSI), Zone III: Low yield and High spread (<90 RYI and >90 RSI) and Zone IV: Low spread and Low yield (<90 RYI and < 90 RSI).

Table 1 Land suitability criteria for castor

		Suitable			
		Highly	Moderately	Marginally	Not suitable
Length of growing period (days) for varieties	Early	>120	90-120	<90	
	Medium	>150	120-150	90-120	
	Late	>210	180-210	150-180	
Soil drainage	Class	Well drained	Moderately well drained	Imperfectly drained	Poorly drained
Texture	Class	L, Scl, Sil, Cl,Sl	Sicl, Sic, Sc	Ls,	S
Effective soil depth (cm)	cm	>75	50-75	25-50	<25
Coarse fragments (Vol %)	Vol %	Non gravelly	Upto 15	15-35	>35
pH	1:2.5	6.5-7.5	6.5-5.0	8.0-9.0	>9.0
			7.5-8.0	4.0-5.0	<4.0

Note: S: sand; L: loam; Ls: loamy sand; Sl: sandy loam; Scl: sandy clay loam; Sil: silt loam; Cl: clay loam; Sicl: silty clay loam; Sic: silty clay; Sc: sandy clay

RESULTS AND DISCUSSION

Agro climatic situations across castor growing region: The crop cultivation is spread in most of the climatic regions i.e., arid condition in Rajasthan and Gujarat; semi-arid climate in southern and central India; sub-humid climate in Orissa and Bihar; and humid to per-humid climate in Assam (Fig. 2). The rainfall varied from 242 mm in Pali (Rajasthan) to 3455 mm in Dhemaji (Assam). Similarly length of growing period varied from <60 days in Rajasthan to >300 days in Assam. Length of growing period (LGP) in southern region (Telangana including AP, Karnataka and Tamil Nadu) varied from 60-90 days, 90-120 days and 120-150 days, respectively. Castor crop suffer from moisture stress during maturity stage in southern region due to cultivation of medium duration cultivars under rainfed conditions. In central region (Maharashtra, Madhya Pradesh) crop growing period ranges from 120-150 days and 150-180 days, respectively. In western region (Gujarat and Rajasthan) crop growing period predominantly ranges from <60 days, 60-90 days and 90-120 days which is insufficient to grow castor successfully under rainfed conditions and hence the crop is grown under protective irrigations as per the need resulting in higher productivity in these two states. In eastern region (Odisha and Bihar states) the predominant LGP is 150-180 days and hence there is no moisture limitation for castor production. On the other hand, in north eastern region, LGP varies from greater than 270 days where there is no limitation of moisture for growing longer/perennial cultivars. In this region perennial cultivars are more suitable than short and medium duration cultivars.

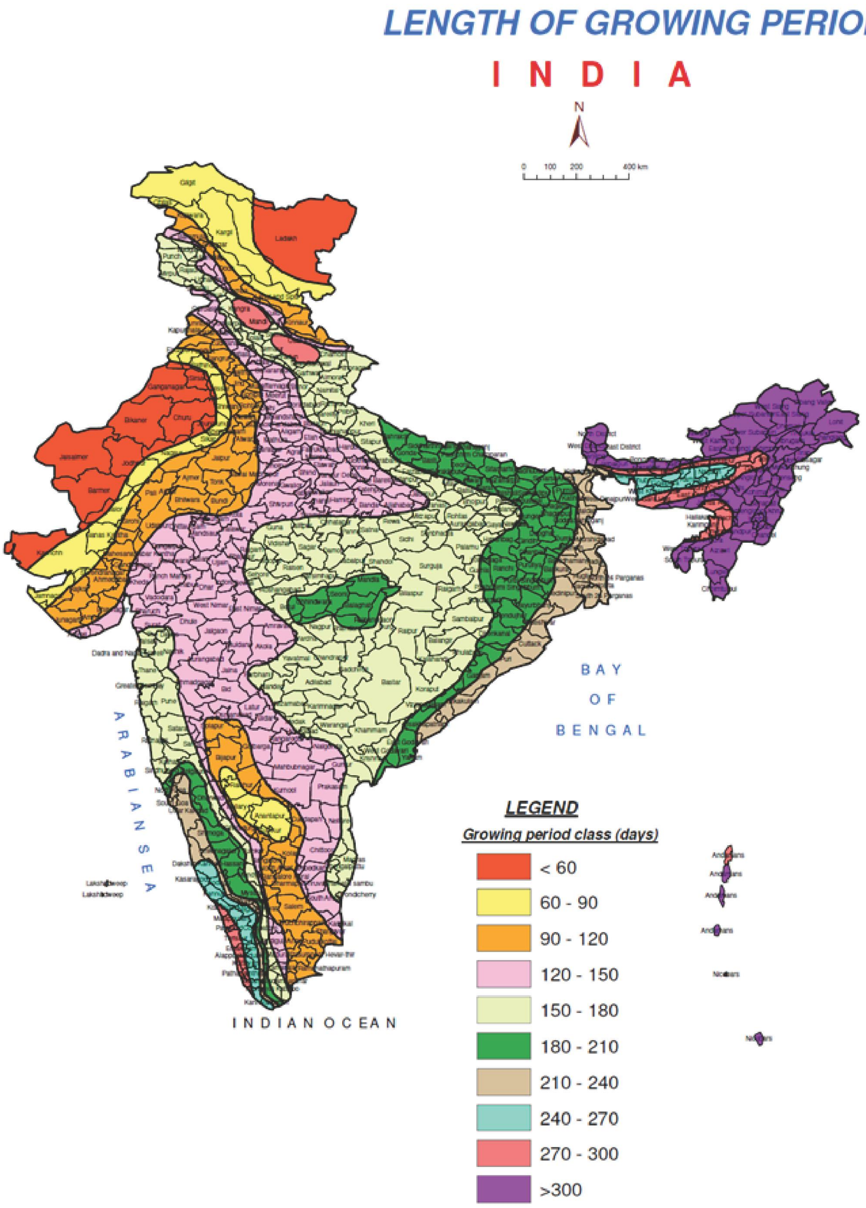

Fig.1. Length of growing period in different districts/states of India (Source: Seghal *et al*., 1992)

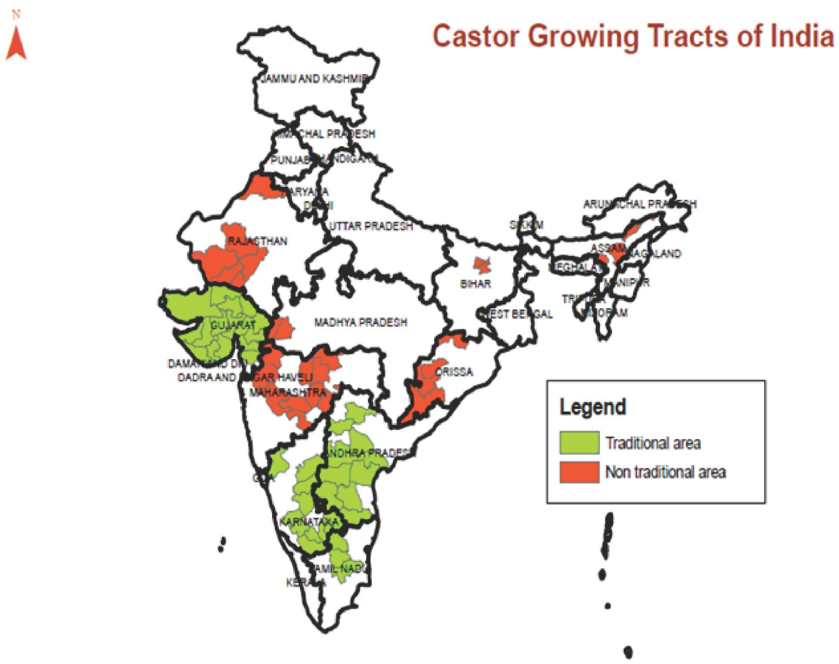

Fig. 2. Castor growing tracts of India

Relative yield and spread index: The analysis of relative yield and spread index carried out in the study gave an opportunity to identify efficient districts for area expansion or productivity improvement of castor in the country. Jamnagar district was found to have highest RYI and RSI followed by Mehsana, Gandhinagar and Banaskantha (Table 4). The districts of Narmada and Porbandar showed high RYI (120-150) and less RSI (90-120) whereas Patan and Ahmadabad districts showed low RYI (90-120) and high RSI (>200). Relative spread index of Amreli, Bhavnagar and Dhoad districts was found to be very low. The districts having low RYI and high RSI belonged to Zone III. The RYI of Sirohi, Barmer and Jalore is 60 to 90, Kurnool, Pali, Mahabubnagar having 30-60 and Namakkal, Prakasam, Rangareddy very low RYI (<30) whereas the relative spread index is greater than 200. In this Zone, Koraput and Medak districts were found with very low yield index (<30). The districts having low RYI and low RSI belongs to Zone IV. Ahmednagar, Buldana, Dhule, Dharmapuri, Dhar, Trichy, Nanded and Beed districts showed very low RYI (<30) and RSI (<30). The strategy in Zone II districts could be oriented towards area expansion by extension activities and awareness programmes whereas zone III districts should be targeted to increase the productivity by recommending short duration varieties and adoption of suitable agronomic measures. The districts with low RYI and RSI under Zone IV needs special strategies to improve the productivity and area expansion based on soil and agro-climatic situations.

Land suitability assessment in traditional castor growing areas

Gujarat: Total area under castor cultivation in the state is 6.27 lakh ha. The dominant castor growing districts in Gujarat are Banaskantha, Mehsana, Patan and Ahmadabad. District wise major soils, rainfall and prevailing growing period are presented in Table 2. In these four major districts, average rainfall ranges from 535 mm in Patan to 702 mm in Ahmadabad with LGP ranging from 60-90 days in Banskantha and Patan; 90-120 days in Mehsana and Ahmadabad. In general, the major soils occurring in these districts are very deep, well drained, calcareous coarse loamy soils followed by very deep, well drained fine loamy soils. The existing soil conditions are highly favourable whereas prevailing crop growing period (60-90 & 120 days) is insufficient to support long duration varieties. Based on climatic limitation these four districts were categorized as marginally suitable with severe limitation of shorter growing period for castor cultivation.

Telangana/Andhra Pradesh: The total area under castor cultivation was found to be 1.79 lakh ha in the erstwhile combined state of Andhra Pradesh. The major castor growing districts are Mahabubnagar, Nalgonda, Rangareddy in Telangana state; Kurnool and Prakasam districts in Andhra Pradesh. The Mahabubnagar district receives an average rainfall of 792.3 mm with LGP of 120-150 days whereas Prakasam district receives an average rainfall of 542.4 mm with LGP of 90-120 days. In general, the major soils occurring in these two districts are shallow to deep, well drained (with some limitations of drainage in Nalgonda Dist.), red clayey soils followed by moderately deep well drained red clayey soils. Overall, soils have no/slight limitation while LGP has moderate limitation for growing successful crop.

Karnataka: The total area under castor cultivation is 0.18 lakh ha. Major castor growing districts are Tumkur, Hassan, Chitradurga and Mysore. District wise major soils, rainfall and prevailing length of growing period are described in Table 2. In these four districts, average rainfall ranges from 638 mm in Chitradurga to 879 mm in Hasan with LGP ranging from 90-120 days in Chitradurga; 90-180 days in Tumkur; 120-150 days in Mysore and 150-180 days in Hassan. Based on soil and agro-climatic conditions it has been grouped under marginally to unsuitable with strong limitations of growing period and problem of drainage, texture and salinity.

Tamil Nadu: Namakkal, Salem, Erode and Dharmapuri are the major castor growing districts of which Namakkal and Dharmapuri are important ones. District wise soils and length of growing period details are presented in Table2. Namakkal district receives an average rainfall of 775 mm with LGP of 150-180 days. In Dharmapuri average rainfall is slightly higher (852 mm) with same LGP as that in Namakkal district. The major soils occurring in these districts are moderately deep, well drained, calcareous gravelly loam soils followed by moderately shallow, well drained, red loamy soils. Based on soils and agro-climatic conditions the district has been categorized as marginally to moderately suitable for castor with strong limitations of rooting depth and sub-soil gravelliness.

Non-Traditional castor growing areas

Rajasthan: Rajasthan is emerging as an important castor growing state with an area of 1.95 lakh ha. Major castor growing districts are Barmer, Jalore, Ganganagar and Hanumangarh. District wise major soils, rainfall and crop growing period are presented in Table 3. The districts of Ganganagar and Hanumangarh receive an average rainfall of 253.7 mm with LGP of <60 days where as Jalore receive about 385.8 mm rainfall with LGP of 60-90 days The major soils occurring in the district are deep, well drained, sandy soils followed by moderately deep, well drained, sandy soils. Prevailing soil and agro-climatic conditions are marginally unsuitable for castor production with strong limitations of shorter growing period and sandy soils. Despite unfavourable growing conditions the crop acreage is on the increasing side as the crop is raised under protective irrigation under drip irrigation leading to higher productivity.

Maharashtra: The current total area under castor cultivation in the state is around 0.11 lakh ha. Major castor growing districts are Beed and Buldhana. District wise major soils, rainfall and prevailing crop growing period details are presented in Table 3. Two districts receive an average rainfall of 726 mm; LGP of 90-120 days and 764mm; LGP of 120-150 days, respectively in Beed and Buldhana districts. The major soils occurring in these districts are deep, well drained, cracking clay followed by very shallow, moderately well drained, clayey soils. Soil and prevailing agro-climatic conditions in the district are marginally to unsuitable for castor due to strong limitations of shallow rooting depth and heavy texture.

Madhya Pradesh: The districts of Jabua and Dhar in Madhya Pradesh receive an average rainfall of 855-956 mm with LGP of 120-150 days. The major soils occurring in these districts are moderately deep, well drained, clayey soils followed by extremely shallow, somewhat excessively well drained, loamy soils. Soil and agro climatic conditions in these districts are moderately to unsuitable for castor production due to shallow rooting depth

Bihar: An average rainfall of 1069 mm is received in Begusarai and Samastipur districts (1234mm) in Bihar with LGP of 180-210 days in both the districts. The major soils occurring in the district are very deep, well drained, fine loamy soils followed by very deep, moderately well drained, fine loamy soils. Soil and agro-climatic conditions in the district are highly to moderately suitable for castor production.

Odisha: The Kalahandi district receives an average of 1330 mm rainfall; Koraput district with an average rainfall of 1567 mm experience LGP of 180-210 days in both the districts. The major soils occurring in the district are deep, somewhat excessively and well to imperfectly drained, gravelly fine loamy soils followed by moderately shallow, well drained, gravelly clayey soils. The prevailing soil and agro-climatic conditions in the districts are marginally to moderately suitable with limitation of drainage. In Koraput, soils are marginally suitable to not suitable for castor production with limitations of gravelliness and steep slopes.

Table 2 Land suitability assessment for castor in different districts of traditional castor growing areas

District	AESR	Depth	Texture	Drainage	RF(mm)	LGP (days)	Suitability
Gujarat							
Banaskantha	2.3	Very deep	Coarse loamy	Well drained	549.4	60-90	S3-N
Mehsana	4.2	Very deep	Coarse loamy	Mod. well drained	618.7	90-120	S3
Patan	2.3	Very deep	Coarse loamy to Fine loamy	Well drained	535	60-90	S3
Ahmadabad	6.1	Moderately deep	Cracking clay	Well to mod. well drained	702	90-120	S3
Amreli	5.1	Moderately shallow	Cracking clay	Well drained	574	90-120	S3
Anand	5.2	Very deep to deep	Fine loamy	Well drained	874.8	120-150	S2
Bharuch	5.2	Very deep	Cracking clay	Mod. well drained	944.7	120-150	S2-S3
Bhavnagar	5.1	Moderately shallow to deep	Cracking clay	Well drained	593.2	90-120	S2-S3
Dhoad	5.2	Shallow	Loamy to clayey	Well drained	873.4	120-150	S3
Gandhinagar	4.2	Very deep	Coarse loamy to fine loamy	Well drained	800	90-120	S3
Jamnagar	2.4	Shallow to moderately deep	Clayey	Well drained	479.4	60-90	S3
Junagadh	5.1	Moderately shallow	Fine to fine loamy soils	Well drained	749.2	90-120	S3
Narmada	5.2	Shallow	Clayey	Well drained	1068	120-150	S3-N
Panchmahal	5.2	Moderately deep to very deep	Fine to coarse loamy	Well drained	941	120-150	S2
Porbandar	2.4	Very deep	Cracking clay	Imperfectly drained	529	60-90	S3
Telangana/ Andhra Pradesh							
Mahbubnagar	7.2	Deep to mod. deep	Clay	Well drained	792.3	120-150	S2-S3
Nalgonda	7.2	Deep to mod. deep	Clay	Imperfectly drained to well drained	762	120-150	S3-S2
Kurnool	7.1	Shallow	Clay	Somewhat excessively drained	606.9	90-120	S3
Prakasam	7.3	Shallow to mod. deep	Clay	Well drained	542.4	90-120	S3-S2
Anantapur	3	Mod. deep (SK)	Clay	Well drained	583	<90/90-120	S3-N
Adilabad	6.2	Shallow to very shallow (SK)	Clay to loamy	Well drained	1070.9	120-150	S3-S2
Medak	7.2	Deep	Cracking clay	Moderately well drained	953.4	150-180	S3-N
Rangareddy	7.2	Very shallow to very deep	Clay	Excessively drained to moderately well drained	783	120-150	S3-N
Warangal	7.2	Mod. deep to very shallow	Loam	Well drained to imperfectly drained	994	150-180	S3-N
Chittor	8.3	Mod.deep	Clay	Well drained	926	180-210	S2
Kadapa	7.1	Shallow	Loamy	Excessively drained	747.6	90-120	S3
Guntur	7.3	Mod. deep to deep	Clay to loamy	Well drained	889.1	120-150	S3-S1
Karnataka							
Tumkur	8.2	Deep	Clay	Well drained	806.2	150-180	S2-S3
Hassan	8.2	Deep	Clay	Mod. well drained to imperfectly drained	878.9	150-180	S3
Chitradurga	8.2	Very deep to shallow	Clay to cracking clay	Mod. well drained to well drained	638	90-120	S3-N
Mysore	8.2	Moderately deep to very deep	Clay to cracking clay	Well drained	809.7	120-150	S3
Belgaum	6.4	Very deep to very shallow	Cracking clay to loamy sand	Well drained	1303	<90/90-120	S3
Bellary	3	Very deep to deep	Clay	Mod. well drained	519	<90/90-120	S3-N
Bangalore rural	8.2	Deep to very deep	Clay	Well drained	824	150-180	S2
Chamrajnagar	8.2	Moderately shallow- very deep	Clay	Well drained	811	90-150	S3
Chikmagalur	19.2	Deep	Clay	Mod. well drained to well drained	1762	>240	S2-S3
Davangere	6.4	Very deep to mod. deep	Clay	Well to moderately well drained	639.9	120-150	N-S2
Haveri	6.4	Moderately shallow	Loamy to clay	Well drained	769.2	150-180	N-S3
Kolar	8.2	Deep to very deep	Clay	Well drained	661.4	120-150	S2
Koppal	3	moderately deep to very shallow	Clay	Well drained	572	<90	S3-N
Mandya	8.2	Deep	Clay	Well to moderately well drained	688.5	120-150	S3-N
Raichur	6.1	Deep to moderately deep	Clay	Well drained	661.3	150-180	S2-N
Ramnagar	8.2	Deep	Clay	Moderately well drained	844.8	150-180	S1-S2
Tamil Nadu							
Namakkal	8.3	Shallow to moderately shallow	Loamy	Well drained	775	150-180	S3-S2
Dharmapuri	8.3	Moderately deep to moderately shallow	Clay	Well to somewhat excessively	852	150-180	S2
Salem	8.3	Moderately shallow to shallow	Clay	Well drained	966	150-180	S2-S3
Erode	8.3	Shallow to very shallow	Loamy	Well drained	795	150-180	S3-N
Trichy	8.3	Deep to moderately shallow	Clay to cracking clay	Moderately well to well drained	869	90-120	S2-S3

Note: S1: Highly suitable, S2: Moderately suitable, S3: Marginally suitable, N: Not suitable

Table 3 Land suitability assessment for castor in different districts of non-traditional castor growing areas

District	AESR	Depth	Texture	Drainage	RF (mm)	LGP (days)	Suitability
Rajasthan							
Barmer	2.1	Deep	Sandy	Excessively drained	281.8	<60	S3-N
Jalore	2.3	Very deep	sandy	Excessively drained	385.8	60-90	S3
Ganganagar	2.1	Deep	Coarse loamy	Well drained	322.3	<60	S3-N
Hanumangarh	2.1	Very deep	Coarse loamy to sandy	Well drained	253.7	60-90	S3
Jothpur	2.1	Deep to mod. deep	Sandy to fine loamy	Excessively drained	326.8	<60	S3-N
Pali	2.3	Moderately shallow to very deep	Fine loamy to coarse loamy	Well drained	242	60-90	S3
Sirohi	2.3	Very shallow to deep	Loamy to fine loamy	Well drained	769.2	60-90	N-S3
Maharashtra							
Ahemednagar	4.2	Deep to moderately shallow	Cracking Clay	Moderately well	568.7	90-120	N-S2
Beed	6.1	Very shallow to shallow	Cracking Clay	Somewhat excessively to well drained	726	90-120	N-S2
Buldana	6.3	Deep to very shallow	Cracking Clay	Moderately well to well drained	764.1	120-150	S3-N
Akola	6.3	Deep to very shallow	Cracking Clay	Moderately well to well	801.7	120-150	N-S3
Amravati	6.3	Deep to very shallow	Cracking Clay	Moderately well	870.5	120-150	S2-N
Dhule	6.2	Deep to very shallow	Clayey to loamy	Moderately well to somewhat excessively	614.7	120-150	S2-N
Nanded	6.2	Shallow to very shallow	Clayey to loamy	Well drained	991.5	120-150	S3-N
Madhya Pradesh							
Dhar	5.2	Moderately deep to extremely shallow	Loamy to clay	Well drained to somewhat excessively	955.6	120-150	N-S2
Jabua	5.2	Shallow to moderately deep	Loamy to clay	Somewhat excessively to well drained	855.5	120-150	S3-S2
Bihar							
Begusarai	13.1	Very deep	Fine loamy	Well to mod. well drained	1069	180-210	S1-S2
Samastipur	13.1	Very deep	Fine loamy	Well to mod. well drained	1234	180-210	S1-S2
Orissa							
Koraput	12.1	Deep to moderately shallow	Fine loamy	Somewhat excessively to poorly drained	1567.2	180-210	S3-N
Kalahandi	12.1	Moderately deep to very deep	Fine loamy to fine	Well to imperfectly drained	1330.5	180-210	S3-S2
Assam							
Dhemaji	15.4	Very deep	Coarse loamy to fine loamy	Well drained	3435	>300	S1
Karbialong	17.1	Very deep	Coarse loamy to fine loamy	Well drained	1205	270-300	S1-S2
Lakimpur	15.4	Deep to moderately deep	Coarse loamy to fine soils	Well drained	2967	>300	S1

Note: S1: Highly suitable, S2: Moderately suitable, S3: Marginally suitable, N: Not suitable

Assam: The important districts of castor cultivation are Karibalong, Dhemaji and Lakimpur in Assam. An average rainfall of 1205 mm with LGP of 270-300 days; 3435 mm and LGP of >300 days; 2967 mm with LGP of >300 days have been recorded in Karibalong, Dhemaji and Lakimpur districts respectively. The major soils occurring in the district are very deep, well drained, coarse loamy soils followed by very deep, well drained, fine loamy soils. Prevailing soil and agro climatic conditions in the district are highly suitable for castor production. Despite favourable climatic conditions, the castor cultivation is limited for rearing eri-silkworms by utilizing leaves of castor for feeding the larvae of eri-silk worm. The crop is not utilized for seed purpose. There is scope for increasing area and productivity of crop.

Evaluation of varietal and agronomic recommendations: In the coordinated castor research project significant achievement has been made in development of improved varieties and hybrids of short and medium duration coupled with biotic stress resistance/tolerance. There is a need for development of production technologies to provide ecological optimum conditions through tailored agronomic practices for different agro-ecological situations and varietal groups. Choice of varieties and fertilizer management plays a major role in improving crop yield and productivity. The varietal recommendation across different states (Table 5) indicated that popular varieties and hybrids which are currently grown in different states have longer duration than the crop growing period prevailing in the area. In Gujarat and Rajasthan, effective LGP is less than 60-90 and 120 days whereas the popular varieties grown in these states have longer duration of 110-240 days. This indicates that castor production in Rajasthan and Gujarat needs supplemental irrigation for successful growing under rainfed conditions. In Orissa, Bihar, most of the varieties grown may not have moisture limitation due to longer growing period. In Assam where crop growing period is more than 270 days necessiate good perennial varieties. The present long duration varieties are utilized for rearing eri-silk worms. Dual purpose cultivars need to be identified/developed for the region. There is a mismatch between varieties recommended with LGP of the areas in all the states needs site specific varietal recommendations. There is an urgent need to breed short duration varieties available to suit southern states.

Crop nutrition /nutrient management in castor plays an important role in production of either sole crops or intercrops or sequential castor based cropping systems. Scheduling crop nutrition in terms of method of application, time of application and sources of nutrients to be applied has a bearing on crop productivity under rainfed and irrigated cultures. Castor is highly responsive to applied fertilizers. In recent years widespread potassium and sulphur deficiencies are observed across the country. The research results under AICRP (Castor) helped in developing location-specific nutrient recommendations and amply demonstrated the need for inclusion of K and S nutrients in fertilizer recommendation apart from N and P applications. Castor crop perform better in drought situations with application of K, improved oil content was realized through sulphur nutrition. Of late, the crop is responding to micronutrient applications especially to foliar application of $ZnSO_4$ @ 0.5% twice at 50 and 90 DAS under rainfed conditions. Hence, the soil test based site-specific nutrient management is the need of the hour instead of blanket application of nutrients for realizing higher productivity and profitability of castor.

Table 4 Relative yield index and relative spread index of castor

Relative Spread index	Relative Yield index						
	Zone I				**Zone III**		
	>200	200-150	150-120	120-90	90-60	60-30	<30
>200		Jamnagar	Mehsana Gandhinagar Banaskantha	Patan Ahemadabad	Sirohi Barmer Jalore	Kurnool Pali Mahabubnagar	Namakkal Prakasam Rangareddy Nalgonda
200-150			Ramnagar Panchmahal Bharuch Anand			Jodhpur Warangal Mysore	
120-150			Junagadh Bangalore rural		Tumkur	Kadapa Hassan Kalahandi	Koraput
90-120			Narmada Porbandar	Hanumangarh		Mandya	Medak
	Zone II				**Zone IV**		
60-90					Chamraj-nagar Koppal Chitradurga	Guntur	
30-60			Amreli		Chikmag-alur	Adilabad Anantapur Raichur	Jabua, Amravati Salem ,Karbialong Erode
<30			Bhavnagar Dhoad		Bellary Samastipur Haveri Davangere Belgaum Kolar Begusarai	Ganganagar Akola Chittor Dhemaji Lakimpur	Ahemednagar Buldana,Dhule Dharmapuri Dhar,Trichy Nanded,Beed

In conclusion, relative yield and spread index indicated that districts falling in zone II (high yield & low spread) and III (low spread & high yield) need special attention to increase productivity and area expansion programme. Based on prevailing soil and climatic conditions in different AESRs of traditional castor growing areas, Anand and Panchmahal of AESR 5.2, Guntur (AESR-7.3), Chitoor, Dharmapuri and Trichy (AESR-8.3) and Tumkur, Bangalore rural, Kolar and Ramanagar (AESR-8.2) have been identified as potential districts for augmenting castor production. In non-traditional areas, Amravati (6.3), Dhule (6.2), Begusarai and Samastipur (13.1), Dhemaji and Lakimpur (15.4) and Karbialong (17.1) have been identified as most potential districts. Traditional castor growing areas have shorter crop growing period as compared to presently grown varietal crop duration. Therefore there is need to breed short duration castor cultivars matching with the length of growing period especially under rainfed conditions. Non-traditional areas like Orissa, Bihar and Assam have favourable growing environments where long and perennial cultivars/for eri culture and seed (dual purpose) can be developed and promoted. Soil-test based site specific nutrient management schedule involving integrated use of major (N,P,K), secondary (S) and micro nutrients (Zn) suiting to different soil types are to be developed.

Table 5 Length of growing period (LGP) castor cultivars grown in different states and their duration

State	District	LGP (Days)	Varieties/Hybrids recommended and its duration (days)
Telangana/ Andhra Pradesh	Mahabubnagar	120-150	GCH-4 (110-240)
	Nalgonda	120-150	DCH-177 (90-180)
	Kurnool	90-120	DCH-519 (105-110)
			PCH-111 (120-180)
	Prakasam	120-150	
Karnataka	Tumkur	150-180	Jyothi (90-150)
	Hassan	150-180	GCH-4 (110-240)
	Chitradurga	90-120	DCH-177 (90-180)
Tamil Nadu	Erode	150-180	YRCH-1(90-180)
	Namakkal	150-180	GCH-7 (210-260)
	Salem	150-180	GCH-4(110-240)
Gujarat	Banaskantha	60-90	GCH-7 (210-260)
	Jamnagar	60-90	GCH-4 (110-240)
	Meshna	90-120	Avani
Rajasthan	Sirohi	60-90	GCH-7 (210-260)
	Jalore	60-90	GCH-4 (110-240)
	Jodhpur	<60	RHC-1 (180)
Assam	Dhemaji	>300	Local
	Karbialong	270-300	
	Lekimpur	>300	
Orissa	Koraput	180-210	DCH-177 (90-180)
	Kalahandi	180-210	Local
Bihar	Begusarai	180-210	Local
	Samastipur	180-210	

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Use of soil test kits in assessing soil fertility of castor growing soils of semi-arid tropics

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(Received: May, 2015; Revised: May, 2015; Accepted: June, 2015)

ABSTRACT

Resource poor farmers use semi-arid tropic soils of southern India for castor cultivation. These soils are well known for their low soil fertility thus resulting in poor castor seed yield. Conventional soil tests of laboratory will take more time. Based on these, fertiliser recommendations to the farmers is seldom delivered in time. Soil test kits (STKs) developed by Acharya N G Ranga Agricultural University, Hyderabad and Coromandal Fertilisers Ltd., Secunderabad is quiet handy in determining the physico-chemical properties on the spot and advice fertiliser recommendations to the farmers. In the present study, results obtained by using these STKs and conventional laboratory tests were compared. The parameters *viz*., pH, organic carbon, available nitrogen, phosphorus, potassium, sulphur and micronutrients (zinc, boron and iron) were in close agreement with that of laboratory tests. Thus, for a quick diagnosis of soil fertility status, STKs are highly useful and accordingly fertiliser recommendations can be given to farmers.

Keywords: Available macro and micronutrients, Castor, Semi-arid soils, Soil test kits

Castor (*Ricinus communis* L.) growing soils of semi-arid tropic (SAT) are poor in soil fertility and it is considered as one of the reasons for low seed yield in this region. Farmer need a quick decision support system about the soil fertility status, which is not possible with the conventional soil tests, conducted at laboratory. Secondly, the analysis data seldom reaches farmer in time to take a decision regarding manure/fertiliser inputs. Development of soil test kits (STKs) for quick diagnosis of pH, E.C., organic carbon (OC) and available nutrient status is an innovative intervention. Of late, there is lot of emphasis on soil testing and on soil test based fertiliser recommendations to realise higher seed yield. In the present study, soil samples from castor growing areas of SAT were collected and analysed for soil fertility parameters using STKs developed by Acharya N G Ranga Agricultural University (ANGRAU), Hyderabad and Coromandal Fertilisers Ltd., (CFL), Secunderabad. Concurrently, the conventional laboratory tests were also conducted for these soils and both the methods were compared to draw conclusions.

MATERIALS AND METHODS

Study area was Manchal mandal (Latitude 17.2106 and Longitude 78.73508), Ibrahimpatnam, Ranga Reddy District, Hyderabad, which is located in SAT region of India. Thirty surface soil samples at plough depth (i.e. 0-15 cm) were collected from the fields of tribal farmers and other castor cultivating farmers as per the standard procedure (Jackson, 1973). These samples were processed (2 mm sieved) at laboratory and used for the estimation of pH (1:2.5), organic carbon (0.2mm sieved) and available soil nutrients *viz.,* nitrogen (N), phosphorus (P), potassium (K), sulphur (S) and boron (B) by laboratory methods (Jackson, 1973). Same soils (0.5 mm sieved) were used to estimate the above parameters using STKs developed by ANGRAU and CFL. Besides, available zinc, iron and calcareous nature of the soil was also tested with these kits.

RESULTS AND DISCUSSION

From the Table 1 it can be inferred that most of these soils are neutral to slightly/moderately alkaline in nature and the pH varied from 6.04 to 8.29. Using the colour charts developed by ANGRAU/CFL these values were verified and found that most of these are in conformity with the laboratory analysis. Organic carbon (OC) content in the soils ranged from 0.17 to 0.44% and classified as low since, <0.5% is considered as the critical level for OC. The STK method showed that the organic carbon content in these soils varied from very low (<0.25%) to low (0.25-0.5%). These results were comparable with the laboratory test for OC. In the SAT soils, Srinivasa Rao *et al.* (2013) reported low OC content and the results of the present study are in agreement with these.

Soil available N: Soil available N content estimated by laboratory test varied from 125.5 to 375.3 kg/ha (Table 1). In general, all these soils are classified as low in available N content by soil fertility classification of Ramamurthy and Bajaj (1969). Available N content colour chart of ANGRAU/CFL has seven classes i.e. <150 (very low), 150-250 (low), 250-350 (low-medium), 350-450 (medium-medium), 450-550 (high-medium), 550-600 (high) and >600 kg/ha (very high). Five farmers soils were in very low, seventeen farmers soils were in low, seven are in low-medium and one farmers soil was in medium-medium range as per the STK colour chart for available N. The available N content estimated by laboratory was in agreement with the ANGRAU/CFL STK colour charts for N (Table1). Rego *et al*. (2007) and Srinivasa Rao *et al*. (2013) reported that available N content in SAT region soils was low. In this study, similar results were recorded.

Soil available P: The available P content of the soil determined by laboratory method varied from 4.84 to 30.4 kg/ha. According to the soil fertility classification (Ramamurthy and Bajaj, 1969) <11 kg P/ha is low and 11-25.6 kg P/ha is medium and >25.6 kg P/ha is high. However, most of the soils were in low to medium in available P content (Table1). The colour charts developed by ANGRAU/CFL for available P content has 7 classes i.e. 0-10 (very low), 10-20 (low), 20-30 (low-medium), 30-40 (medium-medium), 40-50 (high-medium), 50-60 (high) and >60 kg/ha (very high). Available P content in soils of nine farmers are in the range of very low, while in sixteen farmers low and in the five farmers it is in low-medium range. The available P content estimated by laboratory method was compared with the ANGRAU/CFL STK colour charts for P and they were found to be in nearness (Table1). Soil available P content in SAT soils was earlier reported as low to moderate (Rego *et al*., 2007). Results of the present study are in agreement with this.

Table 1 Soil fertility parameters pH, organic carbon, nitrogen (N), phosphorus (P) and potassium (K) of SAT soils

Name of the farmer	pH		Organic carbon %		N (kg/ha)		P (kg/ha)		K (kg/ha)	
	LAB	STK	LAB	STK	LAB	STK	LAB	STK	LAB	STK
Sh. U. Ramu	6.86	7.0	0.24	V.L	125.5	<150	22.5	20-30	156.8	150-225
Sh. D. Kotaiah	7.92	8.0	0.29	L	189.5	150-250	23.2	20-30	168.0	150-225
Smt. N. Ramulamma	8.16	8.0	0.28	L	194.5	150-250	19.0	10-20	336.0	225-300
Sh. U. Lingaiah	8.13	8.0	0.39	L	271.1	250-350	12.5	10-20	152.3	150-225
Sh. N. Balaiah	6.66	7.0	0.38	L	269.9	250-350	4.8	0-10	182.6	150-225
Smt. N. Pedabaimma	6.04	6.0	0.18	V.L	165.7	150-250	20.4	10-20	119.8	75-150
Smt. N. Lingamma	7.72	8.0	0.17	V.L	143.1	<150	9.7	10-20	109.8	75-150
Sh. D. Krishniah	6.90	7.0	0.26	L	158.2	150-250	6.2	0-10	348.3	300-375
Smt. N. Elamma	8.01	8.0	0.32	L	154.4	150-250	13.2	10-20	188.2	150-225
Sh. D. Pinniah	7.64	8.0	0.28	L	143.1	250-350	10.0	10-20	124.3	75-150
Smt. B. Narasamma	7.92	8.0	0.22	V.L	234.5	250-350	10.4	10-20	267.7	225-300
Sh. U. Elliah	8.08	8.0	0.22	V.L	296.2	250-350	6.2	0-10	116.5	75-150
Smt. B. Pochamma	6.08	6.0	0.24	V.L	202.1	150-250	4.8	0-10	259.8	150-225
Sh. D. Pedabaliah	6.79	7.0	0.18	V.L	235.9	150-250	6.6	0-10	469.3	>375
Sh. N. Anjaiah	8.16	8.0	0.29	L	199.6	150-250	9.4	0-10	232.9	225-300
Smt. D. Lakshmma	8.15	7.0	0.26	L	210.9	150-250	17.7	0-10	239.7	225-300
Sh. A. Chinabainna	7.04	8.0	0.33	L	192.1	150-250	20.8	0-10	474.9	>375
Smt. Ch. Sarada	8.02	7.0	0.24	V.L	205.9	150-250	22.2	20-30	187.0	150-225
Sh. N. Malliah	7.85	8.0	0.19	V.L	156.9	150-250	14.9	10-20	164.6	150-225
Sh. B. Malliah	7.43	7.0	0.32	L	134.3	<150	8.0	0-10	473.7	>375
Smt. D. Tripura	7.16	7.0	0.30	L	128.0	<150	13.5	10-20	152.3	150-225
Sh. D. Kasiah	8.40	8.0	0.44	L	192.1	150-250	29.4	20-30	154.6	150-225
Sh. D.Ramachandriah	8.41	8.0	0.42	L	251.1	150-250	30.4	20-30	504.0	>375
Sh. B. Chinbaianna	8.71	9.0	0.35	L	138.4	<150	13.5	10-20	355.4	300-375
Sh. D. Kamaiah	8.26	8.0	0.38	L	241.6	150-250	6.9	10-20	253.1	225-300
Smt. S. Sarada	8.08	8.0	0.43	L	375.3	350-450	11.8	10-20	291.1	225-300
Sh. N. Balakrishnaih	6.73	7.0	0.19	V.L	276.2	250-350	13.5	10-20	675.4	>375
Sh. D. Baliah	7.70	8.0	0.30	V.L	204.1	150-250	8.7	10-20	90.7	75-150
Sh. N. Anjaniah	8.19	8.0	0.28	V.L	274.9	250-350	16.3	10-20	218.4	150-225
Sh. N. Balalingaih	8.29	8.0	0.31	L	198.9	150-250	21.1	10-20	396.5	>375

LAB: Conventional laboratory tests; STK: Soil test kits of ANGRAU/Coromandal Fertiliser Ltd.

Soil available K: The available K content of the soil estimated by laboratory method varied from 90.7 to 675.4 kg/ha. According to the soil fertility classification (Ramamurthy and Bajaj, 1969) <120 kg K/ha is low and 120-280 kg K/ha is medium and >280 kg K/ha is high. However, most of the soils are medium in available K content (Table1). The colour charts developed by ANGRAU/CFL for available K content has 6 classes i.e. 0-75 (very low), 75-150 (low), 150-225 (moderate), 225-300 (high), 300-375 and >375 kg/ha (very high). Available K content in soils of five farmers was low, while in case of eleven farmers, it was moderate and in six farmers case it was high and in case of rest of the farmers it was very high. The available K content estimated by laboratory method was compared with the ANGRAU/CFL STK colour charts for K and the results were found to be in close agreement (Table1). Rego *et al*. (2007) reported that adequate K content was available in SAT soils.

Available S: The available S content of the soil determined by laboratory method varied from 3.73 to 14.92 mg/kg. The critical limit in the soil used for separating deficient fields from non-deficient ones for available (0.15% $CaCl_2$ extractable) S, are 8-10 mg/kg or say <10 mg/kg (Sahrawat *et al*., 2007) and was considered low whereas >10 mg/kg is a sufficient level of S. However, most of the soils are low in available S content (Table 1). The colour charts developed by ANGRAU/CFL for available S content has five classes i.e. 0-8 (very low), 8-16 (low), 16-32 (moderate), 32-40 (high) and >40 mg/kg (very high). Available S content in soils of twelve farmers was in the range of very low, while in case of eighteen farmers it was low. The available S content estimated by laboratory method was compared with the ANGRAU/CFL STK colour charts for S and the results were in close agreement (Table 2). Wide spread deficiency of S was reported by Rego *et al*. (2007) and Murthy *et al*. (2014) in SAT soils and the present study is in conformity with these observations.

Available B: The available B content of the soil determined by laboratory method varied from 0.05-0.78 mg/kg. The critical limit in the soil used for separating deficient fields from non-deficient ones for available (hot water extractable) B is <0.58 mg/kg (Sahrawat *et al*., 2007) and considered low whereas >0.50 mg/kg is sufficient level of B. However, most of the soils are low in available B content (Table 2). The colour charts developed by ANGRAU/CFL for available B content has three classes i.e. <0.50 (low), >0.50-2.00 (sufficient), and>2.00 (toxic). Available B content tested in laboratory in soils of twenty-nine farmers are in the range of low, while in case of one farmer it is sufficient. The available B content estimated by laboratory method was compared with the ANGRAU/CFL STK colour charts for B and the results were found to be in close agreement (Table 2). Rego *et al*. (2007), Sahrawat *et al*. (2007) and Murthy *et al*. (2013) also reported low B content in SAT soil earlier.

Available micronutrients: Considering available zinc critical limit as 0.70 mg/kg and iron critical limit as 5.0 mg/kg, the STK colorimetric tests revealed that they are in <0.70 and <5.0 mg/kg category. Hence, these soils are classified as very low in these nutrients. The calcareousness of these soils was also found very low based on the STK test and can be classified as non-calcareous in nature. This is a common phenomenon in SAT soils (Rego *et al*., 2007; Sahrawat *et al*., 2007). Further, studies conducted by Rego *et al*. (2007) showed that the castor crop responded to the application of nutrients, which were deficient.

From the above studies, it is clear that available nutrients in the castor growing soils of SAT region are poor and needs fertilisers/manures to realise higher seed yield. Portable STKs developed by ANGRAU/CFL are useful in analysing soil (irrespective of soil type) at field level to know the soil fertility status on the spot. The results obtained with these kits are in close agreement with the conventional laboratory test. However, if farmer needs information that is more precise it is advisable to follow the laboratory tests and accordingly may apply the fertiliser. For a quick *in situ* soil fertility tests STKs are found to be highly useful.

Table 2 Soil available sulphur (S), boron (B) contents in SAT soils

Name of the farmer	S (mg/kg)		B (mg/kg)	
	LAB	STK	LAB	STK
Sh. U. Ramu	7.46	8-16	0.20	<0.5
Sh. D. Kotaiah	10.40	8-16	0.05	<0.5
Smt. N. Ramulamma	5.59	0-8	0.12	<0.5
Sh. U. Lingaiah	11.94	8-16	0.20	<0.5
Sh. N. Balaiah	9.70	8-16	0.27	<0.5
Smt. N. Pedabaimma	3.73	0-8	0.37	<0.5
Smt. N. Lingamma	11.19	8-16	0.30	<0.5
Sh. D. Krishniah	14.18	8-16	0.78	<0.5
Smt. N. Elamma	11.19	8-16	0.52	<0.5
Sh. D. Pinniah	11.20	8-16	0.30	<0.5
Smt. B. Narasamma	5.97	0-8	0.20	<0.5
Sh. U. Elliah	6.71	0-8	0.06	<0.5
Smt. B. Pochamma	8.21	8-16	0.05	<0.5
Sh. D. Pedabaliah	14.92	8-16	0.37	<0.5
Sh. N. Anjaiah	6.71	0-8	0.23	<0.5
Smt. D. Lakshmma	10.07	8-16	0.13	<0.5
Sh. A. Chinabainna	4.47	0-8	0.19	<0.5
Smt. Ch. Sarada	7.83	8-16	0.06	<0.5
Sh. N. Malliah	5.59	0-8	0.10	<0.5
Sh. B. Malliah	8.95	0-8	0.16	<0.5
Smt. D. Tripura	5.59	0-8	0.35	<0.5
Sh. D. Kasiah	13.06	8-16	0.14	<0.5
Sh. D.Ramachandriah	7.46	0-8	0.19	<0.5
Sh. B. Chinbaianna	7.83	0-8	0.22	<0.5
Sh. D. Kamaiah	10.44	8-16	0.16	<0.5
Smt. S. Sarada	13.43	8-16	0.18	<0.5
Sh. N. Balakrishnaih	9.33	8-16	0.16	<0.5
Sh. D. Baliah	8.21	0-8	0.20	<0.5
Sh. N. Anjaniah	10.45	8-16	0.11	<0.5
Sh. N. Balalingaih	14.92	8-16	0.18	<0.5

LAB: Conventional laboratory tests; STK: Soil test kits of ANGRAU/Coromandal Fertiliser Ltd.

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Productivity and economic viability of winter niger [*Guizotia abyssinica* (L.f.) Cass.] under varying nutrient management practices

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(Received: July, 2014; Revised: February, 2015; Accepted: March, 2015)

ABSTRACT

Results of the field experiments conducted in Vertisols of Jabalpur, Madhya Pradesh on irrigated niger (cv. JNC-1) during winter season for three consecutive years (2008-09 to 2010-11) revealed that application of 40 kg N + 30 kg P_2O_5 + 20 kg K_2O/ha (recommended dose of fertilizer) along with spraying of 2% DAP twice at flowering and capitula formation stage showed higher seed (647 kg/ha); oil yield (198 kg/ha), and net monetary returns (₹ 7867/ha). This was at par with recommended dose of fertilizer (RDF) along with spraying of 2% urea twice. Application of 75% RDF along with spraying of 2% DAP twice at the same stage was comparable to 100% RDF alone with regard to productivity and economic viability. Numerically, spraying of DAP proved better than spraying of urea in respect of production and profit.

Keywords: Foliar spray, Oil content, Niger, Nutrient management, Seed yield

Niger [*Guizotia abyssinica* (L.f.) Cass.] is traditionally rainy season oilseed crop. It is mostly grown in tribal belts on eroded and skeletal soils with least attention and very low use of agro-inputs. India is the prime producer of niger in the world. It is grown in the country in an area of about 3.5 lakh ha with a production of 0.96 lakh tonnes and a productivity of 273 kg seed/ha. Madhya Pradesh contributes nearly 1.17 lakh ha area under this crop with an annual production of 0.20 lakh tonnes and productivity of 174 kg seed/ha (Kumar and Varaprasad, 2012). It responds well to application of manures and fertilizers, but tribal farmers are unable to afford the desirable nutrient management to raise the productivity. Its seed contain good quality of oil (36 to 40%). The oil is cholesterol free, hence the demand of niger oil is high in the domestic as well as export market. Looking to its high demand, the cultivation of niger in winter season under irrigated conditions as non-conventional crop has been found quite promising and economical in Madhya Pradesh (Agrawal *et al*., 1996; Singh *et al*., 1990; Sharma and Kewat, 1998). But information pertaining to nutrient management of winter season crop under irrigated production system are meager. Hence, the present investigation was undertaken to ascertain the economically viable nutrient management for increasing the seed yield of niger.

MATERIALS AND METHODS

The field experiments were conducted at research farm of Project Coordinating Unit, AICRP on Sesame and Niger, JNKVV campus, Jabalpur, Madhya Pradesh on Vertisols under irrigated conditions for three consecutive years (2008-09 to 2010-11) during winter seasons. The soils of the experimental field was low in organic carbon (0.44%), neutral in reaction (pH 7.40) and normal in electrical conductivity (0.43 ds/m) with low in available N (220 kg/ha), medium in available P (19 kg/ha) and high in available K (323 kg/ha) contents. Nine treatments with different combinations of nutrient management (Table 1 and 2) were tested in Randomized Block Design with three replications. Niger cultivar, JNC-1 was sown during first week of October by drilling the seeds in rows 30 cm apart with the seed rate of 5 kg/ha. The fertilizers were applied in plots as per treatments. The recommended dose of fertilizer (RDF) as 40 kg N + 30 kg P_2O_5 + 20 kg K_2O/ha was applied through urea, single superphosphate and muriate of potash, respectively. Five treatments (T_1 to T_5) received 100% RDF, while four treatments (T_6 to T_9) were fertilized with 75% RDF. Half quantity of N along with full quantity of P and K fertilizers were given as basal dose to each plot and remaining half quantity of N was top dressed at 2 days after first irrigation. Spraying of 2% urea was superimposed at flowering stage in treatments T_2 and T_6, while this spraying was done twice at flowering and capitula formation stages in treatments T_4 and T_8. Similarly, spraying of 2% DAP solution at flowering stage was superimposed in treatments T_3 and T_7 and again this spraying was done twice at flowering and capitula formation stages in treatments T_5 and T_9. The crop received light irrigation immediately after sowing for germination. After this three irrigations were given at 20 days intervals. Two hand weedings were done at 20 and 40 DAS in all plots uniformly. Observations were recorded on various growth parameters, yield attributes, seed and straw yields. Oil contents in seeds were recorded to determine the oil yield. The economics of each treatment were also worked out.

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RESULTS AND DISCUSSION

Growth parameters and yield attributes: The mean data of growth parameters *viz.,* plant-height and number of branches/plant and yield attributes *viz.,* capitulae/plant, seeds/capitula, test weight of seeds and harvest index for three years are given in Table 1. Plant-height did not differ significantly due to different nutrient management, but supplementation of additional spraying of urea and DAP over 100% RDF (T_2, T_3, T_4 and T_5) had shown numerically taller plants than 100% RDF as well as 75% RDF plus spraying of fertilizers. The former treatments significantly produced more basal branches/plant than 75% RDF along with spraying of fertilizers under T_6, T_7, T_8 and T_9. As a consequence, the former treatments also proved significantly superior in producing capitulae/plant and seeds/capitula than later. Spraying of urea and DAP with 2% concentration did not show remarkable variations in any growth parameter and yield attributes. Similarly, there was not much variation in these observations between one and two sprayings also. The test weight of seeds and harvest index did not differ much due to varying nutrient management. Trivedi *et al.* (1998), Paikary *et al.* (1990), Gautam (2009) and Rai *et al.* (2014) have also reported similar results on growth and yield attributes of niger by foliar application of fertilizers from earlier studies.

Seed and straw yield: Both seed and straw yield were higher with application of 100% RDF along with additional spraying of urea as well as DAP only once or twice under T_2, T_3, T_4 and T_5 than those obtained with 100% RDF (T_1) and 75% RDF along with two sprays of urea (T_8) and DAP (T_9) in all three years, but differences were not significant (Table 2). Though spraying of DAP proved superior than spraying of urea at both levels of spraying in seed and straw yield, but variations were not significant. Spraying of DAP or urea twice at flowering and capitula formation stages with 75% RDF proved numerically superior than application of 100% RDF with regard to seed and straw yield. The superiority in production of more branches/plant, capitulae/plant and seeds/capitula probably resulted increase in seed and straw yield. These results are also in close conformity with the findings of Deshmukh *et al.* (2007), Thakur and Umat (2007), Gautam (2009) and Rai *et al.* (2014).

Oil yield: Oil yields are directly related to seed yield and oil content of seeds. Though oil content of seeds did not show any remarkable variation due to varying nutrient management, oil yield differed significantly due to them mainly due to variations in seed yield (Table 2). The treatments receiving two sprays of 2% urea (T_4) and 2% DAP (T_5) along with 100% RDF produced significantly higher oil yield than other treatments mainly due to higher seed yield. Treatments receiving only one spraying of urea (T_2) or DAP (T_3) along with 100% RDF, two sprays of urea (T_8) or DAP (T_9) along with 75% RDF were next to them with regard to oil yield. These findings are in close conformity with the findings of Trivedi and Ahlawat (1991 and 1993), Gautam (2009) and Rai *et al*. (2014).

Table 1 Effect of different nutrient management practices on growth parameters, yield attributes, seed yield and straw yield of niger

Treatment	Pooled Mean of 2009, 2010 and 2011						Seed yield (kg/ha)				Straw yield (kg/ha)			
	Plant height (cm)	Branches/ plant (No.)	Capitulae/ plant (No.)	Seeds/ capitula (No.)	Test weight (g)	Harvest index (%)	2009	2010	2011	Mean	2009	2010	2011	Mean
T_1 = Recommended dose of fertilizer (RDF)	174	6.64	30.50	20.97	4.12	16.31	590	598	620	603	3039	3056	3181	3092
T_2 = T_1 + one foliar application of 2% urea at flowering	173	6.71	31.10	21.05	4.14	16.58	610	617	639	622	3076	3093	3218	3129
T_3 = T_1 + one foliar application of 2% DAP at flowering	173	6.83	31.00	21.44	4.16	16.83	619	626	648	631	3064	3081	3206	3117
T_4 = T_1 + two foliar applications of 2% urea at flowering + capitula formation	174	6.90	31.60	21.75	4.18	16.50	621	639	661	640	3184	3201	3326	3237
T_5 = T_1 + two foliar applications of 2% DAP at flowering + capitula formation	173	6.93	31.45	21.86	4.20	16.69	628	646	668	647	3175	3192	3317	3228
T_6 = 75% RDF + one foliar application of 2% urea at flowering	172	6.56	27.50	20.87	4.16	16.02	568	586	608	587	3024	3041	3166	3077
T_7 = 75% RDF + one foliar application of 2% DAP at flowering	170	6.38	30.35	21.01	4.10	16.18	574	602	624	600	3054	3071	3196	3107
T_8 = 75% RDF + two foliar applications of 2% urea at flowering + capitula formation	169	6.42	3040	21.10	4.06	16.31	582	610	632	608	3066	3083	3208	3119
T_9 = 75% RDF + two foliar applications of 2% DAP at flowering + capitula formation	169	6.53	30.65	21.15	4.10	16.45	597	615	637	616	3075	3092	3217	3128
SEm±	1.71	0.13	0.21	0.19	0.09	0.23	12.0	13.0	12.6		22.50	23.35	24.3	
CD (P=0.05)	NS	0.39	0.65	0.57	NS	NS	36.0	39.0	37.9		67.50	70.65	72.9	

Table 2 Effect of different nutrient management practices on oil content, oil yield and economics of niger

Treatment	Oil content (%)				Oil yield (kg/ha)				Economics*		B:C ratio
	2009	2010	2011	Mean	2009	2010	2011	Mean	GMR (₹/ha)	NMR (₹/ha)	
T_1 = Recommended dose of fertilizer (RDF)	30.42	30.80	30.23	30.48	179	184	187	184	16621	7141	1.75
T_2 = T_1 + one foliar application of 2% urea at flowering	30.67	31.05	30.50	30.75	187	192	195	191	17114	7483	1.77
T_3 = T_1 + one foliar application of 2% DAP at flowering	30.61	30.98	30.40	30.66	189	194	197	193	17333	7632	1.78
T_4 = T_1 + two foliar applications of 2% urea at flowering + capitula formation	30.71	31.10	30.68	30.83	191	199	203	198	17618	7836	1.80
T_5 = T_1 + two foliar applications of 2% DAP at flowering + capitula formation	30.49	30.87	30.45	30.60	191	199	203	198	17789	7867	1.79
T_6 = 75% RDF + one foliar application of 2% urea at flowering	30.78	31.16	30.58	30.84	175	183	186	181	16213	6897	1.74
T_7 = 75% RDF + one foliar application of 2% DAP at flowering	30.47	30.85	30.76	30.69	175	186	192	184	16553	7167	1.76
T_8 = 75% RDF + two foliar applications of 2% urea at flowering + capitula formation	30.49	30.87	30.35	30.57	177	188	192	186	16759	7292	1.77
T_9 = 75% RDF + two foliar applications of 2% DAP at flowering + capitula formation	30.83	31.20	30.70	30.91	184	192	196	190	16964	7357	1.76
SEm±	0.29	0.30	0.34	0.31	3.20	3.30	3.80	3.50	285	145	0.007
CD (P=0.05)	NS	NS	NS	NS	9.60	10.20	11.40	10.80	890	437	0.022

*Pooled mean of 2009, 2010 and 2011, Sale price of niger seed and straw Rs 25/kg and 0.50/kg, respectively; GMR - Gross Monetary Returns; NMR - Net Monetary Returns

Economic viability: Among nutrient management schedule, mean gross monetary returns (₹ 17789/ha) and net monetary returns (₹ 7867/ha) were higher with T_5 (100% RDF + two sprayings of 2% DAP), but this treatment was at par to T_4, T_3, T_2 and T_9. Higher seed yields with these treatments attributed to greater gross monetary returns. The proportionate increase in value of produce was greater with these treatments than that of increase in cost of investment. The B:C ratio recorded in T_4, T_5 and T_3 were at par to each other. These results are in close conformity with the findings of Gautam (2009) and Rai *et al*. (2014).

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Sensory characteristics of different stages of safflower (*Carthamus tinctorius* L.) leaves and leaf powder incorporated products

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(Received: February, 2015; Revised: May, 2015; Accepted: June, 2015)

ABSTRACT

Safflower leaves from four cultivars during different stages of crop growth (30, 50, 70 and 90 days) were incorporated to develop two traditional products i.e., safflower leaves (35%) incorporated roti (SFLR) and safflower leaf powder (15%) incorporated "karam podi" (SLKP). Sensory evaluation was carried out on a 9 point hedonic scale for both the products. Results of sensory evaluation revealed that 35% incorporation of safflower leaves in SFLR and 15% incorporation of safflower leaf powder in SLKP products had high scores for overall acceptability and there was not much difference in sensory attributes among the cultivars used in the study. It was observed that safflower leaf powder "karam podi" was liked more in all the sensory parameters as compared to safflower leaves roti. It can also be inferred that fresh leaves from non-spiny varieties such as NARI-6 can be consumed up to 90 days where as spiny varieties of safflower such as Annigeri-1, Manjira and TSF-1 can be well acceptable up to 50 days. The spiny varieties can be consumed up to 70th day also, due to their nutrient composition, but should be incorporated at a level lesser than 35% or can be tested in other suitable recipes. Spiny varieties of safflower leaves during 70 days of crop growth, when used as powder will not have any detrimental effects of sensory properties.

Keywords: Food products, Leaf powder, Safflower leaves, Sensory analysis, Value addition

Green leafy vegetables are rich sources of vitamins, such as β-carotene, ascorbic acid, riboflavin and folic acid, as well as minerals such as iron, calcium and phosphorus. Some of the commonly consumed leafy vegetables are amaranth, spinach, fenugreek and coriander, the nutritive values of which have been reported in food composition tables (Gopalan *et al.,* 2007). Apart from these there are various types of underutilized leafy vegetables which are seasonal and scant information is available on the nutrient and anti-nutrient content of such vegetables. Identification of such green leafy vegetables, which are believed to be nutritious, may help in achieving nutritional (micronutrient) security (Gupta *et al.,* 2005). In India, each region is endowed with typical traditional food habits which are culturally bound, highly acceptable to the population because these recipes are transferred from generation to generation with little modifications. Hence, enriching the traditional foods with micronutrient rich, nutritious leafy vegetable could pave a way for sustainable utilization in routine diets and to attain good micronutrients level in diet.

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. Safflower petals are known to have many medicinal properties for curing several chronic diseases, and they are widely used in Chinese herbal preparations (Li and Mundel, 1996). The tender leaves, shoots, and thinnings of safflower are used as 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 neighbouring countries (Nimbkar, 2002). The thinned out plants are consumed as leafy vegetable in many parts where the crop is grown. As the crop matures, the bottom leaves are also consumed during various stages till the completion of flowering stage. Some scientific studies on foods have reported changes in chemical composition at different stages of development of fruits, vegetables and leaves (Polyana *et al*., 2014; Peiretti *et al.,* 2013; Oliveira *et al.,* 2011; Celi *et al.,* 2011; Leite *et al.,* 2011). However, there are no such studies that address the different stages of development of safflower leaves. If the sensory characteristics are estimated during different stages, we can have an understanding of the potential and best stage to use the safflower leaves as green leafy vegetable. Therefore, the goal of the present study was to investigate the sensory properties of fresh and powdered safflower leaves of spiny and non-spiny cultivars at different stages of crop growth in order to investigate the use of their leaves as dietary component.

MATERIALS AND METHODS

Safflower leaves during different stages of development (30th day - Rosette stage; 50th day - Elongation stage; 70th day - Flowering initiation stage and 90th day - Flowering stage) were procured from the ICRSAT-IIOR farm, Pantancheru, Hyderabad and Regional Agricultural Research

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Station, Tandur, Ranga Reddy district. Other ingredients like wheat flour, refined sunflower oil, red chilli powder, cumin powder, ajwain (*Trachyspermum ammi*), salt and onion were procured in one lot from the local market for formulation of products.

Washing, blanching and tray drying: The safflower plants (30th day) and leaves (50th, 70th and 90th days) were washed gently under running water to remove the adhering mud particles followed by double glass-distilled water and drained completely. The leaves (50th, 70th and 90th day) were then chopped into the sizes of 0.5 cm × 5 cm. To inhibit enzymatic browning reactions, the safflower leaves were blanched in hot water at 90±2°C for 2 min with the ratio of safflower leaf residues to water of 1:7. The chopped and blanched safflower leaves were then immediately cooled in cold water at 4°C equilibrium value (AOAC, 1995). The leaves were drained after cooling and the residual moisture was evaporated at room temperature, on a clean paper with constant turning over to avert fungal growth (Gupta and Prakash, 2011). One set of fresh leaf sample was used for preparation of SFLR. Another set of samples were then spread on stainless steel trays for drying at 60°C for 6-8h in a pre-heated (60°C) tray drier. The dried leaf sample was ground to fine powder using a grinder (Waring Commercial Blender,WCG75, Torrington, CT) at a medium speed for 2 min. The powder was then sieved using a sieve analyzer (Retsch, AS200 basic, Hann, Germany). The powder with the size in the range of 150-430μm was vacuum packed in an aluminum packet until further use.

Preparation of SFLR and SLKP: Four cultivars of safflower leaves sample were used for the study. Spiny varieties like Annigeri-1, Manjira and TSF-1 were used on 30, 50 and 70 days where as non-spiny variety NARI-6 was used on 30, 50, 70 and 90 days. Two traditional recipes of roti (safflower leaves incorporated roti - SFLR) and *karam* podi (safflower dehydrated leaf powder incorporated "karam podi" - SLKP) were developed by incorporating 35% and 15% of safflower leaves and leaf powder, respectively (Fig. 1 and Fig. 2). SFLR and SLKP were prepared with leaves and leaf powder obtained during different stages of crop growth.

The sensory assessments were conducted in a purpose-built, ten-booth sensory evaluation laboratory. The panel of 30 members consisted of staff and graduate students of the Department of Foods and Nutrition, Professor Jayashankar Telangana State Agricultural University, Hyderabad and Indian Institute of Oilseeds Research, Hyderabad. The panelists had no knowledge of the project objectives. All the products prepared with safflower leaves and powder (Annigeri-1, Manjira, TSF-1 and NARI-6) were coded using random three-digit numbers and served with the order of presentation counter-balanced. Panelists were provided with a glass of water and instructed to rinse and swallow water between samples. They were given written instructions and asked to evaluate the products for acceptability based on its colour, texture, taste, flavour, leafy odour and overall acceptability using nine-point hedonic scale (0=Dislike extremely to 9=Like extremely) (Meilgaard *et al.,* 1999).

All experiments were performed in duplicate and designed in complete random. The data were analyzed and presented as mean values with standard deviations. The data obtained from sensory evaluation was subjected to analysis of variance (ANOVA) to test the difference between means (stages of development and between cultivars) and were analyzed by the Tukey test at 95% ($p < 0.05$) level of significance using statistical software.

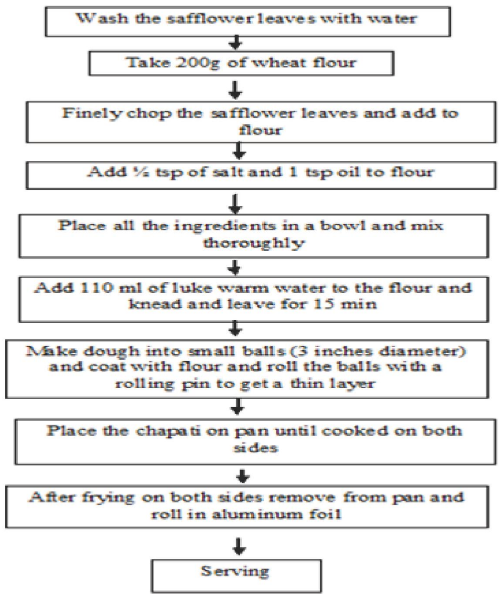

Fig. 1. Flow chart for preparation of safflower leaves incorporated Roti (SFLR)

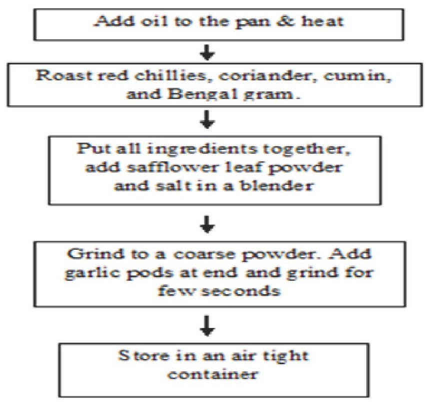

Fig.2. Flow chart for preparation of safflower leaf powder incorporated *Karam podi* (SLKP)

Table 1 Mean scores of sensory evaluation of safflower leaves incorporated roti (SFLR)

Sensory attributes	Days of maturity	Annigeri-1	Manjira	TSF-1	NARI-6	SE Values	F values
Colour	30th day	7.60±0.14b1	7.60±0.13 b1	7.50±.16 a1	7.55±0.15 a1	0.131	0.270ns
	50th day	8.05±0.08 a1	8.00±0.09 a1	7.80±0.12 a1	7.55±0.15 a2		
	70th day	7.05±0.10 c1	7.25±0.12 c1	7.20±0.11 a1	7.30±0.11 a1		
	90th day				7.25±0.22 a		
SE value	0.113						
F-value	8.487**						
Taste	30th day	6.90±0.48 b1	6.55±0.19 b2	7.30±0.17 a1	7.05±0.18 a1	0.201	1.033ns
	50th day	7.35±0.07 a1	7.50±0.10 a1	7.40±0.11 a1	7.20±0.16 a1		
	70th day	6.85±0.15 b1	6.80±0.14 b1	7.00±0.16 a1	7.30±0.07 a1		
	90th day				6.80±0.25 a		
SE value	0.174						
F-value	4.162ns						
Aroma	30th day	7.15±0.15 a1	7.00±0.13 a1	6.55±0.19 a2	6.80±0.17 a1	0.153	2.072ns
	50th day	7.10±0.12 a1	7.20±0.14 a1	6.80±0.15 a1	6.95±0.15 a1		
	70th day	7.05±0.16 a1	6.95±0.12 a1	6.70±0.14 a1	7.05±0.13 a1		
	90th day				6.60±0.28 a		
SE value	0.133						
F-value	0.379ns						
Chewability	30th day	7.40±0.14 a1	7.00±0.16 a1	7.15±0.21 a1	6.65±0.17 b2	0.161	0.959ns
	50th day	6.00±0.14 b2	7.10±0.12 a1	7.10±0.11 a1	7.05±0.12 a1		
	70th day	6.60±0.17 b1	6.15±0.16 b2	6.65±0.15 b1	6.70±0.18 b1		
	90th day				6.35±0.28 b		
SE value	0.139						
F-value	5.529*						
Foldability	30th day	7.25±0.16 a1	7.65±0.11 a1	7.35±0.13 a1	7.30±0.20 a1	0.150	1.570ns
	50th day	6.00±0.17 b2	7.05±0.13 a1	6.95±0.12 a1	6.90±0.10 a1		
	70th day	7.15±0.11 a1	6.15±0.21 b2	6.85±0.12 a1	7.35±0.09 a1		
	90th day				7.35±0.20 a		
SE value	0.130						
F-value	9.654**						
Leafy Odour	30th day	6.75±0.16 a1	7.00±0.17 a1	7.05±0.18 a1	7.10±0.16 a1	0.158	0.944ns
	50th day	6.20±0.12 a2	6.70±0.13 a1	6.65±0.16 b1	6.50±0.18 b1		
	70th day	6.95±0.16 a1	6.85±0.13 a1	6.90±0.12 a1	7.15±0.12 a1		
	90th day				7.25±0.23 a		
SE value	0.137						
F-value	5.554*						
Over All Acceptability	30th day	6.90±0.48 a1	7.25±0.11 a1	7.25±0.21 a1	7.35±0.16 a1	0.193	0.338ns
	50th day	7.35±0.09 a1	7.75±0.12 a1	7.30±0.13 a1	7.20±0.12 a1		
	70th day	7.00±0.10 a1	6.55±0.15 b1	6.95±0.12 a1	7.25±0.09 a 1		
	90th day				7.30±0.19 a		
SE value	0.167						
F-value	4.287ns						

Note: Values are expressed as mean ± standard deviation of three determinations. Mean values with similar superscripts within a column (alphabets) and row (numbers) do not differ significantly (P>0.01). *-significant at 5% level.**-significant at 1% level.

RESULTS AND DISCUSSION

Sensory evaluation of safflower leaves incorporated roti (SFLR): The results of sensory evaluation of SFLR are summarized in Table 1. The results indicate that the colour of SFLR was ranked higher during 50th day in Annigeri-1, Manjira and TSF-1 varieties when compared to 30th and 70th day. There was no significant difference in colour score during 30th day, 50th day, 70th day and 90th day (in NARI-6 variety) indicating the uniformity of colour during any stage of maturity. The results of comparison among the cultivars show that there are no significant differences in the colour on 30th day and 70th day in all the four cultivars. On 50th day, the colour of SFLR was significantly higher in Annigeri-1, Manjira and TSF-1 compared to NARI-6. The overall observation from the results between stages of maturity and among the cultivars show a good acceptability of colour when safflower leaves were used to prepare SFLR.

The taste of SFLR was given significantly (P>0.05) higher scoring on 50th day when compared to 30th and 70th day with Annigeri-1 and Manjira varieties. There was no significant difference in taste of SFLR on 30th, 50th, 70th and 90th day (only for NARI-6 variety) in TSF-1 and NARI-6 varieties indicating that the taste of SFLR did not have any influence of crop stages. The results of taste parameter among the cultivars indicate that Annigeri-1, TSF-1 and NARI-6 had significantly (P>0.05) better taste compared to Manjira variety on 30th day. There was no significant difference in taste of SFLR on 50th day and 70th day among the cultivars indicating that any variety of safflower leaf when incorporated into products like SFLR would be similar in taste and well accepted.

Aroma of SFLR was found to have no significant difference in the days of crop growth as well as among the cultivars indicating that any stage of safflower leaf and any variety of safflower leaf incorporated into products will have similar aroma. The score of aroma ranged between 7.05-7.15 in Annigeri-1, 6.95-7.20 in Manjira, 6.55-6.80 in TSF-1, 6.60-7.05 in NARI-6 varieties at different stages of maturity on a 9 point hedonic scale.

Chewability of SFLR was found to range between 6.00 to 7.40 and a significantly (P>0.05) higher score for chewability was found during 30th day when compared to 50th and 70th day. Chewability in Manjira and TSF-1 varieties were found significantly (P>0.05) better on 30th day and 50th day when compared to 70th day. Chewability in NARI-6 variety was better on 50th day (7.05) followed by 70th day (6.70), 30th day (6.65) and 90th day (6.35). As NARI-6 variety was a non-spiny variety of safflower leaf, the chewability was found to be good till 70th day of maturity where as Annigeri-1, Manjira and TSF-1 were better chewable on 30th and 50th day only, indicating that spiny varieties of safflower leaves can be consumed up to 50 days of maturity when using the leaves in the product. However, non-spiny varieties like NARI-6 can be consumed up to 90 days in fresh form. There were significant (P>0.05) differences in chewability among the cultivars when compared to each other. It was found that chewability was better among Annigeri-1, Manjira and TSF-1 than NARI-6 on 30th day; Manjira, TSF-1 and NARI-6 were better than Annigeri-1 on 50th day; Annigeri-1, TSF-1 and NARI-6 were better than Manjira on 70th day. The results of foldability parameter of SFLR during various stages of maturity were found to be comparable to chewability characteristic of SFLR. The results indicate that as the leaves mature, the tenderness in leaf reduces which in turn reduces the chewability and foldability in roti. Incorporation of fresh green leaves of safflower can be used in other recipes like dhal or curry which may not have any detrimental effects on the texture of product unlike SFLR.

As per the results obtained, it was observed that there was no significant difference in leafy odour of SFLR during all the stages of crop growth in Annigeri-1 and Manjira varieties. In TSF-1 and NARI-6 varieties, leafy odour was found to be present significantly (P>0.05) during 50th day as compared to 30th and 70th day. There was no significant difference in the leafy odour among the cultivars on 30th and 70th day, whereas, there was significantly (P>0.05) higher score for leafy odour in Manjira, TSF-1 and NARI-6 varieties as compared to Annigeri-1 variety.

The results of overall acceptability indicate that there was no significant difference (P>0.05) in acceptability during the three stages of crop growth in Annigeri-1, TSF-1 and NARI-6 varieties. The range of score was between 6.90-7.35 during all the stages of maturity on a 9 point scale indicating high acceptance of SFLR. The over acceptability of Manjira variety was significantly (P>0.05) higher during 30th day (7.25±0.11) and 50th day (7.75±0.12) as compared to 70th day indicating better acceptability till 50 days of crop growth. The results of overall acceptability comparison among the cultivars indicate that there was no significant difference among the cultivars during all the stages of crop growth indicating consumption of any variety of safflower leaves incorporated in SFLR is acceptable.

Incorporation of green leafy vegetables in various traditional recipes helps in value addition. It is a simple method and can be practiced in routine (Mepba *et al.,* 2007). Lakshmi and Kohila (2007) developed agathi (*Sesbania grandiflora*), coriander (*Coriandrum sativum*), curry leaf (*Murraya koenigii*) and drumstick (*Moringa oleifera*) based food mixes and reported that the green leafy vegetable based food mixes had the highest acceptability for all the food mixes. Singh *et al.* (2007) prepared two value added products (green gram dal and paratha) by incorporating dehydrated bathua (*Chenopodium album*) leaves and concluded that value added paratha and green gram dal had many fold greater carotene content.

Safflower leaf powder incorporated "karam podi" (SLKP): Safflower leaves of Annigeri-1, Manjira, TSF-1 and NARI-6 cultivars during different crop stages (30, 50, 70 and 90 days) were dehydrated and ground into fine powders separately. The powder was incorporated into a traditional "karam podi" recipe at 15% level and was subjected to sensory evaluation (Table 2). Dehydration is a simple user friendly, traditional technology which converts the vegetables in to crisp form, reducing in size to facilitate the utility throughout the year. Another added advantage of this method is that the dried vegetable powder can be then easily incorporated into different traditional recipes (Gupta and Prakash, 2011). A number of studies (Gafar and Itodo, 2011; Akubugwo *et al.,* 2007; Singh *et al.,* 2007) have reported that dehydration makes green leaves very rich source of iron.

As per the results of sensory evaluation, it was observed that the colour of the safflower leaf powder incorporated karam podi was highly acceptable during all the stages of crop growth in Annigeri-1, TSF-1 and NARI-6 varieties and there was no significant difference in any stage of crop growth indicating powdered safflower leaves do not have any difference in colour at any stage. However, the colour was ranked significantly higher (P>0.05) during 30th (7.60±0.15) and 70th (7.80±0.12) day as compared to 50th (6.95±0.17) day in Manjira variety on a 9 point hedonic scale. The results of colour comparison among cultivars indicate no significant difference on 30th day. However, the colour had significantly (P>0.05) higher scoring on a 9 point hedonic scale in TSF-1 (7.60±0.13) and NARI-6 (7.60±0.12) on 50th day when compared to Annigeri-1 (7.15±0.16) and Manjira (6.95±0.17) varieties. On 70th day, colour had a significantly (P>0.05) higher score in Manjira, TSF-1 and NARI-6 varieties as compared to Annigeri-1. However, the mean colour score ranged between 6.95 and 7.80 during all the crop growth stages and among all cultivars indicating good acceptance of SLKP from a sensory point of view.

Taste parameter of the SLKP had no significant difference among the stages of crop growth as well as among the cultivars indicating good acceptance of the product. Any cultivar of safflower leaves during any stage of crop growth can be used to prepare SLKP with no difference in taste due to incorporation of safflower leaf powder.

Table 2 Mean scores of sensory evaluation of safflower leaf powder incorporated in Karam Podi (SLKP)

Sensory attributes	Days of maturity	Annigeri-1	Manjira	TSF-1	NARI-6	SE Values	F values
Colour	30th day	7.40±016 a1	7.60±0.15 b1	7.80±0.14 a1	7.65±0.18 a1	0.147	1.90 ns
	50th day	7.15±0.16 a1	6.95±0.17 a1	7.60±0.13 a1	7.60±0.12 a2		
	70th day	7.25±013 a1	7.80±0.12 b2	7.75±0.11 a2	7.70±0.12 a2		
	90th day				7.50±0.35a		
SE value	0.128						
F-value	1.75 ns						
Taste	30th day	7.25±0.13 a1	7.20±0.16 a1	7.20±0.15 a1	7.10±0.18 a1	0.175	0.16 ns
	50th day	7.15±0.16 a1	6.85±0.19 a1	7.25±0.15 a1	7.25±0.17 a1		
	70th day	7.25±0.18 a1	7.10±0.20 a1	7.00±0.17 a1	6.95±0.17 a1		
	90th day				7.40±0.21 a		
SE value	0.151						
F-value	0.14ns						
Aroma	30th day	7.65±0.13 b1	7.40±014 a1	7.05±0.17 a1	7.55±0.17 a1	0.162	0.93ns
	50th day	7.50±0.16 b1	7.15±0.19 a1	6.95±0.17 a1	7.10±0.14 a1		
	70th day	7.10±0.17 a1	7.20±0.15 a1	7.10±0.14 a1	7.05±0.12 a1		
	90th day				7.30±0.26 a		
SE value	0.141						
F-value	1.26ns						
Appearance	30th day	7.50±0.18 a1	7.30±0.18 a1	7.60±0.12 a1	7.45±0.14 a1	0.161	0.67ns
	50th day	7.25±0.16 a1	6.95±0.17 a1	7.40±0.13 a1	7.35±0.13 a1		
	70th day	7.30±0.13 a1	7.10±0.18 a1	7.15±0.16 a1	7.40±0.15 a1		
	90th day				7.20±0.28 a		
SE value	0.140						
F-value	0.86ns						
Overall acceptability	30th day	7.30±0.13 a1	7.40±0.17 a1	7.35±0.15 a1	7.50±0.16 a1	0.163	0.34ns
	50th day	7.30±0.15 a1	7.00±0.18 a1	7.50±0.15 a1	7.35±0.14 a1		
	70th day	7.35±0.15 a1	7.35±0.19 a1	7.45±0.16 a1	7.50±0.14 a1		
	90th day				7.50±0.27 a		
SE value	0.141						
F-value	0.22ns						

Note: Values are expressed as mean ± standard deviation of three determinations. Mean values with similar superscripts within a column (alphabets) and row (numbers) do not differ significantly (P>0.01).

Results of sensory evaluation of SLKP indicate that aroma is significantly (P>0.05) richer during 30th (7.65±0.13) and 50th day (7.50±0.16) as compared to 70th day (7.10±0.17) in Annigeri-1. In other varieties such as Manjira, TSF and NARI-6, there was no significant difference in the aroma component during the stages of crop growth. Also there was no significant difference among the cultivars in the aroma characteristic during the stages of crop growth. The aroma score ranged between 6.95- 7.65 on 9 point hedonic scale during various stages of crop growth among the four cultivars. The results of appearance also indicate no significant difference among the cultivars at various stages of maturity. The score for appearance ranged between 6.95-7.60 on a 9 point hedonic scale.

The results of overall acceptability were statistically similar among all the cultivars during all the stages of crop growth indicating a high overall acceptability of SLKP product. The mean score of overall acceptability ranged between 7.00-7.50 on 9 point hedonic scale. There was no impact of stage of growth of the leaves nor the difference in cultivar in the product, which implies any stage of safflower leaf from any cultivar can be utilized to develop a product like SLKP with very good overall acceptability. Five products i.e., missi roti, dalia, dhokla, chana dal and barley snack were prepared in the laboratory by using 5%, 10% and 15% of broccoli floret and leaves powder by Madhu and Anitha (2014) and concluded that incorporation of broccoli floret powder at 5-15% and broccoli leaves powder at 5-10% was highly acceptable in all five products. Gupta and Prakash (2011) formulated micronutrient rich products with dried greens (keerae, *Amaranthus paniculatus* and shepu, *Peucedamum graveolens*) and reported that acceptability scores reduced with increasing concentration of greens. Similar studies by Shanthala and Prakash (2005) on dried curry leaf powder incorporated in chapathis; Pandey *et al.* (2006) on dehydrated green leafy vegetable incorporated products concluded that value addition of traditional products with dehydrated green leafy vegetables is advocated as a feasible food based approach. SLKP can be consumed with products like idli and dosa etc. enhancing the nutritional quality of the meal. From the literature available and the results of our study on SFLR and SLKP, it can be noted that incorporation of green leaves enhances the nutrient content of regular and traditional recipes.

In conclusion, 35% incorporation of safflower leaves in roti and 15% incorporation of safflower powder in karam podi products had high scores for overall acceptability. Safflower leaf powder karam podi was liked more in all the sensory parameters as compared to safflower leaves roti. Fresh leaves from non-spiny varieties can be consumed up to 90 days where as spiny varieties of safflower can be well acceptable up to 50 days. Safflower leaves or powder from any stage of maturity and any cultivar adds variety in the diet and also has good overall acceptability. There will be a substantial increase in the nutritional value of all the products developed by incorporating fresh or dried green leaves of safflower.

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Morphological and molecular characterization of anamorph associated with gray mold of castor (*Ricinus communis* L.)

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(Received: May, 2015; Revised: June, 2015; Accepted: June, 2015)

ABSTRACT

Gray mold of castor caused by the anamorph of *Botryotinia ricini* is the most important disease and causes severe losses when there are heavy and continuous rains during capsule formation stage. In the present investigation, the anamorph of *B. ricini* was characterized based on morphological and molecular studies. The size of conidia and conidiophores were recorded from the culture grown on oat meal enriched medium for morphological characterization. Cultural characters like colony colour, growth pattern and sclerotial production were studied on six growth media. Based on microscopic observations, the anamorph was identified as *Amphobotrys ricini.* Further, the identity was confirmed by amplifying fungal DNA using two universal Internal Transcribed Spacer (ITS) primers, ITS1 and ITS4 in a polymerase chain reaction. A single 0.5 kb band was amplified and amplified region is sequenced and analyzed in a standard Gen Bank BLAST search for fungal species identification. BLAST search has shown 99% similarity of the query sequence with *Amphobotrys ricini.* The results of this study confirmed that *A. ricini* is the anamorphic state associated with castor gray mold in Hyderabad region of Telangana state.

Keywords: *Amphobotrys ricini, Botryotinia ricini,* Castor gray mold, Molecular identification

Castor (*Ricinus communis* L.) is an important non-edible oilseed crop. It contains 50-55% oil and plays a vital role in Indian vegetable oil economy. It is mainly grown in tropical and sub-tropical climate. Castor is prone to many fungal and bacterial diseases at different crop growth stages. Among these, one of the most destructive diseases of castor is gray mold, caused by the fungus *Botryotinia ricini* (Godfrey) Whetzel. The anamorphic phase of *Botryotinia ricini* is responsible for disease epiphytotics and heavy yield losses occur during the inflorescence and capsules, formation stage. Several anamorphs of *Botryotinia ricini* are found to incite gray mold in various countries. The ambiguity on the anamorph of castor gray mold pathogen still exists as three anamorphs *viz., Amphobotrys ricini, Botrytis ricini* and *Botrytis cinerea* are found to be associated with this disease in literature (Buchwald, 1949; Hennebert, 1973; Sung-Kee *et al*., 2001). The management strategies vary with respect to the pathogen associated with the disease. Hence, the preliminary step in the management of a pathogen is its recognition and taxonomy is the best approach which helps us to distinguish pathogens. The present investigation was carried out to identify the anamorph associated with gray mold of castor in Hyderabad region of Telangana state, India.

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MATERIALS AND METHODS

Morphological characterization of anamorph of *Botryotinia ricini*: The fungus causing gray mold of castor was isolated on oat meal enriched medium and examined periodically and identified based on morphological characteristics *viz.,* conidiophores length, conidial size, phialide structure and sclerotial production (Soares, 2012). Temporary aqueous mounts were prepared from the pure culture of the fungus and observed under the microscope. Measurements of conidia and conidiophore of the fungus were taken with the help of an ocular micrometer after calibration.

Cultural characters of *A. ricini* on various growth media: Cultural characters *viz.,* colony colour, growth pattern and sclerotial production of the anamorph of *Botryotinia ricini* were studied on potato dextrose agar (PDA), oat meal agar (OMA), oat meal enriched medium (OME), castor leaf extract agar (CLE), corn meal agar (CMA) and V8 juice agar. The experiment was laid out in completely randomized design with four replications. Observations on cultural characters were recorded when complete growth of the mycelium is observed in one of the treatments.

Molecular identification of anamorph of *Botryotinia ricini*

DNA extraction: Pure culture of the pathogen was multiplied on potato dextrose broth for 8 days at 23±1°C.

Mycelial mat was harvested by filtration through Whatman No.1 filter paper and the DNA was isolated according to the protocol given by Sambrook *et al.* (1989). DNA pellet was dissolved in Tris-EDTA buffer and stored at 4°C for further use.

PCR amplification: PCR amplification was performed in a 50 µl reaction volume containing of 6.66 µl template DNA, 6.66 µl PCR buffer (10x), 0.66 µl of dNTPs (10 Mm/2.5mM), 5 µl of each primer (5 pmol/µl), 0.56 µl of Taq (5 u/µ Fermentas) and 25.46 µl of dH_2O. A region of nuclear rDNA was amplified by polymerase chain reaction (PCR) using two universal Internal Transcribed Spacer (ITS) primers, ITS 1 (5'-TCCGTAGGTGAACCTGCGG-3') and 4 (5'-TCCTCCGCTTATTGATATGC-3') (White *et al.*, 1990). Different dilutions of genomic DNA were used for PCR amplification as indicated below.

To prepare 1ml of template DNA, given dilutions were followed:

10 µl of genomic DNA+ 90 µl of distilled water =100 µl template DNA
15 µl of genomic DNA+ 85 µl of distilled water =100 µl template DNA
40 µl of genomic DNA+ 60 µl of distilled water =100 µl template DNA

PCR reactions were performed in a Thermocycler (Bioer, Japan) using the following parameters: 4 min initial denaturation at 94°C, followed by 35 cycles of 30s denaturation at 94°C, 1 min primer annealing at 58°C, 1 min extension at 72°C and final extension for 7 min at 72°C. The PCR product was separated by electrophoresis on a 1.5% agarose gel in 1x TBE buffer and visualized by staining with ethidium bromide. The amplified PCR products were purified and direct sequencing of the PCR amplicons corresponding to the ITS region of DNA (rDNA) was performed through outsourcing (Bioserve, Hyderabad). The partial sequences were compared with the reference sequences in the NCBI Gene bank using BLAST search.

RESULTS AND DISCUSSION

Morphological identification of anamorphic state of *Botryotinia ricini*: The fungus on oat meal enriched medium produced septate and branched mycelium which is thin, hyaline to light brown in colour. Conidiophores are produced individually or in clusters, erect, cylindrical, hyaline to pale brown, branched dichotomously, which developed from conidiogenous cells and measured 1-1.3 µm length, 9.6-11.8 µm wide. Conidia were produced synchronically on denticles or sterigmata measuring 2.2-3 µm in length and are globose, unicellular, smooth, hyaline to pale brown colour, and measured 5.74-10.05 µm (7.18 µm) in diameter (Fig. 1). On the basis of morphology, the fungus was identified as *Amphobotrys ricini*. The morphological characters obtained are in accordance with the descriptions of Hennebert (1973).

Similar observations were made by Sung-Kee *et al.* (2001) on potato dextrose agar. The conidia were globose, unicellular, pale brown, smooth, and measured 5.0-10.8 µm (av. 8.1 µm) in diameter. The conidiophores were found scattered over the infected plant parts and were single, erect, and 1.2-1.3 mm high. Stipes were found to be long, slender, cylindrical, pale brown and 10.0-12.5 µm wide, with unswollen basal cells, branches bifurcating at about two-thirds height from the basal portion and branched dichotomously again two to three times. Each apical cell of the branches and branchlets was delimited by a septum. Conidiogenous cells were ampulliform, somewhere inflated at the apices, 6.3-8.8 µm wide, and produced conidia on cylindrical sterigma measuring 2.0-2.5 µm in length which were in accordance with the present findings.

Effect of different culture media on the growth of *Amphobotrys ricini*: The diversity in cultural characters of *A. ricini* was studied on six different growth media. The results of cultural variations of *A. ricini* on various media are presented in Table 1. The radial growth of *A. ricini* was higher on oat meal agar medium with mean colony diameter of 4.04 cm. This was followed by castor leaf extract agar medium (3.56 cm), V8 juice agar medium (2.98 cm), oat meal enriched medium (2.75 cm), corn meal agar medium (2.11 cm) and potato dextrose agar medium (1.83 cm).

Colony characters of *A. ricini* on various culture media are presented in Table 2. Different growth patterns were observed on various media at 23±1°C under dark conditions (Fig. 2). Colonies with compact, sparse or profuse mycelial growth were observed at the center of the Petri plate near the point of pathogen inoculation. Colonies were white to dirty white in colour at the center and creamish yellow or brown at the periphery. Conidia were produced at the advancing margins of the colonies, varying in abundance. Sporulation of the fungus was observed in the cultures grown on oat meal enriched medium and castor leaf extract medium, but not in other media tested.

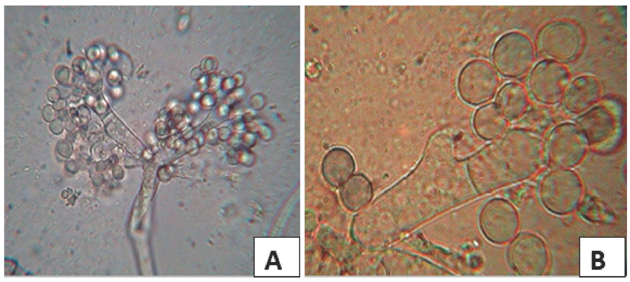


Fig. 1. Conidia and conidiophore characters of *Amphobotrys ricini*

(A= Dichotomous branching of the conidiophore;
B= Conidiogenoues cell with globose conidia)

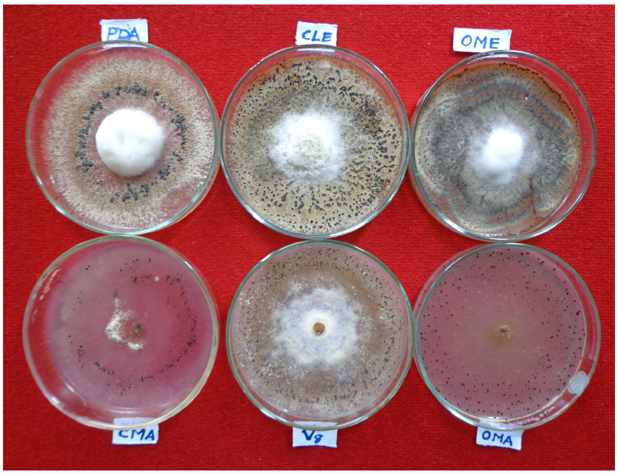


Fig. 2. Growth pattern of *A. ricni* on various culture media (PDA- Potato dextrose agar; CLE-Castor leaf extract agar; OME-Oat meal enriched medium; CMA-Corn meal agar; V8-V8 juice agar; OMA- Oat meal agar)

Table 1 *In vitro* evaluation of various culture media in supporting the mycelial growth of *Amphobotrys ricini*

Medium	Mycelial growth (cm)
Oat meal enriched medium	2.75 (1.94)
Corn meal agar	2.11 (1.76)
V8 Juice agar	2.98 (1.99)
Potato dextrose agar	1.83 (1.68)
Castor leaf extract agar	3.56 (2.14)
Oat meal agar	4.04 (2.24)
CD (P=0.05)	0.071
SEm (±)	0.024
CV (%)	2.409

Sclerotia were black and varied in size, abundance and distribution. Sclerotial production was observed from 9th day after incubation in oat meal agar medium, whereas, sclerotia appeared to produce after 10 to 12 days in the other evaluated media. The number of sclerotia produced on various media varied (68-720/plate) with the type of medium used. Sclerotial production is either superficial or deeply embedded in agar. The pattern of distribution also varied with the type of medium. On oat meal extract medium, sclerotia were formed in concentric circles in a stellate pattern. However, the sclerotia were scattered throughout the medium in castor leaf extract, V8 juice agar and oat meal extract agar medium. They were flattened or convex, hemispherical, rounded or irregular in shape. Sclerotia were discrete on oat meal and corn meal agar and confluent on PDA, castor leaf extract and oat meal enriched medium.

The results are in accordance with Sung-Kee *et al.* (2001) who reported that *A. ricini* produced effuse, pure white colonies on PDA with somewhat cottony mycelium and black irregular sclerotia. Mirzaei *et al.* (2007) characterized 355 isolates of *Botrytis cinerea* from gray mold infected plants in Israel and identified the species based on morphological characters such as conidiophore length, conidial and sclerotial dimensions. Different kinds of growth pattern were observed on potato dextrose agar at 20°C under light. Tangent colonies or aerial mycelium were produced. They were compact, cottony, warty, powdery, radial or in concentric rings. Colonies were white, dirty white, grayish white, or hyaline at first but soon becoming light gray, dark gray to dark brown, celadon, soiled or mousy.

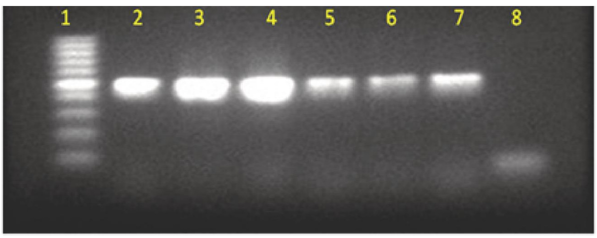
Table 2 Morphological growth characteristics of *A. ricini* on different culture media

Medium	Colony characters		Sclerotial characters		
	Colony colour	Growth pattern	Number*/plate	Size	Formation pattern
Oat meal enriched	Initially white later turn medium to brown colour	Irregular growth with pluffy mycelium at inoculation point, sparse growth with sporulation at colony edges.	720	Large, flat irregular shape	Form in concentric rings in a stellate pattern (10 DAI)
Corn meal agar	White	Sparse mycelial growth at the center with irregular margins without sporulation.	116	Small, irregular	Sclerotia formed in a ring at approximately 1.5 cm from the center (11 DAI)
V8 Juice agar	Initially white to dirty white in colour and later turned to cream colour	Pluffy mycelium at the center with irregular margins without sporulation	560	Small, irregular shape	Initially form in the center (11 DAI) then scattered throughout the plate
PDA	Whitish at the center and creamish yellow at the periphery	Pluffy mycelium at the inoculation point with sparse growth at the periphery without sporulation	68	Large, irregular shape	Form in rings at about 0.5 cm away from the mycelial growth (12 DAI)
Castor leaf extract	Whitish at the center and creamish yellow at the periphery	Round pluffy mycelium at the inoculation point with sparse growth at the periphery with sporulation	600	Large, irregular shape	Sclerotia scattered throughout the plate (11 DAI)
Oat meal agar	White	Sparse mycelial growth at the center without sporulation	536	Small, round, brown in colour	Form individually at about 2cm away from the center (9 DAI)

*Mean of four replications; DAI: Days after inoculation

Botrytis taxonomy has traditionally been based on morphological and cultural characteristics coupled with host specificity (Hennebert, 1973). However, cultural conditions could considerably modify taxonomic characters such as dimension and shape of conidia (Jarvis, 1977). Despite these, morphological characters are so far used in taxonomy and in recent years molecular markers have been used in the recognition of *Botrytis* species (Mirzaei *et al.,* 2007).

Molecular identification of anamorphic state of *Botryotinia ricini*: The DNA of the fungus was isolated and the Internal Transcribed Spacer (ITS) region of the fungal genome was amplified in a PCR using ITS 1 and ITS 4 primer pair. The amplified region is typically 500 bp in length in all dilutions tested with 10 mM and 2.5mM dNTPs (Fig. 3). No band was amplified in negative control or non template. The amplified region was sequenced and analyzed in a standard GenBank BLAST search for fungal species identification. BLAST search has shown 99% similarity of the query sequence with *Amphobotrys ricini.* The results of this study confirmed that the anamorph associated with castor gray mold in Hyderabad region of Telangana state is *Amphobotrys ricini.* The sequence was deposited in NCBI, GenBank database and the accession number (KR527112) was obtained.



1. Ladder; 2,3,4-dilutions with 10mM dNTPs; 5,6,7. dilutions with 2.5mM dNTPs; 8. Negative control

Fig. 3. Amplification of fungal DNA in the ITS region using ITS1 and ITS4 primer pair

The anamorphic state of *Botryotinia ricini* was named as *Botrytis ricini* by Buchwald (1949). This led to the general confusion between the non-mycologist communities, which adopted the name *Botrytis ricini* N.F. Buchw., instead of *Botryotinia ricini* (Godfery) Whetzel (Soares, 2012). In 1973, Hennebert erected the genus *Amphobotrys* to accommodate the anamorphic state of *B. ricini,* based mainly on the distinctive pattern of conidiophores ramification, and since then the anamorphic state became known as *Amphobotrys ricini* (N.F.Buchw.) Hennebert (Hennebert, 1973). Even so, several author's used, and still use, the erroneous name *Botrytis ricini* attributing to Godfrey (Moses and Reddy, 1989; Bheemaraju, 1999; Aswani Kumar, 2001).

The ITS rDNA region has been widely used for species-level discrimination of fungal species (Nielsen *et al.,* 2001). Sung-Kee *et al.* (2001) reported two anamorphs associated with castor gray mold in Korea caused by *Botrytis cinerea* and *Amphobotrys ricini* using morphological and molecular methods. Though morphological methods can help us in recognition of *A. ricini,* the molecular studies confirm traditional classification. An example for the application of molecular methods to species recognition in *Botrytis* has been provided for the neck-rotting species of onion. Universal-primed polymerase chain reaction (UP-PCR) fingerprinting, coupled with restriction analysis of ITS rDNA regions, allowed five groups to be distinguished: *B. cinerea, B. squamosa, B. byssoidea,* and two groups in *B. aclada* (AI and AII) (Nielsen *et al.,* 2001).

Jin-Hyeuk Kwon *et al.* (2011) reported gray mold of blueberry caused by *Botrytis* spp. for the first time in Korea. A detailed description of the fungus is given based on morphological characters and amplification of rDNA using ITS primers 1 and 4. The fungus was identified as *Botrytis cinerea.* Khazaeli *et al.* (2010) characterized 30 isolates of *Botrytis cinerea* collected from rose greenhouses using specific primer pairs C729. Based on the morphological identification, all the isolates were found to be *B. cinerea.* Using specific primer pairs (5'-AGCTCGAGAGAGATC TCTGA-3'; 5'-CTGCAATG TTCTGCGTGGAA-3'), a DNA fragment of 700 bp was amplified for most of the isolates, thus confirming the presence of *B. cinerea* on rose samples.

In the present investigation, the anamorph associated with gray mold of castor in Hyderabad region of Telangana state is identified as *Amphobotrys ricini* by morphological and molecular methods. However, intensive surveys need to be conducted on regular basis to know the association of any other pathogen associated with the disease for devising efficient management strategies.

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Evaluation of integrated pest management module for insect pests of castor (*Ricinus communis* L.)

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(Received: April, 2015; Revised: May, 2015; Accepted: June, 2015)

ABSTRACT

A field experiment was conducted to evaluate integrated pest management (IPM) module in castor using three popular cultivars (DCH-519, DCH-177, DCS-107) and compared with farmers' practice and untreated control. IPM module comprised of mechanical control of gregarious stages of tobacco caterpillar and older larvae of semilooper, economic threshold level based application of thiodicarb 75WP @ 375 g a.i./ha against tobacco caterpillar (at 25% foliage damage), indoxacarb 15.8EC @ 75 g a.i./ha against capsule borer (at 10% capsule damage) and dimethoate 30EC @ 250 g a.i./ha against leafhopper (at 10% hopper burn damage) superior in reducing the insect pest population over farmers' practice. In the IPM module, the mean population of semilooper, tobacco caterpillar, leafhopper and capsule borer damage was 0.3 larvae/plant, 0.8 larvae/plant, 16.2 leafhoppers/3 leaves/plant and 10.3% capsule damage as against 0.6 larvae/plant, 2.3 larvae/plant, 20.7 leafhoppers/3 leaves/plant and 16.5% capsule damage in farmers' practice, respectively. IPM module found safer to its larval parasitoid, *Snellenius* (*Microplitis*) *maculipennis* as compared to farmers' practice. The higher mean castor seed yield (1348 kg/ha) and avoidable yield loss (67.6%) was obtained from IPM module over farmers' practice with seed yield of 1008 kg/ha and avoidable yield loss of 55.5%. Further, higher net profit of ₹ 26889/ha and incremental cost-benefit ratio of 1:5.95 was recorded in IPM module as compared to ₹ 15584/ha and 1: 3.97 under farmers' practice.

Keywords: Castor, Economics, Insect pests, Integrated pest management

India is the largest producer of castor (*Ricinus communis* L.) both in area and production occupying the *numero uno* position in the world. Though castor productivity in India is more than world average, there are several production constraints. One of the major constraints is the excessive damage caused by insect pests *viz.,* defoliators (castor semilooper, *Achaea janata* L. and tobacco caterpillar, *Spodoptera litura* Fabr.), capsule borer (*Conogethes punctiferalis* Guen.) and leafhopper (*Empoasca flavescens* Fabr.). Incidence of defoliators is generally noticed from vegetative to early reproductive phase of the crop, while capsule borer and leafhopper infestation starts from flowering stage onwards and active till crop maturation (Lakshminarayana *et al*., 2013). In pursuit of managing pests for increased castor yield, insecticides have continued to play a major role. At present, application of conventional insecticides *viz.,* monocrotophos and acephate are made for the control of insect pests. But, these insecticides are less effective against *S. litura,* particularly the older larvae and the capsule borer (Suganthy, 2010). Further, unwise and indiscriminate use of these broad spectrum insecticides are unsafe to *Snellenius* (*Microplitis*) *maculipennis* Zepligate (Braconidae: Hymenoptera), a potential and unique larval parasitoid of castor semilooper, which is parasitizing more than 75% of larvae in the field under favourable conditions (Basappa and Lingappa, 2004). Integrated Pest Management (IPM) programmes are an attempt to promote favourable, ecological, economic and sociological outcomes which is accomplished by the best mix of pest control tactics together. Use of action economic thresholds and conservation of occurring natural enemies are fundamental component of a sound IPM programme. Similarly, inclusion of new insecticide molecules in the IPM strategy is a healthy sign as it will lead to the reduced selection pressure on the limited number of efficacious products. Therefore, the present investigation was carried out to evaluate IPM module for the management of castor insect pests so that the farmers can get higher yield with better returns without affecting the environment.

MATERIALS AND METHODS

A field experiment was conducted at Research Farm, Indian Institute of Oilseeds Research (formerly, DOR), Hyderabad (Latitude 17.53°N, Longitude 78.27° E, Altitude 545 MSL) to evaluate IPM module for the management of insect pests of castor during *kharif* 2013-14. There were three treatments *viz.,* IPM module, farmers' practice and untreated control as check. Three castor cultivars *viz.,* DCH-519, DCH-177 and DCS-107 were sown in larger plots of 200 m^2 for each treatment with a spacing of 90 x 90 cm. All agronomic practices were followed as per the recommendations except for insect pest management. The IPM module included mechanical control of gregarious stages of tobacco caterpillar and older larvae of semilooper, Economic Threshold Level (ETL) based application of thiodicarb 75WP @ 375 g a.i./ha (0.075%) against tobacco caterpillar at 25% foliage damage, indoxacarb 15.8EC @ 75 g a.i./ha (0.015%) against capsule borer at 10% capsule damage and dimethoate 30EC @ 250 g a.i./ha (0.05%) against leafhopper at 10% hopper burn damage. Farmers' practice involved indiscriminate use of monocrotophos 250 g a.i./ha i.e. 0.05% (six sprays at 15-20 days interval), while the crops were grown under unprotected conditions in untreated control. In each treatment, the plot was divided into four blocks (each block of 50 m^2 and considered as one replication) and the observations on insect pests and natural enemies was taken from five randomly selected plants in each block at fortnightly intervals. In each harvest, the data on total number of capsules and number of capsules damaged by the capsule borer was recorded from five randomly selected plants from each block and then per cent capsule damage was worked out. Mean insect numbers, per cent damage and natural enemies counts across sampling intervals were determined to provide a single index of pest/natural enemy population for making comparison across treatments. The final pooled mean data was analyzed and presented. The yield was recorded on each block individually by spike order (at the time of harvest of each primary, secondary and tertiary) which was converted to kg/ha for statistical interpretations. Treatment effects were analyzed using Factorial Randomized Block Design with four replications. Following ANOVA, differences between datasets were determined using least significant difference at P = 0.05 using AGRES statistical software.

RESULTS AND DISCUSSION

Effectiveness of IPM module on the incidence of insect pests: The results emerged from field experiment on evaluation of IPM module along with farmers' practice and untreated control against insect pests on three popular castor cultivars *viz.,* DCH-519, DCH-177 and DCS-107 are presented in Tables 1 and 2. Mean population of semilooper was low in IPM module (0.3 larvae/plant) followed by farmers' practice (0.6 larvae/plant) while untreated control recorded high population of 2.4 larvae/plant. IPM module was the best with reference to *S. litura* registered the lower population of 0.8 larvae/plant. Farmers' practice found less effective against *S. litura* as compared to IPM module with population of 2.3 larvae/plant. IPM module recorded minimum population of leafhopper (16.2/3 leaves/plant), which was significantly different from farmers' practice (20.7/3 leaves/plant) and untreated control (65.4/3 leaves/plant). Castor cultivars raised in IPM module registered a minimum infestation of capsule borer (10.3% capsule damage) as compared to farmers' practice (16.5%) and untreated control (26.7%). The mean population of insect pests under untreated control revealed that the single bloom cultivar DCH-177 recorded relatively low population of semilooper (1.5 larvae/plant) as compared to triple bloom cultivar DCH-519 (3.0 larvae/plant). Contrary to this, the triple bloom cultivar DCH-519 recorded significantly minimum infestation of leafhopper (14.3/3 leaves/plant) as compared to single bloom cultivar DCH-177 (118/3 leaves/plant). *S. litura* and capsule borer did not show reliable preference among the different bloom cultivars (Tables 1 and 2).

The present findings on effectiveness of mechanical control of defoliators in IPM module over chemical intensive farmers' practice are in accordance with the findings of Lakshminarayana (2005) and Suganthy (2010), who has reported very good protection from defoliators by mechanical removal over foliar application of insecticide. Ineffectiveness of farmers' practice against *S. litura* may be due to insecticide resistance in the insect to monocrotophos (Armes *et al.,* 1997) commonly used by the farmers. Effective control of *S. litura* and capsule borer in IPM module over farmers' practice was supported by Basappa (2007), who reported that mechanical control and ETL based application of insecticides found effective against the castor pests as compared to indiscriminate use of conventional insecticides. The triple bloom castor cultivar DCH-519 was found to be least preferred by leafhopper over double (DCS-107) and single bloom (DCH-177) cultivars. In contrast single bloom cultivar DCH-177 relatively less preferred by semilooper over triple bloom cultivar DCH-519. This corroborates the results of Lakshminarayana (2005) and Vijayalakshmi *et al.* (2005), who reported that the bloom character of castor was found to play a major role in determining the resistance/susceptibility of different castor genotypes to insect pests.

Impact of IPM module on the occurrence of natural enemies: The data on impact of pest management module on the semilooper larval parasitoid, *S. maculipennis* revealed that IPM module found to be safer and recorded significantly more number of cocoons of the parasitoid compared to farmers' practice (Table 2). Higher number of cocoons was observed in IPM module and untreated control plots (1.3 and 1.2 cocoons/plant, respectively) and which were lowest in farmers' practice (0.6 cocoons/plant). More number of *S. maculipennis* cocoons in IPM module may be due to non-application of insecticides against semilooper and self-perpetuation of the parasitoid on the leftover population after mechanical removal. On the other hand, application of chemical insecticides in farmers' practice reduced the population of both semilooper and its parasitoid. The results on the safety of IPM module to semilooper larval parasitoid are in accordance with the findings of Basappa and Lingappa

(2004) and Suganthy (2010) who reported maximum parasitisation of *S. maculipennis* in the treatment involving mechanical removal of defoliators over foliar application of insecticides.

Impact of IPM module on yield and economics: Significant impact of IPM module and farmers' practice over untreated control in consideration of yield was noted. IPM module exhibited higher mean seed yield (1348 kg/ha) followed by farmers' practice (1008 kg/ha) as against the lowest yield (451 kg/ha) in untreated control (Table 2). The avoidable seed yield losses by adopting IPM module in three castor cultivars ranged between 37.4 to 84.8% with an average of 67.6% over untreated control. The avoidable yield losses with farmers' practice ranged between 11.4 to 78.8% with an average of 55.5% over untreated control. Net profit of castor cultivars raised under IPM plots was relatively higher (ranged between ₹14507/ha to 34812/ha with an average of ₹ 26889/ha) than farmers' practice (ranged between ₹102/ha to 26632/ha with an average of ₹ 15584/ha). The cost effectiveness of IPM module was high with incremental cost-benefit ratio (ICBR) ranged between 1: 3.44 to 1:7.46 with an average of 1: 5.95 as compared to farmers' practice (ranged between of 1: 0.03 to 1: 6.79 with an average of 1: 3.97). The results were in accordance with the findings of Singh *et al.* (2005) and Basappa (2007), who also reported highest seed yield and highest return per rupee with the IPM module as compared to chemical intensive farmers' practice in castor.

IPM practice involving mechanical control of gregarious stages of tobacco caterpillar and older larvae of semilooper, ETL based application of thiodicarb 75WP @ 375g a.i./ha against tobacco caterpillar at 25% foliage damage, indoxacarb 15.8EC @ 75g a.i./ha against capsule borer at 10% capsule damage and dimethoate 30EC @ 250g a.i./ha against leafhopper at 10% hopper burn damage can be used for effective and economic management of insect pests in castor.

Table 1 Effectiveness of IPM module on the incidence of defoliators and leafhopper in castor

Cultivar	Semilooper (larvae/plant)				*Spodoptera litura* (larvae/plant)				Leafhopper (No./3 leaves/plant)			
	IPM	FP	Control	Mean	IPM	FP	Control	Mean	IPM	FP	Control	Mean
DCH-519	0.5 (1.0) ab	0.8 (1.1)b	3.0 (1.9) d	1.4 (1.3) b	0.3 (0.9) a	2.3 (1.6) d	2.7 (1.7) d	1.8 (1.4) a	6.5 (2.6) a	11.5 (3.4) ab	14.3 (3.7) b	10.8 (3.2) a
DCH-177	0.3 (0.9) a	0.8 (1.1) b	1.5 (1.4) c	0.9 (1.1) a	0.8 (1.1) ab	1.9 (1.5) cd	2.9 (1.8) d	1.9 (1.5) a	24.8 (5.0) cd	26.3 (5.1) d	118.0 (10.8) f	56.4 (7.0) c
DCS-107	0.2 (0.8) a	0.3 (0.9) a	2.8 (1.8) d	1.1 (1.2) a	1.3 (1.3) bc	2.6 (1.7) d	5.8 (2.5) e	3.2 (1.8) b	17.3 (4.1) bc	24.3 (4.9) cd	63.8 (7.9) e	35.1 (5.6) b
Mean	0.3 (0.9) a	0.6 (1.0) b	2.4 (1.7) c	1.1 (1.2)	0.8 (1.1) a	2.3 (1.6) b	3.8 (2.0) c	2.3 (1.6)	16.2 (3.9) a	20.7 (4.5) b	65.4 (22.4) c	34.1 (5.3)
	F-test	SEm±	CD at 5%		F-test	SEm±	CD at 5%		F-test	SEm±	CD at 5%	
Modules (M)	*	0.06	0.12		*	0.09	0.18		*	0.27	0.56	
Cultivars (C)	*	0.06	0.12		*	0.09	0.18		*	0.27	0.56	
Interaction (MxC)	*	0.10	0.21		*	0.15	0.31		*	0.47	0.97	

IPM - Integrated Pest Management module; FP- Farmers' Practice; Control - Untreated control; * - Significant; NS- Non Significant
Figures in the parentheses are square root transformed values; In a column means followed by the same alphabet do not differ significantly by LSD (0.05)

Table 2 Effectiveness of IPM module on capsule borer and impact on parasitoid and yield in castor

Cultivar	#Capsule damage due to capsule borer (%)				$*Microplitis* parasitoid (cocoon/plant)				Yield (kg/ha)			
	IPM	FP	Control	Mean	IPM	FP	Control	Mean	IPM	FP	Control	Mean
DCH-519	12.2 (20.4) ab	18.1 (25.1) cd	23.9 (29.1) de	18.1 (24.9)	1.2 (1.3)	0.7 (1.1)	0.9 (1.2)	0.9 (1.2) b	1432 a	1012 c	897 d	1114 a
DCH-177	8.2 (16.6) a	13.7 (21.7) bc	30.3 (33.2) f	17.4 (23.8)	0.8 (1.1)	0.3 (0.9)	1.0 (1.2)	0.7 (1.1) b	1213 b	868 d	184 f	755 c
DCS-107	10.5 (18.8) ab	17.6 (24.7) c	25.8 (30.4) ef	18.0 (24.6)	1.9 (1.5)	0.9 (1.2)	1.8 (1.5)	1.5 (1.4) a	1400 a	1145 b	272 e	939 b
Mean	10.3 (18.6) a	16.5 (23.8) b	26.7 (30.9) c	17.8 (24.4)	1.3 (1.3) a	0.6 (1.1) b	1.2 (1.3) a	1.0 (1.2)	1348 a	1008 b	451 c	936
	F-test	SEm±	CD at 5%		F-test	SEm±	CD at 5%		F-test	SEm±	CD at 5%	
Modules (M)	*	1.13	2.34		*	0.06	0.12		*	21.07	43.49	
Cultivars (C)	NS	1.13	2.34		*	0.06	0.12		*	21.07	43.49	
Interaction (MxC)	*	1.96	4.10		NS	0.10	0.21		*	36.49	75.32	

IPM-Integrated Pest Management module; FP- Farmers' Practice; Control - Untreated control; * - Significant; NS- Non Significant; # -Figures in parentheses are arc sine values;
$ - Figures in the parenthesis are square root transformed values; In a column means followed by the same alphabet do not differ significantly by LSD (0.05)

Table 3 Economics of IPM module in castor

Cultivar	Yield (kg/ha)			Avoidable yield loss over control (%)		Increase in yield over control (kg/ha)		Cost of increased yield (₹)		Plant protection cost (₹/ha)*		Net profit (₹/ha)		ICBR	
	IPM	FP	Control	IPM	FP	IPM	FP	IPM	FP	IPM	FP	IPM	FP	IPM	FP
DCH-519	1432	1012	897	37.4	11.4	535	115	18725	4025	4218	3923	14507	102	3.44	0.03
DCH-177	1213	868	184	84.8	78.8	1029	684	36015	23940	4668	3923	31347	20017	6.72	5.10
DCS-107	1400	1145	272	80.6	76.2	1128	873	39480	30555	4668	3923	34812	26632	7.46	6.79
Mean	1348	1008	451	67.6	55.5	897	557	31407	19507	4518	3923	26889	15584	5.95	3.97

IPM - Integrated Pest Management module; FP- Farmers' Practice; Control - Untreated control; Market price of Castor: ₹35/kg
*Treatment costs including labour charges (Spray against leafhopper was not imposed in DCH-519 under IPM since the pest damage not crossed ETL)

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Soybean economy of India : Performance, problems and prospects

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(Received: August, 2014; Revised: February, 2015; Accepted: March, 2015)

ABSTRACT

Soybean crop has witnessed a phenomenal growth in production in the country during the last four decades but growth has been driven majorly by area expansion. During the last two decades, area expansion drove about 80 per cent of the increased production while yield contributed about 20 per cent to the increase in soybean production. One of the most important changes observed in the soybean acreage and production over the last three decades has been a declining share of Madhya Pradesh in area and production and increasing share of Maharashtra and Rajasthan. The demand for soybean is increasing rapidly due to higher demand from poultry feed industry and soybean based products such as soybean oil, soymilk, soy flour and soy protein. However, soybean producers face a variety of biotic, abiotic, socio-economic and policy-related constraints that affect soybean production. Economic constraints were the most important constraints faced by soybean producers, followed by technological constraints, agro-climatic factors, institutional and post-harvest management and marketing related problems. The findings show that there exist huge yield gaps in case of soybean in the country. It was estimated that soybean productivity can be increased by about 47 per cent and production from current level of 11.64 million tonnes to about 18.6 million tonnes by bridging the gap between improved technology at farmers' field and actual farm yield in the country through improving extension services. Therefore, concerted efforts are needed to bridge soybean yield gaps through strengthening institutional factors including better extension services, timely availability of quality inputs and services and improved post-harvest management and marketing facilities.

Keywords: Abiotic, Biotic, Production Constraints, Socio-economic, Soybean, Yield gap

Soybean is not only an important oilseed crop and a feed for livestock and aquaculture, but also a good source of protein for the human diet. Of late, it has also emerged as a major biofuel feedstock. It accounts for about 56 per cent of total oilseeds production, 25% of global edible oil, and about two-third of the world protein concentrate for livestock feed. Soybean acreage has expanded mainly by substituting other crops, e.g. sunflower in Argentina, cotton in the United States, and utilizing pasture lands in Argentina and Brazil (Masuda and Goldsmith, 2009). The world soybean production was 28.6 million metric tonnes in 1961-65, and reached 256.9 million metric tonnes in 2010-12, which was an increase of about 9 times during the half century. During the last decade, world soybean production increased by 38 per cent between triennium ending (TE) 2002-03 (185.8 million tonnes) and TE 2012-13 (256.9 million tonnes). Though the world-wide soybean area increased by 33%, it drove about 87% of the increased production during the last decade. Yield increased by only four per cent since early-2000s and contributed only 13% to the increased output. Major global producers of soybean in the order of importance include the United States of America, Brazil, Argentina, China and India. The USA produced more than 50 percent of the world soybean production until the 1980s but its share has declined to about 33% in 2010-12. Brazil and Argentina have significantly increased their shares steadily over the same period. Brazil is the second largest producer with 74.6 million tonnes or 29% of the world production. Argentina ranks third, producing 46.2 million tonnes and 18% of the world output. The top five countries, United States, Brazil, Argentina, China, and India, produce about 90% of the world's soybean. Even though India ranks 5th globally in respect of soybean production, the yield levels of soybean in India are far below (1.2 tonnes/ha) compared to yield recorded in major soybean producing countries and the world average (2.4 tonnes/ha).

The commercial cultivation of soybean crop in India started in late sixties. Starting with about 30,000 ha in 1970, soybean acreage reached 10.2 million ha in 2011-12. Similarly, the production and productivity levels of soybean increased from 14000 tonnes and 430 kg/ha in 1970 to 12.2 million tonnes and 1208 kg/ha in 2011-12, respectively. Soybean has emerged as one of the most important rainfed *kharif* crop and despite low level of irrigation (<1% area under irrigation), the crop productivity has improved (22.7%) during the last decade. The area under soybean is mainly spread in the states of Madhya Pradesh, Maharashtra, Rajasthan, Chhattisgarh, Andhra Pradesh and Karnataka. Soybean is grown either as a pure crop or in mixture with maize or autumn paddy. The products and by-products of soybean have great potential in the domestic and world markets. However, soybean farmers face a multitude of constraints including biotic and abiotic stresses. This paper is an attempt to study trends and patterns of growth of soybeans over time and across states and provide an overview of the major constraints faced by soybean farmers and suggest policy options for increasing soybean production and productivity in the country.

MATERIALS AND METHODS

The analysis of trends and patterns of growth of soybean over time and across states was done for the last three decades (1971-72 to 2011-12) with special focus on post-reforms period. In order to understand soybean supply response, soybean acreage response functions are estimated for major states. The factors that influence soybean acreage and production are investigated using regression model. The time series data used for supply functions cover the period 1990-91 to 2011-12.

Farmer's decision about allocation of land to a specific crop at the farm level depends on various factors such as price of own and competing crops, yield of competing crops, irrigation, rainfall, access to inputs and markets, input prices etc. Some argue that price factors, through their effect on relative profitability, play an important role in crop acreage allocation decisions and farmers respond to these changes by adjusting crop acreage in order to maximize profits. Some have argued that non-price factors such as technology and infrastructure are more powerful in influencing crop acreage allocation decisions and therefore, price policy should precede technological change.

In estimating the acreage, a simple linear relation of the following type was assumed between total planted area and the factors that influence soybean acreage:

$$Ln\ A_t = \alpha_0 + \alpha_1 Ln\ X_1 + \alpha_2 Ln\ X_2 + \alpha_3 Ln\ X_3 + \alpha_4 Ln\ X_4 + \alpha_5 Ln\ X_5 + Ut \qquad (1)$$

At denotes the soybean acreage planted in the current year (year t) in thousand ha, X_1 is total planted area of soybean in the previous year (year t-1), X_2 is total area under the competing crop in the current year, X_3 is price ratio of soybean to competing crop(s) for the previous crop year, X_4 is yield ratio of soybean to competing crops for the previous year, X_5 is rainfall during the pre-sowing months in the current year.

The price and yield ratios of soybean to competing crops are better measures of relative profitability of soybean than the actual prices/yields of soybean. Hence, price and yield ratios are used as variables to relate soybean with other crops. In Madhya Pradesh, jowar and maize are major competing crops while in Maharashtra groundnut and cotton are important competing crops and in Rajasthan bajra competes with soybean for area allocation. In order to capture the impact of technological change, crop yield variable has been used as proxy for technical change. Since the farmer's decision about area allocation depends on the previous crop year experience, soybean and competing crop yield and price lagged by one year have been used in this study. It is expected that higher relative profitability through better yield and/or prices of soybean would have positive relationship with area planted under the crop. Rainfall has a prominent effect on crop area allocation to crops and has impact on yield and hence on crop output. For soybean, which is mostly grown under rainfed conditions, rainfall during pre-sowing month is an important determinant of crop choice. Therefore, rainfall during pre-sowing months has been included in the model. Multiple linear regression using ordinary least squares (OLS) technique has been used in order to estimate the acreage response functions.

In order to examine constraints in soybean production, detailed household data were collected from a sample of 490 soybean farmers (240 from Madhya Pradesh and 250 from Maharashtra, major soybean producers) consisting of 172 marginal (<1 ha), 117 small (1-2 ha), 162 medium (4-10 ha) and 39 large (>10ha) during 2011-12. Data obtained were analyzed using descriptive statistics.

RESULTS AND DISCUSSION

Trends in area, production and yield: The growth in area and production has been unparallel during the last four decades (Table 1). Area under soybean increased from 0.04 million ha in 1971-73 to 0.7 million ha in 1981-83 and further to 3.78 million ha in 1991-93. During the 1990s, area under soybean almost doubled and reached a level of about 6.3 million ha during TE2001-02. Soybean acreage increased at an annual compound growth rate of about 5.5% during the last decade and reached about 9.8 million ha during the TE2011-12. Soybean production, which was about 30 thousand tonnes during 1971-73 increased sharply to about half a million tonnes in 1981-83 and 3.5 million tonnes in 1991-93. Soybean production increased at an annual growth rate of 8.9% during the last decade and was 11.6 million tonnes in TE2011-12. Soybean productivity has also increased from 691 kg/ha in 1971-73 to 704 kg/ha in 1981-83 and 921 kg/ha in 1991-93. Productivity growth rate decelerated during the 1990s (from 2.6% in 1980s to 1.6% in 1990s) but average productivity increased from 921 kg/ha in TE1993-94 to 967 kg/ha during TE2001-02. However, yield picked up during the last decade and recorded a growth rate of 3.2%, the highest ever during the last four decades. It is clear from the above trends that soybean crop has witnessed a phenomenal growth in production in the country during the last four decades but growth has been primarily driven by area expansion. During the last two decades, area expansion drove about 80% of the increased production while yield contributed about 20% to the increase in soybean production.

Table 1 Average area (million ha), production (million tonnes), and yield (kg/ha) of soybean in India: 1971-72 to 2011-12

	1971-72 to 1973-74	1981-82 to 1983-84	1991-92 to 1993-94	1999-00 to 2001-02	2009-10 to 2011-12
Area	0.04	0.70	3.78	6.33	9.81
Production	0.03	0.48	3.54	6.11	11.64
Yield	691	704	921	967	1186
	Compound annual growth rate (%)				
	1970s	1980s	1990s	2000s	All Period
Area	43.4	17.8	8.1	5.5	14.7
Production	47.3	21.1	9.9	8.9	16.2
Yield	2.3	2.6	1.6	3.2	1.3
	Coefficient of Variation (%)				
Area	102.3	45.5	22.9	17.8	87.6
Production	93.1	61.5	30.1	28.4	98.1
Yield	23.4	17.9	12.6	15.3	22.0

Source: Authors calculations using GoI (2013)

Soybean cultivation like many other crops grown in the country faces several risks related to production and prices, which result in fluctuations in the income of soybean producers. Production risks can be observed from the deviations in area, yield and output, while price risks can be measured through instability of prices. During the period 1971-1972 to 2011-12, soybean acreage, production and yield witnessed significant variability as measured by coefficient of variation. The highest instability was observed in production (98.1%), followed by acreage (87.6%) and yield (22%). However, instability in area, production and yield has declined significantly during the last 2-3 decades. The coefficient of variation in area declined from 102.3 per cent in 1970s to 17.8% in 2000s and instability in yield declined from 23.4% to 15.3% between the two periods, leading to significant decline in fluctuations in soybean production (Table 1).

Soybean has played an important role in meeting edible oil demand in India and it constitutes about 30% of edible oil produced in the country. In addition, it has been a major foreign exchange earner due to export of soybean de-oil cake. The soybean oil cake exports have increased from about ₹ 2731 crores in 1996-97 to ₹ 14156 crores in 2012-13 (DGCI&S, 2013).

Shifts in area: The relative position of major soybean producing states in terms of acreage in different time periods is presented in Table 2. It is evident from Table 2 that Madhya Pradesh, Maharashtra and Rajasthan account for the bulk of area under soybean in the country, accounting for 57.4, 29.8 and 8.3% during the TE2011-12, respectively. The share of Madhya Pradesh in total area has declined from 80.4% during TE1993-94 to 70.5% during TE2001-02 and 57.4% during TE2011-12. In contrast, the share of Maharashtra has increased during the last two decades from about 10% in early-1990s to nearly 30% in TE2010-11. The share of Rajasthan increased during the 1980s and 1990s but declined during the last decade. The share of Uttar Pradesh showed a dramatic decline from 21.7% in the early-1970s to insignificant share (0.2%) in the recent period.

Table 2 Share of major states in area under soybean in India: TE1983-84 and TE2011-12

State	Share (%) in all-India acreage				Share (%) in edible oilseed acreage in state			
	TE1983-84	TE1993-94	TE2001-02	TE2011-12	TE1983-84	TE1993-94	TE2001-02	TE2011-12
Madhya Pradesh[1]	65.9	80.4	70.5	57.4	25.3	62.9	76.2	77.0
Maharashtra	-	10.1	18.0	29.8	-	14.8	44.5	78.4
Rajasthan	2.7	6.9	9.5	8.3	1.6	7.4	19.3	17.1
Uttar Pradesh[2]	21.7	0.8	0.3	0.2	5.8	1.7	1.4	2.0
Gujarat	1.3	0.5	0.1	0.7	0.4	0.7	0.2	2.4
Others	8.3	1.4	1.6	3.6	-	-	1.3	5.6
India	100.0	100.0	100.0	100.0	4.5	14.5	27.2	37.0

Source: GoI, various sources

[1]-TE2011-12 data includes data for both Madhya Pradesh and Chhattisgarh for comparison purpose

[2]-TE2011-12 data includes data for both Uttar Pradesh and Uttarakhand

The share of soybean in total cropped area has increased substantially from about 0.8% in mid-1980s to about 5% in TE2010-11. Looking at the importance of soybean vis-à-vis other oilseeds, soybean enjoys an important place in the edible oilseeds economy of the country, accounting for about 37% of area under edible oilseeds in TE2011-12. It is also interesting to note that the share of soybean in total area under edible oilseeds showed an increasing trend in the last three decades, from about 4.5% in 1980-83 to 27.2% in TE2001-02 and 37% in TE2010-12. Soybean is an important oilseed crop in Madhya Pradesh with a share of about 77% in total oilseeds acreage during 2009-11 but has remained almost constant during the last decade. Soybean has gained prominence in Maharashtra particularly during the last two decades and its share in total edible oilseeds acreage in the state has increased from 14.8% in 1980-83 to 78.4% in 2009-11. It has also gained importance in Rajasthan where the share has increased from 1.6% in the early-1980s to 19.3% in TE2001-02 but marginally declined to 17.1% in 2009-11.

Shifts in production: In terms of production, Madhya Pradesh, Maharashtra and Rajasthan are the largest producers accounting for about 96% of the production in 2009-11 (Table 2). The share of Madhya Pradesh has increased from 74.5% during TE1983-84 to 78% during TE1993-94 and then declined to about 65% during TE2001-02 and reached 56.3% in 2009-11. Maharashtra was the major gainer, as it improved its share from 11.5% in 1991-93 to 30% in 2009-11. The other notable gainer is Rajasthan, whose share increased from less than 2% in 1980-83 to 9.8% in 2009-11. Looking at the importance of soybean *vis-à-vis* other edible oilseeds, it is evident from the Table 3 that soybean has gained importance in the edible oilseeds economy and increased its share in total oilseeds production. The share of soybean in total edible oilseeds production has increased from 4.5% in 1980-83 to over 40% in 2009-11.

In Madhya Pradesh, the share of soybean in total oilseeds production in the state has more than doubled from 40.4% in 1980-83 to 82% in 2009-11. Soybean has gained momentum in Maharashtra and its share has increased significantly from 23.5% in 1990-93 to about 85% in 2009-11. Soybean production has also increased in Rajasthan and the share has improved from 1.3% in 1980-83 to over 20% in TE2011-12. Hence, the share of soybean in edible oilseeds acreage and production has witnessed a significant increase at the national level as well as in major states like Madhya Pradesh, Rajasthan and Maharashtra.

Yield trends: The world average soybean yield doubled from 1.16 metric t/ha in 1961-65 to 2.41 metric t/ha in 2005-12 (Fig. 1). Out of the top five soybean producing countries, USA, Brazil and India produce about 2.82 metric t/ha, 2.76 metric t/ha and 1.14 metric t/ha, respectively. Soybean yields are not merely low in India compared to that of other major soybean producing countries, but it also suffered a decline in yield during the 1990s in comparison with other countries. More than quadrupling of the area under soybean and a doubling of the yield since 1961 has increased world soybean production by about 9.5 times. During the same period, the main production area of soybean shifted to South America, especially Brazil and Argentina.

Fig. 2 presents data on yield levels in India as well as in individual states. Soybean yields, which were low (about 729 kg/ha on the average) during the early-1980s, increased (about 1026 kg/ha on the average) during the late-1990s, and then declined (about 975 kg/ha on the average) during the early-2000s but improved (1150 kg/ha) in the recent period. The state of Madhya Pradesh and Maharashtra followed almost the same pattern of trend in yields, whereas yield trends were found to be positive in Rajasthan. One of the interesting observations is that yield levels were lower for the largest soybean producing state, Madhya Pradesh, than in any other state and even all India level.

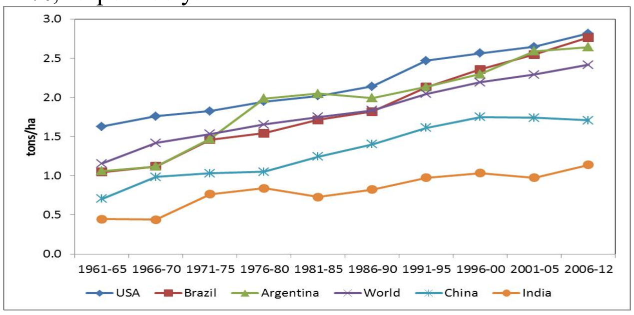
Table 3 Share of major states in soybean production in India: TE1983-84 and TE2011-12

State	Share (%) in all-India oilseed production				Share (%) in edible oilseed production in state			
	TE1983-84	TE1993-94	TE2001-02	TE2011-12	TE1983-84	TE1993-94	TE2001-02	TE2011-12
Madhya Pradesh	74.5	78.0	65.1	56.3	40.4	73.4	81.2	82.0
Maharashtra	-	11.5	23.3	30.0	-	23.5	61.1	85.0
Rajasthan	1.8	7.8	9.7	9.8	1.3	10.9	20.7	20.4
Uttar Pradesh	22.1	1.0	0.2	0.3	8.2	2.5	1.2	3.4
Gujarat	0.9	0.4	0.1	0.5	0.2	0.6	0.2	1.3
Others	0.8	1.3	1.6	3.1	-	-	1.5	3.7
India	100.0	100.0	100.0	100.0	4.5	17.6	30.6	40.1

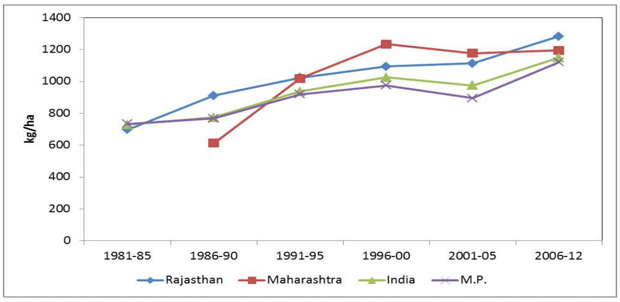
Source: GOI (2013)

Growth rates in area, production and yield: Growth rates of area, production, and yield of soybean in major producing states and at national level during different time periods were computed and the results are presented in Table 4. The compound annual growth rate for India in soybean production during the period 1981-2011 (31 years) was, 16.23%, and can be disaggregated into area (14.68%) and yield (1.27%). In the long term, of the 16.23 per cent annual growth in soybean production, the increase in yield accounted for less than 10% of the growth in production.

After 1990s, however, the contribution of yield growth to production growth has improved. The compound annual growth rates of soybean yield were 2.64% in the 1980s, 1.64% in the 1990s and 3.17% in 2000s. The soybean production growth rates during the above three periods (21.08%, 9.85%, and 8.88%) are mainly supported by the area growth rates (17.75%, 8.08%, and 5.53%). Out of the annual 9.85% and 8.87% production growth in the decades of the 1990s and 2000s, the yield contributed about 17% and 36%, respectively.



Source: FAOSTAT and authors' calculation
Fig. 1. Changes in soybean yield by major producing countries and world average: 1961-2011



Source: GoI (2013) and authors' calculation
Fig. 2. Changes in soybean yield by major producing states and all India average: 1981-2012

All the major soybean producing states, Madhya Pradesh, Maharashtra, and Rajasthan, witnessed an impressive growth rate in production. The growth rate of production was highest in Maharashtra (20.38%) followed by Rajasthan (16.64%) and the lowest in Madhya Pradesh (9.71%) between 1981-82 and 2011-12. This steep increase in production was the result of a significant expansion of area. Increase in crop productivity also contributed to increased production but the contribution was marginal. There were spectacular increases in the growth rates of area under soybean cultivation in Maharashtra (16.72%), Rajasthan (14.24%), and Madhya Pradesh (7.95%). The growth rate in Gujarat was also considerable but the state's share in national production was negligible. Area seems to be the most important source of soybean output expansion while yield being of less importance. In Gujarat, the growth rate in yield was the lowest (1.52%). Maharashtra and Rajasthan reported higher growth rates in yield compared with national average. The lower growth in yield may be because of more marginal lands being brought under soybean cultivation, less area under assured irrigation and lack of appropriate technological breakthroughs in soybean production in the country.

Factors influencing soybean acreage: The results of the regression model for soybean acreage for major producing states; Madhya Pradesh, Maharashtra and Rajasthan are presented in Table 5. The value of R^2 is given for each regression equation and Durbin-Watson d statistics for testing serial correlation in the residuals was also computed for each equation. The model gave a good fit in all states, where the value of R^2 was high, ranging from 0.88 in Rajasthan to 0.99 in Maharashtra.

Table 4 Annual growth rates of soybean area, production, and yield in selected states, 1981-82 to 2011-12

Period	Madhya Pradesh	Maharashtra*	Gujarat	Rajasthan	All India
			Area		
1980s	20.7***	-	7.1	38.6***	17.9***
1990s	6.2***	17.1***	-15.5***	13.3***	8.1***
2000s	3.4***	10.4***	25.3***	5.1**	5.5***
All	8.0***	16.7***	6.1***	14.2***	9.4***
			Production		
1980s	23.7***	-	17.4**	46.9***	21.0***
1990s	7.2***	22.2***	-13.5***	13.6***	9.9***
2000s	7.8***	10.0***	26.0***	9.9**	8.9***
All	9.7***	20.4***	7.8***	16.6***	11.3***
			Yield		
1980s	2.5	-	9.6**	6.0**	2.6
1990s	1.0	4.4	2.4**	0.3	1.6
2000s	4.4**	-0.4	0.6	4.5*	3.2**
All	1.6***	3.1***	1.5**	2.1***	1.8***

*For Maharashtra, analysis is based on data from 1986-87 to 2011-12; ***, **, * Significant at 1%, 5% and 10%, respectively; Source: Authors' computation using MoA data

Table 5 Regression coefficients (with standard errors in parentheses) and R^2 values for soybean acreage in selected states

Variable	Madhya Pradesh	Maharashtra	Rajasthan
Constant	3.4009 (4.4676)	3.3271 (3.4717)	-3.7991 (2.6302)
Soybean area for previous year	0.5987*** (0.1404)	0.9311*** (0.0767)	0.8412*** (0.0855)
Area ('000 ha) under competing crop			
Jowar	-0.1303 (0.1170)		
Bajra			0.5743 (0.2964)
Maize	01285 (0.6810)		
Groundnut		-0.2449 (0.2709)	
Cotton		-0.1157 (0.2423)	
Yield ratio of soybean (for previous year) to			
Jowar	-0.0563 (0.1330)		
Bajra			-0.0364 (0.1176)
Maize	0.1186*** (0.0613)		
Groundnut		-0.0270 (0.1611)	
Cotton		0.0829 (0.1270)	
Price ratio of soybean (for previous year) to			
Jowar	-0.6078 (1.6537)		
Bajra			-0.1060 (0.0940)
Maize	0.5819 (1.5534)		
Groundnut		-0.5329 (0.5650)	
Cotton		0.5380 (0.5855)	
Rainfall	0.0108* (0.0283)	00052 (0.0346)	0.0338*** (0.0156)
R^2	0.9563	0.9903	0.8858

***, **, * Significant at 1%, 5% and 10%, respectively

We find that current crop acreage is positively related to the acreages in previous years, providing evidence that unobservable factors lead to slow transition in land use. The coefficients of the estimated lagged area variable are significant at the 1% level. The adjustment coefficient for area is very small (0.0689) for Maharashtra, which indicates that farmers adjust slowly toward the desired acreage. While in case of Madhya Pradesh, adjustment coefficient is relatively higher (0.4013) indicating that farmers in Madhya Pradesh adjust faster toward the desired acreage. The coefficient of the rainfall is positive and significant at the 10% level in case of Madhya Pradesh, indicating that rainfall during pre-sowing months is an important determinant of area allocation. Yield ratio of soybeans to competing crop (maize) has a significant and positive impact on current acreage, whereas area under competing crop (jowar) has a negative impact on soybean acreage. In case of Maharashtra, area under competing crops has a negative impact on current acreage while yield and price ratio of soybean to main competing crop (cotton) has a positive impact on soybean acreage in the state. Rainfall during pre-sowing months has a significant impact on soybean acreage in Rajasthan.

It is evident that current crop acreage is positively related to the acreages in previous years, while area under competing crops is negatively related to soybean acreage. Better yield and prices of soybean compared to competing crops have positive impact on crop acreage. Rainfall seems to have a dominant impact on acreage in all the states as soybean is mostly cultivated as rainfed crop.

Problems and prospects of soybean cultivation: Future increases in soybean production will be based on yield improvement because little productive land is available for expansion in crop area. However, farmers face a series of constraints which affect soybean productivity. Moreover farmers are not able to achieve potential yield because of poor crop management practices, non-availability of quality inputs, etc. Therefore, a yield gap analysis, which evaluates magnitude of the difference between crop yield potential and actual farm yields, provides a measure of production capacity for the country. Based on the data provided by Directorate of Soybean Research, Indore, the yield gaps between potential and achievable yields, between achievable and farmers' yields and total yield gaps between potential and farm level yields were estimated. This section also discusses problems and prospects of soybean cultivation using primary data from soybean farmers in two major producing states, namely, Madhya Pradesh (Chhindwara, Narsingpur, and Khandwa districts) and Maharashtra (Amravati and Kolhapur districts) collected during 2011-12.

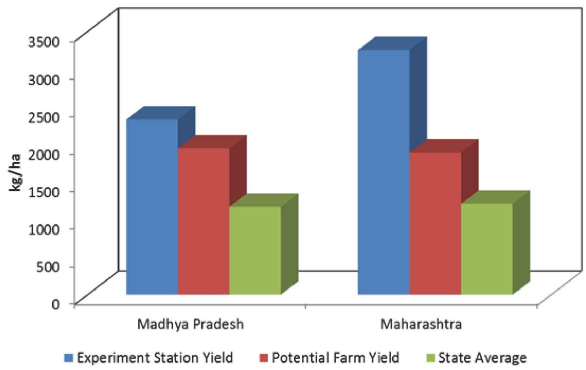
Yield gap analysis: Among the major soybean producing states, both Madhya Pradesh and Maharashtra, which account for more than 85% of total soybean area and production in the country, the average potential yield was 2331 and 3255 kg/ha, respectively during the TE2011-12. The magnitude of yield gaps in soybean in Madhya Pradesh and Maharashtra are presented in Fig. 3. The average yield gap between potential and farm level yield under improved technology was 384 and 1363 kg/ha in Madhya Pradesh and Maharashtra, respectively. The average yield gap between improved technology and under farmers' practices was 576 and 398 kg/ha in Madhya Pradesh and Maharashtra, respectively. The average yield gap between potential and actual farm level yields was quite large (960 kg/ha in Madhya Pradesh and 761 kg/ha in Maharashtra). There is also a wide gap even between actual farm level yields obtained under the Front Line Demonstrations (FLDs) and the state average (203 kg/ha in Madhya Pradesh and 285 kg/ha in Maharashtra).

Although yield gap between experimental/potential and farm level yields is difficult to bridge because of environmental differences between on-farm and research station situations, and technical expertise available at experimental stations. On the other hand, gap between FLD improved technology and farm level yields can be managed as it is due to the differences in the management practices and input use.

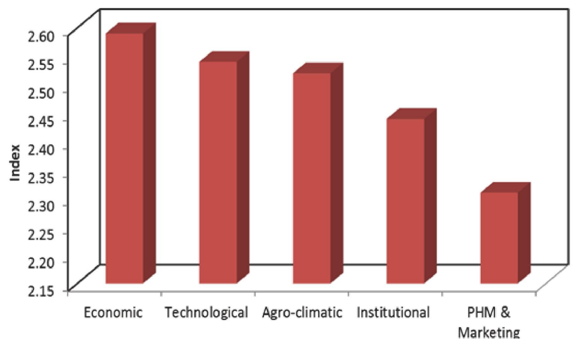
The high variation in yield gap among states indicates the varying levels of adoption of technology and improved package of practices among soybean farmers in these states. The extent of yield gaps particularly that of under improved technology and farmers' practices shows that there is considerable scope to improve the productivity levels in India provided the factors responsible for these yield gaps are understood and appropriate interventions are made to abridge these gaps.

The above trends clearly show that there exist huge yield gaps in case of soybean in the country. Therefore, there is a need to understand reasons for extent of yield gaps and variations among different states/regions and to suggest appropriate strategies in order to narrow down such large gaps. This will help in increasing production of soybean in the country. The following section examines major constraints faced by soybean producers.

Constraints in soybean cultivation: As soybean production has increased significantly over the past three decades, so has the intensity of biotic and abiotic constraints that ultimately threaten crop yield and farm income. In order to identify major constraints faced by the farmers in soybean cultivation, farmers were asked to identify main constraints to increasing soybean production and productivity. The constraints were broadly categorized into five major categories *viz.,* technological, agro-climatic, economic, institutional and post-harvest management and marketing related issues. Fig. 4 shows the constraints experienced by soybean farmers. Economic constraints (2.59) were the most important constraints faced by soybean producers, followed by technological constraints (2.54), agro-climatic factors (2.52), institutional (2.44) and post-harvest management and marketing (2.31) related problems. High risk in soybean cultivation compared with other crops, relatively less profitability, high input costs, low and fluctuating crop prices and shortage of human labour were major economic constraints. Among technological constraints, incidence of insect pests, weed infestation, non-availability of suitable varieties, and poor crop germination were major constraints faced by farmers in the study area. The important agro-climatic constraints experienced by farmers were risk of crop failure/yield variability due to biotic and abiotic stresses, poor grain setting, drought, excessive rains and extreme temperature variations at critical stages of crop growth. Poor extension services leading to lack of knowledge about insect pest and disease management, non-availability of quality inputs and services including institutional credit were important institutional constraints being faced by soybean farmers. Rural infrastructure particularly poor road conditions leading to high transportation costs, lack of storage facilities, lack of reliable and timely information about prices and adequate processing facilities were impacting soybean cultivation in the area. Among all constraints, incidence of insect pests and high price and production risks were ranked as the most severe constraints in production of soybean.



Source: ICAR (2013)
Fig. 3. Potential yield and front line demonstration on-farm average yields of soybean in Madhya Pradesh and Maharashtra: 2009-10 to 2011-12



Source: Field Survey
Fig. 4. Constraints faced by farmers in cultivation of soybean

Farmers were asked to give suggestions to address the constraints they faced in soybean cultivation. About 84 per cent of respondents in Madhya Pradesh advocated for timely availability of better quality high yielding seed and other inputs, more regulated markets or purchase centers for sale of produce and appropriate farm machinery and implements for soybean cultivation to cope with labour shortage and timely completion of farm operations, while 75 suggested proper storage facility at village level. More than half of the respondents demanded better crop insurance cover and other price risk management instruments including futures trading. In Maharashtra, farmers suggested improvement in irrigation facilities and subsidies on inputs to improve crop productivity and profitability. Other suggestions included higher minimum support price, technical assistance for soybean cultivation and timely availability of inputs.

Impact of reduction in yield gap on soybean production: While efforts should be made to improve crop yields, there is a more urgent need to address the problem of yield gaps. The yield gap reduction can not only increase yield and bring additional production, but also improve the input use efficiency, reduce production costs, and increase food security. Yield gaps have two components, first component (research gap) is mainly due to factors that are generally not transferable such as environmental factors and some in-built component of technologies available at research stations, therefore cannot be bridged. The second component of yield gaps (extension gap) is mainly due to differences in management practices such as suboptimal use of inputs and cultural practices. This yield gap is manageable and can be reduced through government intervention, particularly strengthening of institutional factors like better extension services, timely availability of inputs and services.

The results of yield gap analysis presented in Table 6 show that soybean production can be increased from 11.64 million tonnes to about 18.6 million tonnes in TE2011-12 by bridging the gap between improved technology at farmers' field and actual farm yield in the country through improving extension services. If extension gap can be bridged by 25%, soybean production will increase from about 6.45 million tonnes to 7.53 million tonnes, Maharashtra from about 3.5 million tonnes to over 4 million tonnes, Rajasthan from 1.14 million tonnes to 12.1 million tonnes and all-India production by about 15% (from 11.64 million tonnes to 13.4 million tonnes). Soybean production would increase by about 30%, from 11.64 million tonnes to 15.14 million tonnes, if extension gap be reduced by about 50%.

Table 6 Likely Impacts of reduction in yield gap on soybean production
('000 tonnes)

State	Actual Production TE2011-12	Estimated Production, if extension gap is reduced by		
		25%	50%	100%
Madhya Pradesh	6452	7531	8607	10759
Maharashtra	3494	4028	4526	5523
Rajasthan	1139	1209	1285	1437
Others	553	637	719	884
India	11638	13405	15138	18605

ACKNOWLEDGEMENTS

The author wishes to thank Mr. Harsh Wardhan for providing excellent research assistance, Agro-Economic Research Centre, Jablapur and Pune for collecting household data and Dr. S. K. Srivastava, Director and Dr. V.S. Bhatia, Principal Scientist, Directorate of Soybean Research, Indore for providing data and insights about Indian soybean economy.

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Household demand and supply projections of major edible oils in Tamil Nadu State, India

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(Received: February, 2015; Revised: May, 2015; Accepted: June, 2015)

ABSTRACT

This paper analysed the household demand, projected the supply and assessed the domestic demand-supply gap of edible oils consumed in Tamil Nadu State, India. The primary data were collected from randomly selected 1000 sample households at Tamil Nadu collected during the year 2009-10. The growth rate, AIDS model and supply projection techniques were employed to derive appropriate conclusions. The area under groundnut and sesame crop was found declining over years in Tamil Nadu. The sunflower area was also declining, but, the yield showed increasing trend implying the production growth mainly driven by yield. Unlike other oilseed crops, the coconut production was driven by area rather than productivity. The results of demand estimation revealed that about 66% increase in demand is expected by 2020 for groundnut oil whereas the demand for sesame, coconut and other edible oils would increase by 67%, 66% and 78%, respectively in Tamil Nadu. Among all major edible oils, sunflower oil's demand was the highest followed by groundnut, palm, sesame and coconut oil. It is projected that there will be leapfrog jump in sunflower oil demand in the coming years, mainly due to increased awareness about low-saturated fat content in this oil. The total edible oil demand would increase from 6.38 lakh tonnes to 10.75 lakh tonnes by 2020. The results from this study also revealed that, the groundnut oil and sesame oil supply available from the state sources would decline and widen the production-household demand gap. Hence, urgent policy measures have to be initiated to increase the current level of production in these crops.

Keywords: Edible oils, Growth rate, Household demand, Supply projection, Tamil Nadu

The major edible oilseed crops grown in Tamil Nadu state are groundnut, sesame and sunflower. The total area under all oilseed crops in the state is 0.659 million ha with total production of 1.15 million tonnes (Damodaram and Hegde, 2007). The groundnut crop is grown in 0.53 million ha followed by sesame (0.07 million ha) and sunflower (0.04 million ha). Groundnut crop production was 1.05 million tonnes followed by sunflower (0.07 million tonnes) and sesame (0.03 million tonnes). The gross value of output from all oilseeds was ₹3891.11 crores during the year 2007-08.

The dynamics of edible oil production and consumption in Tamil Nadu is changing in recent years due to several crop production, socio-economic and policy related factors. The *kharif* area under oilseed crops especially, crops that are solely rain dependant have come down drastically due to less rain as well as due to variability in distribution. The majority of the oilseeds are grown by small and marginal farmers under minimal input conditions resulting in low production. The policy towards oilseeds is also not encouraging *vis-à-vis* other competing crops resulting in declining area and thereby production. Besides production changes, the consumption of edible is also changing in recent years. It is evident that there is a rise in consumption of edible oils and also the shift towards healthier and relatively newer oils in the recent past.

The demand structure and supply prospects are very vital for developing appropriate policies. It helps the policy makers to implement suitable crop production policy, support policy (price or income), subsidy policy, trade policy etc., that direct in increasing the domestic production of crops. The above facts amply highlight the importance of household demand and supply gap study. Hence, this work was carried out to understand the trend of major edible oilseeds production, the household demand for major edible oils, supply prospects for important edible oils and suggest appropriate policy measures for meeting the demand domestically. There are several empirical studies that projected the demand for food commodities for India as a whole, whereas, very few attempts have been made at the disaggregated level (state). The majority of the macro level studies in India concentrated on the demand-supply gap of oils as-a-group and not for individual oils. Hence, this study on household demand-supply gap of major edible oils was undertaken for Tamil Nadu state. In this background, the study was taken up with the objectives to analyse the demand for different edible oils in Tamil Nadu State, and to assess the demand-supply gap to propose suitable policy options.

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MATERIALS AND METHODS

The primary survey was carried during the year 2009-10, to collect complete information on different edible oils consumed by the households like sunflower, sesame, palm oil, etc., besides traditional oils. Though National Sample Survey Organization (NSSO) dataset covers large sample and available readily, owing to its serious shortcomings, it is not used in this study. Stratified multistage random sampling procedure was followed to collect the edible oil household consumption data. In the first stage, Tamil Nadu was categorized into five zones *viz*., North, South, West, East/Coastal and Central zones. From each zone, one district was randomly selected. Accordingly, Vellore district in the north, Coimbatore district in the west, Tiruchirappalli district in central zone, Nagapattinam district in the east/coastal zone and Kanyakumari district in south zone were selected for the study. In the second stage, one taluk from each of the selected districts and one block from each selected taluk were selected randomly. In the third stage, from each of the selected blocks, a cluster of three villages were selected. The household samples from the selected district headquarters were considered as urban samples and the household samples from the selected cluster of villages constituted the rural sample. In the final stage, rural and urban households were randomly selected and interviewed using the pre-tested questionnaire developed for the purpose. A sample of 100 in each zone for both urban and rural households was selected thus constituting 1000 sample households in the study.

The analytical tools used in this study are briefly mentioned below:

Growth of area, production and productivity of major edible oilseeds: The growth in area, production and yield of different edible oilseeds in Tamil Nadu was analysed by employing an exponential growth model. The exponential model is given by:

$$Y_t = ab^t e^u$$

Where;

- Y_t = Dependent variable for which growth rate is to be estimated (area / yield / production)
- a = Intercept
- b = Regression coefficient
- t = Time variable
- u = Disturbance term
- e = Naperian base

The model was transformed to log linear form and estimated using regression technique. From the regression coefficients, the growth rate is estimated as follows

Growth rate (G) = [antilog (b)-1] x 100

Demand model: The Almost Ideal Demand System (AIDS) model in linearized form was chosen to estimate the demand for different types of edible oils. This model is preferred due to the following reasons. First, the system is linear in parameters and simple to estimate. Second, the functional form is general and flexible (Deaton and Muellbauer, 1980). Third, the model is most satisfactory in terms of being able to test the restrictions of adding up, homogeneity and symmetry through linear restrictions on fixed parameters. Further, it can also be employed to estimate with cross-section and time series data (Green and Julian, 1990; Chen and Veeman, 1991; Buse, 1994) and also testing the predictions of the consumer demand theory.

The Almost Ideal Demand System (AIDS) formulated in terms of budget share is given by:

$$Wi = \alpha i + \sum_{i=1}^{n} \gamma ij\ (Pj) + \beta\ iF\ Xi + \Sigma_i\ d_i\ Z_i + e_i\ IMR_i + g\ i\ Ni \qquad \text{Eq.(1)}$$

Where Wi (dependent variable) is the expenditure share of the i^{th} commodity (selected edible oil), P_j is the independent variable of the equation i.e., the price of each good j (price vector of all edible oils), F X_i is the per capita food expenditure vector of the individual household, Z_i is the household variable vectors *viz.,* household size, education of the decision maker, IMR is the Inverse Mills Ratio for the specific edible oil type 'i' and N_i is the dummies for different zones within Tamil Nadu. The adding up, homogeneity and symmetry restrictions were imposed on the demand systems. The homogeneity and symmetry restrictions were imposed at the simple mean. Adding up restrictions was imposed while composing the parameters of the last equation of the model which was not included in the estimation. The expenditure elasticities were derived by

Expenditure elasticity: $n_i = 1 + [\beta_i/w_i]$ Eq.(2)

Demand projection: The demand projections for different edible oils for rural and urban Tamil Nadu are obtained by using the following formula (Kumar, 1998).

$D_{it} = di_0 \ {}^*N_{it}\ (1+y \times n_i)^t$ Eq.(3)

Where, D_{it} is the demand for an edible oil for the group 'i' (rural/urban) in 't' period; d_{i0} is *per capita* consumption per month for 'i' group in the base year; N_{it} is population in 't' year belonging to 'i' group; y is growth in per capita income and n_i is the expenditure (income) elasticities for rural/urban population.

Supply projections: In order to the study the prospects of major oilseeds production in Tamil Nadu, the area and productivity growth rates were calculated for the preceding ten years, i.e., from 1997 to 2008 and that growth was assumed for the future productions. The production projections were arrived by multiplying the projected area and productivity for the succeeding twelve years from 2008 to 2020. The crops considered for studying the prospects of production were groundnut, sesame, sunflower and coconut since these form the major oilseed crops in Tamil Nadu. The palm oil was not considered in supply model since production was very minimal. The data on production of other edible oils like rice bran, corn, soybean etc., in Tamil Nadu was not available and hence the projection of these oils was not attempted in this study.

Only a certain percentage of the total production is available for oil extraction/crushing. In groundnut crop, only 50% of the kernel produced is available for crushing, whereas, in sesame, sunflower, and coconut only 65%, 99% and 30%, respectively (Singh 1998) are available for crushing. Accordingly, from the projected production figures, the amount used for sowing, direct consumption, exports etc., were subtracted to arrive at marketable surplus of kernels available for oil extraction/crushing. The percentage analysis was employed to estimate the edible oil supply of major oil seed crops. After estimating the oil supply for different crops, they were compared with the estimated demand to deduce the oil demand and production gap for Tamil Nadu state.

RESULTS AND DISCUSSION

Area, production and productivity growth: The growth performance of major edible oilseeds were evaluated for different periods *viz.,* period I (1980-1990), period II (1990-2000), period III (2000-08) and for the entire period (1980-2008). The results are presented in Table 1.

Table 1 Growth in area, production and productivity of major edible oilseeds in Tamil Nadu in different periods (per cent)

Period	Area	Production	Productivity
		i) Groundnut	
1980-90	2.65	5.55	2.83
1991-01	-3.27	-0.23	3.14
2001-08	-2.97	-1.81	1.20
1980-08	-1.99	0.45	2.49
		ii) Sesame	
1980-90	4.72	4.78	0.05
1991-01	-4.75	-0.27	4.70
2001-08	-5.54	-9.32	-4.00
1980-08	-1.67	-0.09	1.60
		iii) Sunflower	
1991-00	-8.33	-1.90	7.02
2001-08	31.24	36.63	4.11
1991-08	-3.55	1.30	5.03
		iv) Coconut	
1980-90	5.22	4.67	-0.53
1991-01	6.83	3.71	-2.92
2001-08	2.25	9.24	6.84
1980-08	4.99	4.86	-0.12

Note: For sunflower crop, the growth for the period 1980-90 was not calculated due to non-availability of data

Groundnut: Groundnut area registered a positive growth of 2.65% per annum during the period I, whereas negative growth of -3.27, and -2.97% per annum during period II and period III, respectively. For the entire period, the negative growth rate of area (-1.99%) was observed. The yield growth rate was positive in all the periods but highest growth of 3.14% was registered during the period II and this might be due to better implementation of Technology Mission on Oilseeds and Pulses (TMOP) programme during this period. The production growth was positive (5.55%) during the period I, whereas, negative growth of -0.23% and -1.81% was registered during the period II and period III, respectively. From the growth results, it can concluded that, the production of groundnut crop was mainly driven by productivity growth rather area growth. The area fall in groundnut crop might be due to failure of *kharif* monsoon in recent years or might be due to profitability of other competing crops. Since the area is declining, the production level may fall in future, if some urgent policy measures are not initiated.

Sesame: The growth rate of area under sesame was 4.72% per annum during the period I, whereas negative growth rate was observed during the period II (-4.75%), period III (-5.54%) and for the entire period (-1.67%). The production registered a positive growth of 4.78% per annum during the period I, whereas negative growth of -0.27 and -9.32% during period II and period III, respectively. For the entire period, no significant growth in area was observed. The yield growth was positive in the period I and II and whereas, negative during the period III. The highest yield growth of 4.7% was observed during the period II. The productivity growth of 1.6% was exhibited during the entire period. We can conclude that, the stagnant growth in production of sesame crop was mainly due to negative growth in area, though the productivity exhibits some positive growth.

Sunflower: The cultivation of sunflower was meagre before 1990 and the data for this crop was not available for the period-I, i.e. 1980-1990. Hence, the growth was calculated only for period II, period III and for the entire period. The growth rate of area under sunflower was -8.33% during the period II, whereas leapfrog jump in growth (31.2%) was observed during period III and this might be due increase in demand for sunflower oil in recent years i.e. demand driven growth. During this period, the area has increased from a mere 6610 hectares to 44100 while the production recorded steep growth from 8348 tonnes to 70074 tonnes. The productivity growth was 7.02% and 4.11% during the periods II and III, respectively. An overall 5.03% growth was observed during the entire period. The production growth was -1.90% during the period II, where as positive during the period III. The production growth of 36.6% in period II was mainly due to area growth and to a less extent due to productivity growth.

Coconut: The growth rate of area under coconut was 5.22% for period I, 6.83% during period II, 2.25% during period III and 4.99% for the overall period. The productivity growth was -0.53% during the period I, -2.92% during period II and 6.84% during the period III. The productivity growth of -0.12% per annum was observed during the entire period. The production growth was 4.67% during period I, 3.71% during period II, 9.24% during period III and 4.86% for the entire period. It can be inferred from growth results that the production growth in coconut crop was driven by the area growth rather than productivity growth.

Income elasticity of demand for rural and urban Tamil Nadu: Income elasticities for rural and urban regions were estimated for groundnut oil, sunflower oil, sesame oil, coconut oil, palm oil, and other oils group which is composed of rice bran, corn oil, etc. (Table 2). The income elasticities imply the responsiveness of demand for the change in real income. The estimated income elasticities are positive and less than one for all edible oils in rural Tamil Nadu except for sunflower oil (1.259) and groundnut oil (1.058). This indicated that in rural areas sunflower oil/groundnut oil are consumed by the higher income group. The well-educated households in rural areas also consume sunflower oil due to awareness about the low-saturated fat content in this oil. Though groundnut oil was the traditional oil consumed in rural areas, off-late due to high price, people are shifting from groundnut to other oils and hence its consumption has become a luxury (income elasticity was more than one) especially for the low income households.

The estimated income elasticities for urban Tamil Nadu were less than one for all oils except sunflower oil (1.131). This indicates that sunflower oil is consumed more when income rises and it is consumed more by higher income group. The income elasticity for groundnut oil was higher in rural compared to urban households and this might be due to more preference for groundnut oil in rural areas by high income households whereas, their counterparts in urban areas prefer other oils (sunflower oil, sesame oil, rice bran oil, corn oil etc.) instead of groundnut oil. The income elasticity for sunflower oil was higher in rural areas *vis-a-vis* urban counter parts implying more incremental demand for sunflower oil in rural compared to urban areas for the unit change in income. The income elasticity of sesame oil and coconut oil was more or less same in rural and urban areas implying that these oils are preferred by habit and not much due to variation in income or region (rural/urban). The income elasticity for palm oil in rural areas was higher than the urban counter parts, it might be due to low income and lack of awareness about the high-saturated fat in this oil. The income elasticities estimated in the present study was found to be very close to the estimates of the earlier study done at aggregate level (edible oils) for Tamil Nadu households (Srinivasan, 2005). However, the elasticities at disaggregate level, i.e., for selected edible oils could not be compared as there was hardly any study available which attempted such work pertaining to Tamil Nadu State.

Table 2 Income elasticity of demand for different edible oils in rural and urban Tamil Nadu

Oil type	Income elasticity in Rural Tamil Nadu	Income elasticity in Urban Tamil Nadu
Groundnut oil	1.058	0.774
Sunflower oil	1.259	1.131
Sesame oil	0.965	0.963
Coconut oil	0.892	0.931
Palm oil	0.512	0.338
Other oils	0.186	0.176

Demand projections: The demand projections were made for groundnut oil, sunflower oil, sesame oil, coconut oil, palm oil and other edible oils group. The demand for these oils were projected using the income elasticities estimated, projected population in rural and urban areas, per capita oil consumption and income growth. The edible oil demand was projected for period up to 2020 based on *per capita* consumption during the base year (2009-10). The results revealed that the groundnut oil demand in Tamil Nadu state would increase from 1.18 to1.96 lakh tonnes in a decade (Table 3). Around 66% increase in demand for groundnut oil is expected by 2020. Similarly, the sesame, coconut and other oils demand would increase by 67%, 66% and 78%, respectively by 2020. Among all the oils, sunflower oil demand was the highest followed by groundnut oil, palm oil, sesame oil, other oils and coconut oil. There will be leapfrog jump in sunflower oil demand in the coming years mainly due to increased awareness about low-saturated fat content in this oil as well as due to surge in income growth. The least increment in demand would be for palm oil (31%) since this oil is substituted when income increases. The total edible oil demand would increase from 6.38 lakh tonnes to 10.75 lakh tonnes by 2020. About 69% hike in edible demand over the level of 2009-10 is expected by 2020. Hence, appropriate policy measures have to be implemented for increasing the domestic production so as to meet the ever increasing edible oil demand.

Supply prospects: The crops considered for studying the prospects of edible oilseed production were groundnut, sesame, sunflower and coconut, since these form the major oilseed cops in Tamil Nadu. The production of groundnut would decline in the coming years from 10 lakh tonnes during 2009-10 to the level of meagre 6.7 lakh tonnes during the 2019-20. In consonance with the production fall, the oil supply may also fall to 0.941 lakh tonnes from the current levels of 1.409 lakh tonnes (Table 4). It implies that the groundnut oil supply available from the state sources will decline drastically if the present limiting factors are not addressed. Hence, it warrants urgent measures to increase the production of groundnut to meet the growing oil demand. Similar to groundnut, the production of sesame may also fall from the current production of 0.249 lakh tonnes to 0.099 lakh tonnes by 2020 (Table 5). In consonance with the production fall, the oil supply may also reduce from 0.073 lakh tonnes during 2009-10 to 0.029 lakh tonnes during 2020, implying, the sesame oil available from state sources will fall drastically in future. Contrary to groundnut and sesame production trend, the production of sunflower would increase to 1.583 lakh tonnes during 2020 from the present production level of 0.755 lakh tonnes (Table 6). The oil supply would also increase from the present level of 0.261 lakh tonnes to 0.549 lakh tonnes during 2020. However, the question remains whether the increase in production will meet ever growing sunflower demand domestically. Similar to sunflower, the coconut production and its oil supply from State sources would increase in the future (Table 7).

Table 3 Demand estimates for different edible oils in Tamil Nadu

Type of oil/Year	Groundnut oil	Sesame oil	Sunflower oil	Coconut oil	Palm oil	Other oils	Total edible oils
2014	1.45	1.06	3.04	0.43	1.31	0.58	7.87
2015	1.53	1.12	3.24	0.46	1.34	0.61	8.30
2016	1.61	1.18	3.45	0.48	1.38	0.65	8.75
2017	1.69	1.24	3.67	0.50	1.42	0.69	9.21
2018	1.78	1.3	3.91	0.53	1.46	0.73	9.71
2019	1.87	1.37	4.16	0.55	1.50	0.77	10.22
2020	1.96	1.44	4.42	0.58	1.53	0.82	10.75
% increase in 2020 over base year	66.1	67.4	87.3	65.7	30.8	78.3	68.5

Table 4 Projection of groundnut production and oil supply in Tamil Nadu (lakh tonnes)

Years	Projected production in shell*	Projected kernel availability	Marketable surplus for crushing	Expected oil supply
2009-10	10.061	7.043	3.521	1.409
2010-11	9.663	6.764	3.382	1.353
2011-12	9.281	6.497	3.248	1.299
2012-13	8.914	6.240	3.120	1.248
2013-14	8.561	5.993	2.996	1.199
2014-15	8.222	5.756	2.878	1.151
2015-16	7.897	5.528	2.764	1.106
2016-17	7.584	5.309	2.655	1.062
2017-18	7.284	5.099	2.550	1.020
2018-19	6.996	4.897	2.449	0.979
2019-20	6.719	4.703	2.352	0.941

*Projected based on previous ten years area and yield trend (1997-2008); 50% of kernel production is available for crushing (www.seaofindia.com); Shell to kernel conversion is 70% and oil recovery is 40%

Table 5 Projection of supply of sesame seed and its oil in Tamil Nadu (lakh tonnes)

Years	Projected production of sesame seed*	Marketable surplus for crushing	Expected oil supply
2014-15	0.157	0.102	0.046
2015-16	0.143	0.093	0.042
2016-17	0.130	0.085	0.038
2017-18	0.119	0.077	0.035
2018-19	0.108	0.070	0.032
2019-20	0.099	0.064	0.029

*Projected based on previous ten years area and yield trend (1997-2008); 65% of the production is available for crushing (www.seaofindia.com) and oil recovery is 45%

Table 6 Projection of supply of sunflower seed and its oil in Tamil Nadu (lakh tonnes)

Years	Projected production of sunflower seed*	Marketable surplus for crushing	Expected oil supply
2009-10	0.755	0.747	0.261
2010-11	0.813	0.805	0.282
2011-12	0.875	0.866	0.303
2012-13	0.943	0.934	0.327
2013-14	1.015	1.005	0.352
2014-15	1.093	1.082	0.379
2015-16	1.177	1.165	0.408
2016-17	1.268	1.255	0.439
2017-18	1.365	1.351	0.473
2018-19	1.470	1.455	0.509
2019-20	1.583	1.567	0.549

Note: *Projected based on previous ten years area and yield trend (1997-2008); 99% of the produce is available for crushing and oil recovery is 35%

Table 7 Projection of supply of coconuts and its oil in Tamil Nadu

Years	Projected production ('000 nuts)*	Projected nuts available for crushing ('000 nuts)	Projected copra availability (tonnes)	Projected oil availability (lakh tonnes)
2014-15	5732589	1719777	253917	1.650
2015-16	5870964	1761289	260046	1.690
2016-17	6012680	1803804	266323	1.731
2017-18	6157816	1847345	272751	1.773
2018-19	6306455	1891937	279335	1.816
2019-20	6458682	1937605	286078	1.860

Note: *Projected based on previous ten years area and yield trend (1997-2008); At all India level 30% of the nuts produced is available for crushing and the same was assumed for Tamil Nadu (Singh, 1998); One tonne of copra= 6773 nuts and oil recovery is 65% (www.seaofindia.com)

Household demand-production gap: The household demand and production gap revealed that the demand for groundnut oil would increase from 1.18 lakh tonnes during 2009-10 to 1.96 lakh tonnes during 2020 whereas, the groundnut oil supply from domestic sources would decrease from 1.41 lakh tonnes to 0.94 lakh tonnes if same area and yield trend in past decade prevails in future (Table 8). The gap in household demand for groundnut oil and edible oil production in Tamil Nadu is expected to widen since 2012 onwards. Hence, it warrants immediate policy measure to step up the current groundnut production levels. Similar to groundnut, the sesame and sunflower production and household oil demand gap is expected to widen over the years. The household sunflower oil demand may increase to 4.42 lakh tonne from 2.36 lakh tonnes during 2009-10. The deficit increases over the years and reaches peak deficit of 3.87 lakh tonnes by 2020. The household demand and supply gap of sunflower oil will be very high compared to all other oils since households are shifting to sunflower oil consumption as income and awareness increases. Contrary to trend observed in groundnut oil, sesame oil and sunflower oil, the coconut oil production and demand gap is widening and it is expected to continue beyond 2020 unless suitable intervention is made to stem the gap.

Table 8. Projection of demand, production and gap for major edible oils in Tamil Nadu (lakh tonnes)

Year	Groundnut oil			Sesame oil			Sunflower oil			Coconut oil		
	Yd	Yp	Gap	Yd	Yp	Gap	Yd	Yp	Gap	Yd	Yp	Gap
2014	1.45	1.20	-0.25	1.06	0.05	-1.01	3.04	0.35	-2.69	0.43	1.61	1.18
2015	1.53	1.15	-0.38	1.12	0.05	-1.07	3.24	0.38	-2.86	0.46	1.65	1.19
2016	1.61	1.11	-0.50	1.18	0.04	-1.13	3.45	0.41	-3.04	0.48	1.69	1.21
2017	1.69	1.06	-0.63	1.24	0.04	-1.20	3.67	0.44	-3.23	0.50	1.73	1.23
2018	1.78	1.02	-0.76	1.30	0.04	-1.27	3.91	0.47	-3.44	0.53	1.77	1.25
2019	1.87	0.98	-0.89	1.37	0.03	-1.34	4.16	0.51	-3.65	0.55	1.82	1.26
2020	1.96	0.94	-1.02	1.44	0.03	-1.42	4.42	0.55	-3.87	0.58	1.86	1.28

Yd: Projected edible oil demand; Yp: Projected edible oil production within the state; Gap = Yp-Yd

The groundnut oil and sesame oil supply available from the state sources would decline drastically resulting in widening household demand-production gap. Hence, it warrants urgent measures to increase the current production levels in these crops. Contrary to groundnut and sesame production, the production of sunflower would increase but the issue here is to what extent the growing demand for sunflower oil would be met, if current rate of production is continued in future. Hence, strategies in terms of the horizontal expansion (area) and vertical increase (productivity) need to be adopted to bridge the gap and to reduce the dependence on other states or imports in the future.

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Productivity enhancement in sesame (*Sesamum indicum* L.) as influenced by different improved production technologies

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(Received: May, 2014; Revised: August, 2014; Accepted: January, 2015)

ABSTRACT

Sesame is one of the important oilseed crops in India. The major constraint of its low productivity is non-adoption of improved technologies by the farmers. Frontline demonstrations to highlight the impact of different improved technologies like method of sowing, nutrient management, weed management and adoption of whole package of practices of improved technologies for the crop were conducted at 45 farmers' fields during *kharif* 2011, 2012 and 2013 under rainfed conditions. The improved technologies improved the yield attributing traits as well as seed yield of the crop. The improved technology recorded a mean yield of 470 kg/ha which was 30% higher than that obtained with farmer's practice yield of 363 kg/ha. Higher mean net returns of ₹25,063/ha with a benefit: cost ratio of 2.85 was obtained with improved technologies in comparison to farmer's practice (mean net returns of ₹17,802/ha and benefit: cost ratio of 2.57).

Keywords: Frontline demonstration, Improved technology, Net return, Productivity, Sesame

Sesame (*Sesamum indicum*) is an ancient oilseed crop of India. The crop is grown in a wide range of environments, extending from semi-arid tropics and subtropics to temperate regions. Therefore, the crop has a large diversity in cultivars and cultural systems. India ranks first in the world in terms of sesame-growing area (23%) and second largest producer of sesame in the world after Myanmar. But the productivity is only 335 kg/ha (FAO, 2012) which is lower than most of the sesame growing countries. This probably indicates great opportunity for a higher increase in sesame productivity in India. Potential yields are probably as high as 2000 kg/ha (Mkamilo and Bedigian, 2007). In general, average productivity of sesame continues to be lower than expected from agricultural technology for the last 40 years, mainly due to its cultivation on marginal lands, poor management practices and low input application except seed. The major constraint responsible for lower yield is adoption of inappropriate production technologies by farmers viz., broadcast method of sowing, no use of fertilizer and untimely or poor weed management (Khaleque and Begum, 1991). The yield of sesame can be increased substantially with adoption of improved technologies such as improved variety, recommended dose of fertilizer, weed management and plant protection. Keeping this in view, frontline demonstrations on sesame were conducted in the farmer's fields to demonstrate the production potential and economic benefits of latest improved technologies to the farmers.

MATERIALS AND METHODS

Forty five frontline demonstrations (FLDs) to demonstrate the effect of improved production technologies on the productivity of sesame were conducted during *kharif* season from 2011- 2013 on farmers' fields under rainfed conditions in villages such as Naude Majra, Rajgiri, Jhandian, Jatawar, Dhamana (Rupnagar District), Nainwan (Hoshiarpur District) and Thanawal, Takarla, Thopia, Saunkhri, Ballowal, Ratewal (SBS Nagar District) of Punjab. The soils of the farmers fields were light to medium with low to medium fertility status. Each demonstration was conducted on an area of 0.4 ha and 0.1 ha adjacent plot to the demonstration plot was kept for assigning farmer's practices. The package of improved technologies like line sowing, nutrient management, weed management and whole package were used for the demonstrations. The RT 346 variety of sesame was used for sowing in the demonstrations and the details of the improved practices demonstrated to the farmers through the FLDs are given in Table 1. The crop was harvested in the month of October after the leaves turn yellow and start dropping while the capsules are still greenish-yellow. Data on yield attributing traits and seed yield were recorded. Economic analysis was done on the basis of prevailing market price of input used and the output obtained from farmer's practice and improved technology demonstrated fields.

RESULTS AND DISCUSSION

Yield attributing traits: The number of productive capsule per plant under improved technologies were 45.4, 44.8, 48.0 and 48.8 as against that of farmer's practice, 37.6, 36.0, 36.2 and 37.0 (Table 2) under line sowing, weed management, nutrient management and whole package FLDs, respectively. There was increase of 20.7, 24.4, 32.6 and 31.9% in number of productive capsules under demonstration of improved technologies over farmer's practice. The number of seeds/capsule under improved technologies i.e. line sowing, weed management, nutrient management and whole package and farmer's practice were 70.2, 70.8, 72.4 & 75.6 and 67.4, 68.0, 70.1 & 70.2, respectively. The percentage increase in number of seeds/capsule ranged from 3.9 to 7.7 under different improved technologies. Test weight (g/1000-seed) observation showed that during the test weight also increased under the improved technologies in comparison to farmer practice and it was 2.78, 2.82, 2.90 & 2.98 under line sowing, weed management, nutrient management and whole package, respectively, whereas it was 2.16, 2.14, 2.21 & 2.25, respectively under farmer's practice. Overall, there was 27.4, 4.8 & 31.0% increase in number of productive capsules/plant, number of seeds/capsule and test weight under the improved technologies in comparison to farmer's practice.

Seed yield: The productivity of sesame under improved production technologies ranged between 354 and 650 kg/ha with mean yield of 470 kg/ha (Table 3). The productivity under improved technologies varied from 354 to 522, in case of line sowing and there was 16.1% enhancement in yield over farmer's practice. This agrees with the findings Imoloame *et al.* (2007) who reported the superiority of row planting over broad casting to control weed and this factor resulted in considerable yield increased and also grain yield increased significantly. Under the frontline demonstrations on weed management, the productivity varied from 375 to 538 and it was 18.0% higher in comparison to farmer's practice. Singh *et al.* (1992) and Upadhyay (1985) reported weed-induced reductions of sesame yield up to 65% and a need for a critical weed-free period up to 50 days after planting. Under weedy conditions, Eagleton *et al.* (1987) recorded a weed biomass six times that of sesame 48 days after planting and Bennett (1993) reported a weed biomass 1.3 fold that of sesame 42 days after planting. The higher weed infestation under farmer's practice reduced the amount of nutrients and water available to the cultivar under farmer's practice. The productivity varied from 394 to 575 kg/ha under frontline demonstrations on nutrient management and the increase in productivity was to the tune of 37.1% over farmer's practice. Fertilizer response has been widely studied in other countries and the extent of the response depends on many factors: with high yielding varieties higher fertiliser rates are needed and also in cases of lower soil fertility (Tripathi and Rajput, 2007). The increase in productivity was 49.3% under the frontline demonstration on whole package in comparison to farmer's practice and productivity ranged from 410 to 650 kg/ha with an average productivity of 509 kg/ha under improved technology as compared to 341 kg/ha, in case of farmer's practice. The additional yield under improved technologies over farmers practice ranged from 62 to 168 kg/ha with a mean of 107 kg/ha. The increased grain yield with improved technologies was mainly because of line sowing, use of nutrient management, weed management and adoption of these improved technologies as a whole. Adoption of improved technology increased sesame yield by 34% as compared to farmer's practice (Raikwar and Srivastava, 2013). Improved technology produced higher grain yield this could be the inter plant competition for the moisture and nutrients which could be more severe under farmer's practice.

Economics: The economic viability of improved technologies over traditional farmer's practices was calculated depending on prevailing prices of inputs and output costs (Table 4). It was found that cost of production of sesame under improved technologies varied from ₹12,728 to 14,080/ha as against ₹ 10,696 to 12,086/ha under farmer's practice. The improved production technologies registered an additional cost of production ranging from ₹ 642 to 3,384/ha over farmer's practice. The additional cost increased in the improved technologies was mainly due to more cost involved in balanced fertiliser, improved seed, weed management and crop protection practices. Cultivation of sesame under improved technologies gave higher net return which ranged from ₹18,040 to 34,475/ha as compared to farmer's practices which ranged from ₹ 14,429 to 22,198/ha. Similar results also have been reported by Khan *et al.* (2009) and Raikwar and Srivastava (2013). The improved technologies i.e. line sowing, nutrient management, weed management and whole package also gave higher benefit cost ratio of 2.43, 2.44, 3.10 and 3.43 as compared to 2.19, 2.27, 2.79 and 3.03 under farmer's practice, respectively. The results from the present study clearly indicate the potential of improved production technologies in yield enhancement under rainfed condition. Thus, to get maximum yield of sesame recommended package of practices for the crop should be followed.

In conclusion, the frontline demonstrations conducted on sesame at the farmers' fields revealed that the adoption of improved production technologies significantly increased the yield as well as yield attributing traits of the crop and also the net returns to the farmers. The highest productivity and net returns were obtained under the frontline demonstrations laid out on whole package of practices for the crop, which emphasizes the adoption of recommended production technologies. So, there is need to disseminate the improved technologies among the farmers with effective extension methods like training and demonstrations. The farmers should be encouraged to adopt the recommended package of practices for the crop for higher returns.

Table 1 Particulars showing the details of sesame growing under FLD and existing practices

Operation	Farmer's practice	Improved practices demonstrated
Line sowing	Broadcasting of seed	Spacing was 30 cm between rows and 10 cm between plants in the row.
Weed management	No weed management	Weed management by using herbicide Alachlor (Lasso 50 EC) at 3 litres/ha in 500 litre of water as pre-emergence treatment for effective control of weeds within two days of sowing. The thinning and weeding was done invariably 30-35 days after sowing to ensure recommended plant spacing within a row.
Nutrient management	Only FYM and no fertilizer application	10 tonnes farm yard manure and 35 kg N/ha.
Whole package	Farmers are cultivating the sesame crop without adoption of any improved technology	All the crop management practices as per the package of practices for kharif crops by Punjab Agricultural University, Ludhiana (Anonymous, 2011) were followed for raising the crop.

Table 2 Yield attributing traits of sesame as affected by improved and farmer's practices in farmers fields

Type of Frontline demonstration	Yield attributing characters								
	No. of productive capsules/plant			No. of seeds/capsule			Test weight (gm)		
	Improved Technology	Farmer's practice	% increase	Improved Technology	Farmer's practice	% increase	Improved Technology	Farmer's practice	% increase
Line sowing	45.4	37.6	20.7	70.2	67.4	4.2	2.78	2.16	28.7
Weed management	44.8	36.0	24.4	70.8	68.0	4.1	2.82	2.14	31.8
Nutrient management	48.0	36.2	32.6	72.4	70.1	3.9	2.90	2.21	31.2
Whole package	48.8	37.0	31.9	75.6	70.2	7.7	2.98	2.25	32.4
Average	46.8	36.7	27.4	72.3	68.9	4.8	2.87	2.19	31.0

Table 3 Seed yield of sesame as affected by improved and farmer's practices in farmers fields

Type of Frontline demonstration	Demonstration (No.)	Yield (kg/ha)				Additional yield (kg/ha) over farmer's practice	% increase in yield over farmer's practice
		Improved Technology (IT)			Farmer's practice (FP)		
		Maximum	Minimum	Average			
Line sowing	7	522	354	448	386	62	16.1
Weed management	5	538	375	452	383	69	18.0
Nutrient management	8	575	394	469	342	127	37.1
Whole package	25	650	410	509	341	168	49.3
Average		571	383	470	363	107	30.1

Table 4 Economics of sesame as affected by improved and farmer's practices in farmers fields

Type of Frontline demonstration	Cost of cultivation (₹/ha)		Net returns (₹/ha)		Additional cost of cultivation (₹/ha)	Additional net returns (₹/ha)	B:C Ratio	
	IT	FP	IT	FP			IT	FP
Line sowing	12,728	12,086	18,040	14,429	642	3,611	2.43	2.19
Weed management	13,010	11,817	18,497	14,750	1,193	3,747	2.44	2.27
Nutrient management	13,754	11,283	29,240	19,829	2,471	9,411	3.10	2.79
Whole package	14,080	10,696	34,475	22,198	3,384	12,277	3.43	3.03
Average	13,393	11,471	25,063	17,802	1,923	7,262	2.85	2.57

Sale rate of sesame: ₹ 85/kg (2011), ₹ 100/kg (2012) and ₹ 100/kg (2013)

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Stability analysis for traits related to seed yield in sunflower (*Helianthus annuus* L.)

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(Received: June, 2014; Revised: February, 2015; Accepted: March, 2015)

ABSTRACT

An investigation was made to test the adaptability of twenty two hybrids along with four check hybrids for seed yield/plot (g), head diameter (cm) and hundred seed weight (g) over six environments. Environmental variances were significant for all the characters suggesting the presence of genetic variability among genotypes over environments. The G x E (linear) were non-significant for all the characters under studied when tested against pooled deviation, indicates unpredictable performance of genotypes over the environments. The environment indices revealed that E_2 was the most favourable environment for seed yield/plot (g), head diameter and 100-seed weight. For the stability parameter, none of the hybrid was ideal with an average adaptability for all the traits. The hybrid SVSH-473 had bi value nearer to unity (b=1), non-significant value of S^2di and higher mean than the population mean indicating average stability and suitable for all environments. Based on the mean performance for head diameter the hybrid, SVSH-467 and for 100-seed weight the hybrid, SVSH-458 showed stable performance.

Keywords: G x E interaction, Hybrids, Seed yield, Sunflower

Sunflower is an important oilseed crop of India. Its adaptability to a wide range of soil and climatic conditions which makes its cultivation possible during any part of the year in the tropical and sub tropical regions of the country with high yield potential. Improvement of complex traits, such as seed yield which is strongly influenced by environments, should be evaluated in many locations with different environment. Data obtained from those tested environments can be used to identify genotypes or varieties that perform well across environments. Many techniques have been developed to evaluate the stability of crop varieties or lines over a range of environments. The regression method developed by Yates and Cochron (1938) provides the main basis of this type of study. The method was later modified by Finlay and Wilkinson (1963) and refined by Eberhart and Russell (1966) and Perkins and Jinks (1968). The method which does not use the regression of crop performance on environments but uses the conventional coefficient of variation (%) was developed by Francis and Kannenberg (1978). Therefore, the purpose of this study was to evaluate the performance of promising hybrids of sunflower for yield and yield related traits.

The materials of the present investigation comprised 22 hybrids with three check hybrids *viz.,* KBSH-44, GK-2002 and Phule Raviraj and one open pollinated variety Bhanu. The experiments were conducted during *kharif* 2010 at six different centres of Mahatma Phule Krishi Vidyapeeth, Rahuri *viz.,* Savalvihir, Niphad, Jalgaon, Chas, Dhule and Rahuri. Each hybrid was represented by four rows of 3.6 m length with 60 x 30 cm spacing between and within rows, respectively. Recommended packages of practices were followed by each centre to raise the healthy crop. The observations were recorded on per plot basis for seed yield and on five plant basis for other characters. The data were subjected to stability analysis as per the method of Eberhart and Russell (1966) in order to estimate the three parameters of stability *viz.,* mean, regression coefficient (b), and mean squared deviation (sd^2) for each genotype.

Estimates of environmental indices (Ij), given in the Table 1 suggested that E_2 was the most favourable environment for seed yield/plot (g), head diameter (cm) and 100-seed weight (g), while E_3 and E_5 were favourable for head diameter (cm). Whereas the environment E_6 was only favourable for seed yield/plot (g). The analysis of variance (Table 2) indicated that the mean differences due to genotypes were statistically significant only for seed yield/plot when tested against pooled deviation. Environmental variances were significant for all the characters suggesting the presence of genetic variability among genotypes and even over environments.

The genotype x environment (linear) were non-significant for all the characters under studied when tested against pooled deviation, it indicates unpredictable performance of genotypes over the environments. Significant pooled deviations for all the traits indicated predominance of non-linear component in the manifestation of genotype x environment interaction for the significant traits. Similar observations were made by Rao *et al.* (2004) and Binodh *et* *al.* (2009). Bajpai and Parabhakaran (2000) observed that the presence of highly significant genotype x environment interaction for seed yield under the present study necessitated identifying most stable and high yielding genotypes through stability.

Table 1 Environmental indices for different traits of sunflower

Character	Environmental indices					
	E_1	E_2	E_3	E_4	E_5	E_6
Seed yield (g/plot)	-0.088	0.454	-0.439	0.226	-0.193	0.039
Head diameter (cm)	-2.569	0.856	1.585	-0.875	1.493	-0.488
100-seed weight (g)	-0.281	0.852	-0.267	0.248	-0.379	-0.175

Table 2 Analysis of variance for stability parameters for seed yield and other important characters in sunflower

Source	D.F.	Seed yield/plot	Plant height	Head diameter	100-seed weight
Genotype	25	0.17**	170.51	2.134	0.73
Environment	5	2.59**	20904.34**	67.99**	5.78**
GxE	125	0.09	101.88	1.81	0.49
E+(GxE)	130	0.19**	901.98**	4.36**	0.70**
Environment (L)	1	12.93**	104521.7	339.96	29.91
GxE (L)	25	0.10	66.62	1.24	0.46
Pooled deviation	104	0.08	106.44	1.88	0.40
Pooled error	150	0.05	57.94	0.46	0.16

*,**=Significant at P=0.05 and 0.01, respectively when tested against pooled deviation

In considering the stability of genotypes, the three stability parameters *viz.,* grand mean over environment, the regression coefficient and the squared deviation from the regression are considered to be important. The regression coefficient around unity and deviation from regression around zero indicate that the genotypes possessing these attributes are stable over environments.

The data presented in Table 3 indicates that, out of twenty six hybrids, sixteen hybrids were observed to have only non linear portion of G x E interaction as only S^2di values were significant for seed yield/plot (g), indicating that response may not be predicted across the environments for these sixteen hybrids. Fourteen hybrids were observed to have only linear portion of G x E interaction as only bi values were significant which revealed that response might be predicted across the environments for these fourteen hybrids. Both linear and non linear portion of G x E interaction was observed for seven hybrids *viz.,* SVSH-435, SVSH-455, SVSH-456, SVSH-468, SVSH-469, SVSH-470 and SVSH-471 respectively in seed yield/plot (g). Among the hybrids SVSH-454, SVSH-458 and KBSH-44 had higher mean than the population mean, bi nearer to unity and higher S^2di indicating that these hybrids suitable for rich environments.

Table 3 Estimates of stability parameters in sunflower

Hybrid	Seed yield/plot (g)			Head diameter (cm)			100-seed weight (g)		
	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di
SVSH-402	1.967	1.054	-16.25**	17.40	1.34**	0.25	6.40	1.68*	0.31**
SVSH-405	1.874	0.962**	237.34	16.68	1.39*	1.19**	5.59	1.03	0.84**
SVSH-435	1.827	0.971*	-6.75**	16.18	0.96	2.91**	6.15	0.83	0.15*
SVSH-454	1.940	1.198	11.39**	16.74	1.08*	1.70**	6.42	0.91	0.31**
SVSH-455	1.760	0.993*	6.11**	16.09	1.53	4.44**	5.76	1.06	0.39**
SVSH-456	2.035	0.943*	-8.07**	17.48	1.06	1.95**	6.35	2.56*	0.47**
SVSH-458	1.989	1.081	-21.67**	16.58	1.07*	0.93**	6.48	1.47*	0.10
SVSH-463	1.966	0.901**	45.39	17.27	1.45**	0.92**	6.50	0.81	0.22**
SVSH-467	1.933	0.779	42.26*	16.93	1.07**	-0.07	6.35	1.42	0.31**
SVSH-468	1.658	0.869*	235.15*	16.43	0.99**	0.18	6.53	2.07**	0.12*
SVSH-469	1.750	0.884*	71.639*	16.64	0.85**	0.76**	6.38	0.98	0.16*
SVSH-470	1.753	1.019*	266.57*	17.54	1.23**	0.71**	5.43	0.30	0.10
SVSH-471	1.672	1.140*	16.44**	17.04	0.70**	-0.03	6.10	0.79	0.40**
SVSH-472	1.726	0.932**	85.99	15.97	1.19*	1.95**	5.96	0.35	0.54**
SVSH-473	1.822	1.028	-3.13	16.54	0.67	0.97**	6.06	1.02*	0.30
SVSH-401	1.627	1.088*	171.10	16.13	0.25	0.76**	5.98	1.42*	0.02
SS-807	1.320	0.914	202.66**	14.93	0.91	4.70**	6.49	0.54	0.48**
SS-808	1.535	1.075	48.62**	15.56	1.09	2.48**	5.43	0.25	0.43**
SS-809	1.769	0.859	60.25*	16.58	0.69**	-0.07	5.84	0.40	-0.03
SS-902	1.612	1.066**	44.41	17.08	0.88	2.34**	5.76	1.52**	0.01
SS-903	1.627	1.353**	29.43	16.10	0.98	2.67**	5.96	-0.01	0.63**
SS-904	1.665	0.899	11.51	16.51	0.99**	0.25	5.98	0.14	0.05
Bhanu (C)	1.779	0.939	14.56	16.38	1.55**	0.90**	5.72	0.93	0.50**
P.Raviral (C)	1.516	0.856*	116.83	16.90	0.68	3.71**	6.19	1.62	0.72**
GK-2002 (C)	1.692	1.178	252.02**	17.08	0.59	3.11**	5.61	0.17	2.02**
KBSH-44 (C)	1.917	1.019	94.09**	16.69	0.83	2.81**	6.21	1.68	1.01**
Mean	1.76			16.59			6.02		
SEbi±	0.41			0.38			0.66		
SEm±	0.13			0.61			0.31		

bi=Regression coefficient, S^2di= Deviation from regression, *, ** = Significant at 5% and 1% level, respectively; C=Check

The hybrid SVSH-473 exhibited regression coefficient nearly equal to unity, high seed yield and deviation from regression coefficient was low indicating that this hybrid showed average stability and suitable for all environments. Hybrid SVSH-456 showed higher mean, bi less than one and low S^2di value, it indicated that this hybrid was responsive to favourable environment. Based on the mean performance for head diameter hybrids SVSH-402 and SVSH-471 were found to be higher mean, bi nearer to unity and non-significant value of S^2di, it indicating their average stability. Hybrid SVSH-467 showed its stable performance for head diameter. The data on 100-seed weight (g), indicated that eight hybrids exhibited significantly higher 100-seed weight (g) than the average population mean. Of these, only one hybrid SVSH-458 had non-significant deviation from regression, bi value nearer to unity, it indicated that this hybrid was stable for the 100-seed weight (g). The hybrid KBSH-44 had higher mean than the population mean, bi nearer to unity and higher S^2di indicating their suitability under favourable environments where as the hybrid SVSH-463 showed higher mean, bi less than one and low S^2di value, it indicated that this hybrid suitable in average environment.

From the above discussion, it could be summarized that none of the hybrids were stable for all characters under investigation. Similar results were also reported by Bhoite *et al.* (2010) and Shinde *et al.* (1992). Based on the mean performance for high yield the hybrid KBSH-44, for head diameter the hybrid SVSH-467 and for 100-seed weight (gm) the hybrid SVSH-458 showed its stable performance under favourable environment. The hybrid SVSH-473 had bi value nearer to unity (b=1), non-significant value of S^2di and higher mean than the population mean indicating average stability and suitable for all environments.

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Performance of linseed (*Linum usitatissimum* L.) varieties to varying seed rates under *utera* system of cultivation in North West Himalayas

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(Received: February, 2015; Revised: April, 2015; Accepted: June, 2015)

ABSTRACT

A field experiment was conducted to study the influence of varieties ('Bhagsu', 'Surbhi' and 'Baner') and seed rates (40, 50 and 60 kg/ha) on linseed production under *utera* condition at experimental farm of Oilseed Section, CSK HPKV, Palampur. Variety, 'Bhagsu' being at par with 'Baner' has recorded significantly higher yield attributes and seed yield of linseed (565 and 566 kg/ha, respectively). Sowing using seed rate of 60 kg/ha was proved to be significantly best for recording significantly highest plant stand, growth, yield attributes and yield of linseed (643 kg/ha). Interaction of varieties and seed rate was significant on seed yield and plant population. 'Bhagsu' and 'Baner' when sown with seed rate of 60 kg/ha found to be best for recording significantly higher seed yield of linseed (94.0 and 92.3%, respectively over the most inferior combination).

Keywords: Linseed, Seed rate, Utera, Varieties, Yield

Linseed (*Linum usitatissimum* L.) is one of the most important cultivated plants concerning its high nutritional potential such as protein content, water-soluble fiber fraction (Warrand *et al.,* 2005), lignan content, mucilage, linamarin (a cyanogenic glycoside), enzymes and is mainly grown for its oil (Oomah, 2001). In North West Himalayas linseed is generally broadcasted in paddy crop, 15-20 days before the harvest of the crop. This system of cultivation is known as *utera* or paira system of cultivation, which limits the scope of application of modern improved technology along with use of inputs generally associated with increased productivity. The cultivation of linseed in this system is under total "Nature's care and cure" which results in lower productivity. In this system the succeeding crop (linseed) faces many constraints like poor seed soil contact leading to poor germination resulting in low plant population, plant mortality at paddy harvest. Also, use of local varieties, lack of fertilization and plant protection measures limit its production. This situation may continue in future also as the present efforts are limited to verification of genotypes and also agro-techniques only for prepared seed bed conditions and not for *utera* cultivation. For such situation varieties having small seed size and deep root system will be of much importance as variety is important input under *utera* system (Agarwal *et al.,* 1986). Performance of such varieties with respect to different agronomic manipulations like optimum seed rate needs to be confirmed under this system of cultivation.

The present study was conducted at experimental farm of Oilseed Section, CSK HPKV, Palampur during *rabi* 2006-07. The experiment was conducted in factorial Randomized Block Design keeping 9 treatment combinations, comprising of three varieties ('Bhagsu', 'Surbhi' and 'Baner') and three seed rates (40, 50 and 60 kg/ha) replicated thrice. The soil of the experiment site was silty clay loam in texture with pH 5.9 and medium in available nitrogen, phosphorus and potassium. The crop was supplied with 50, 40 and 20 kg N, P_2O_5 and K_2O/ha. The crop was sown by broadcasting of linseed at dough stage of paddy using 40, 50 and 60 kg/ha seed rates as per the treatments. The total number of plants present in 0.25 m^2 area were counted by using a quadrate of 0.5 m x 0.5 m at random in each plot and expressed in number of thousand plants/ha. Plant height, number of primary, secondary branches and capsules/plant were recorded from the selected five plants in each net plot. After maturity, the crop was harvested from the net plot area, sun dried and threshed with wooden mallet and the seed yield was expressed in kg/ha.

The results revealed that variety 'Bhagsu' has recorded significantly highest plant stand followed by statistically on par with other varieties ('Surbhi' and 'Baner'). Variety 'Baner' has recorded significantly highest plant height. Among yield attributes, 'Baner' being at par with 'Bhagsu' has recorded significantly higher primary and secondary branches and capsules per plant and resulted in getting significantly more seed yield (Table 1). 'Baner' and 'Bhagsu' has increased the seed yield to the tune of 30.1 and 29.9%, respectively over 'Surbhi'. This might be due to better root development of these varieties which helped in better absorption of nutrient and water in this system and have resulted in more plant stand with better growth for contributing to higher yield and yield attributes. Based on the best performance of 'Bhagsu' in *utera* system, this variety was released by CVRC during 2010 (Anonymous, 2011). Similarly, 'Baner' was found to be significantly best in terms of yield and disease resistance and released for *utera* cultivation in Zone-I of India (Anonymous, 2006). However, no statistical difference was recorded among varieties for secondary branches and seeds/capsule.

Using 60 kg seed/ha has recorded significantly highest plant stand with tallest plants having significantly more yield attributes *viz.,* primary and secondary branches, capsules/plant and seeds/capsules which have contributed in getting significantly highest seed yield (643 kg/ha). However, seed rate of 50 kg/ha was also at par with it for secondary branches, seeds/capsules and followed by 60 kg/ha for plant stand, plant height, primary branches and capsules/plant (Table 1). This resulted in proving 50 kg/ha seed rate as the next best treatment in recording significantly higher seed yield of linseed (507 kg/ha). The significantly lowest plant stand, yield attributes and seed yield was recorded with 40 kg seed rate/ha. The per cent increase in the seed yield by following seed rate of 60 and 50 kg/ha was 54.2 and 21.6, respectively over 40 kg/ha. The results are in direct conformity with the findings of Badiyala *et al.* (2004) and Nayital and Singh (1984).

Varieties and seed rate interacted significantly with regard to plant population (Table 2). Variety, 'Bhagsu' sown with a seed rate of 60 kg/ha was proved to be the best combination for recording significantly highest plant population of linseed. Same variety i.e. 'Bhagsu' sown with seed rate of 50 kg/ha also behaved statistically similar to 'Surbhi' and 'Baner' sown using 60 kg/ha seed rate.

The interaction between entries and seed rate was also significant for seed yield. 'Bhagsu' being at par with 'Baner' when sown using a seed rate of 60 kg/ha were proved to be significantly superior for increasing seed yield. Increase in the respective seed yield of 94.0 and 92.3% was noticed with these combinations over the most inferior combination of 'Surbhi' sown with seed rate of 40 kg/ha. Same entries i.e. 'Bhagsu' and 'Baner' behaved statistically similar to each other when sown using seed rate of 50 kg/ha and proved to be the other best combination.

Table 1 Effect of varieties and seed rate on growth, yield attributes and seed yield of linseed

Treatments	Plant stand (‘000/ha)	Plant height (cm)	Primary branches	Secondary branches	Capsules/ plant	Seeds/ capsules	Seed yield (kg/ha)
Varieties							
Bhagsu	758	62.3	5.0	3.0	28.0	7.6	565
Surbhi	661	5.2	4.6	2.7	21.1	7.2	435
Baner	689	68.8	5.2	3.0	27.1	7.5	566
CD (P=0.05)	28	1.52	0.23	0.9	1.41	NS	17
Seed Rate (kg/ha)							
40	632	54.4	4.2	2.3	20.8	6.6	417
50	698	59.7	5.0	2.9	26.3	7.7	507
60	780	64.2	5.6	3.4	29.1	8.1	643
CD (P=0.05)	28	1.52	0.23	0.9	1.41	0.5	17

Table 2 Interaction effect of treatments on plant population and seed yield of linseed

Varieties/ Seed rate (kg/ha)	Bhagsu	Surbhi	Baner
Plant stand (000/ha)			
40	642	615	638
50	761	653	679
60	873	716	750
CD (P=0.05)	48		
Seed yield (kg/ha)			
40	442	365	443
50	548	420	553
60	708	520	702
CD (P=0.05)	29		

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Performance of sorghum and linseed intercropping system with different row proportion and planting geometry under rainfed condition

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(Received: July, 2014; Revised: September, 2014; Accepted: January, 2015)

ABSTRACT

A field experiment was conducted at Main Agricultural Research Station, Raichur, Karnataka during *rabi* season of 2013-14 under rainfed condition in medium black soil to study the yield performance and economics of sorghum and linseed intercropping system with different row proportion and planting geometry. The results revealed that, among various intercropping systems, sorghum+linseed in 1:2 with 30 cm rows spacing recorded significantly higher sorghum equivalent yield of 1822 kg/ha followed by chickpea+ linseed in 2:1 with 45 cm rows (1671 kg/ha) and sorghum+linseed in 1:1 with 30 cm rows (1653 kg/ha). The land equivalent ratio was significantly highest in sorghum+ linseed in 1:2 with 30 cm rows (1.70) followed by chickpea+linseed in 2:1 with 45 cm rows (1.10). Higher net returns was recorded in sorghum+linseed in 1:2 with 30 cm rows (₹ 34,348/ha) followed by sorghum+chickpea (2:1) 45 cm rows (₹ 31,211/ha) and sorghum+linseed (1:1) 30 cm rows (₹ 29,876/ha). However, higher B:C was recorded in sorghum+linseed (1:2) 30 cm rows (2.05).

Keywords: Intercropping system, LER, Linseed, Rainfed, Sorghum

The productivity of dryland crops is very low because of low and erratic rainfall, variation in soil fertility, improper management of resources by the farmers. To bridge this gap, crop diversification is required for increasing the productivity and profitability per unit area per unit time. In Northern Karnataka linseed is cultivating under rainfed area during *rabi* season as a sole crop or mixed cropping with sorghum and safflower without proper row proportion but this proportion has no substantial gain in productivity of linseed and difficulties in cultural practices during crop growth. To increase the productivity of cropping system under rainfed condition, investigation was carried out to find out the remunerative intercropping system to be productive and economically viable with suitable row proportion and spacing.

A field experiment was conducted during *rabi* season of 2013-14 at Main Agricultural Research Station, University of Agricultural Science, Raichur, Karnataka on medium black soil under rainfed agro eco-system. The soil was medium in organic carbon (5.9 g/kg), low in available nitrogen (188.1 kg/ha), high phosphorous (33.3 kg P_2O_5/ha) and medium potassium (184.9 kg K_2O /ha) with pH 7.9. Sorghum (cv. M-35-1) and linseed (cv. NL-115) were intercropped in 1:1 and 1:2 row proportions at 22.5, 30 and 45 cm rows and both crops were grown as sole crop at their recommended row spacing (45 cm for sorghum and 30 cm for linseed), along with these treatments sorghum+chickpea (2:1) and mixed cropping of sorghum and linseed were also included. The experiment was laid out in randomized complete block design and replicated thrice. Both the crops were sown simultaneously and recommended dose of fertilizer were applied to sole crops and in intercropping system, the components crops received fertilizer at the time of sowing in proportion to their plant density in the form of urea and DAP. The crops were sown as per the row proportions and spacing during second fortnight of October. The rainfall received during 2013-14 was 752.7 mm, while during cropping period was 149.5 mm. The growth and yield observations were recorded from net plots and grain yield of various crops were converted on hectare basis in kilograms. The economics of each system was computed with prevailing prices of each commodity during the year. The data was statistically analyzed and discussed. The yield was further computed in terms of sorghum equivalent yield, land equivalent ratio, gross returns as well as B:C to assess the system productivity and viability.

Grain yield of sorghum was influenced significantly due to intercropping systems with different row proportions, spacing and plant population. Sole sorghum recorded significantly higher grain yield (1553 kg/ha) and it was on par with mixed cropping of sorghum and linseed (1475 kg/ha). Reduction in yield of sorghum due to various intercropping combinations were in the order of sorghum+chickpea (2:1) 45 cm rows, sorghum + linseed (1:2) 30 cm rows, sorghum + linseed (1:1) 45 cm rows, sorghum + linseed (1:1) 30 cm rows, sorghum+ linseed (1:2)

45 cm rows, sorghum + linseed (1:1) 22.5 cm rows and sorghum + linseed (1:2) 22.5 cm rows (Table 1). Variation in the sorghum yield might be due to several causes *viz.,* variation in population levels, planting geometry, crop combinations, inter and intra species competition for light, moisture, nutrients, space etc. Superior values of yield in solitary stand of sorghum might be attributed to competition free environment and optimum population level compared to intercropping treatments. Owing to higher population levels per unit area under intercropping systems resulted in inter and intra species competition for available resources. The results are in conformity with the findings of Balasubramanian *et al.* (1986) and Biru Amedie *et al.* (2004). They reported that sole sorghum recorded significantly higher grain yield as compared to intercropping systems.

The seed yield of linseed showed significant variations due to intercropping system. Linseed performed better under pure stand compared to intercropping with varying row proportion and row spacing. Among intercropping system, linseed was superior under sorghum + linseed in 1:2 with 30 cm row proportion and inferior under mixed cropping of sorghum and linseed in 45 cm row spacing (Table 1). The variations in linseed yield could be attributed to variation in the yield attributes and population levels. The higher seed yield of linseed was contributed by higher number of capsules/plant, capsule weight, seeds/capsule and test weight (Table 1). The higher yield of linseed under sorghum+ linseed 1:2 with 30 cm row may be attributed to least competition offered by sorghum. These results are in conformity with the findings of Sarkar *et al.* (2004). They reported higher seed yield of linseed when intercropped with lentil. Intercropping of lentil + linseed in 5:1 row ratio resulted bonus yield of linseed.

Table 1 Grain yield of sorghum, seed yield of linseed, sorghum equivalent yield, LER and economics of the systems as influenced by different row proportion and spacing

Treatment	Sorghum grain yield (kg/ha)	Linseed seed yield (kg/ha)	SEY	LER	Gross returns (₹/ha)	Net returns (₹/ha)	Per day return (₹)	B:C
Sorghum + linseed (1:1) 22.5 cm rows	1255	148	1550	1.00	38750	26013	219	1.70
Sorghum + linseed (1:2) 22.5 cm rows	1012	222	1456	0.94	36409	23579	198	1.57
Sorghum + linseed (1:1) 30 cm rows	1267	193	1653	1.06	41321	29876	251	1.90
Sorghum + linseed (1:2) 30 cm rows	1288	267	1822	1.17	45566	34348	289	2.05
Sorghum + linseed (1:1) 45 cm rows	1247	118	1483	0.96	37076	26473	222	1.85
Sorghum + linseed (1:2) 45 cm rows	1044	256	1555	1.00	38889	27855	234	1.80
Sorghum + chickpea (2:1) 45 cm rows	1365	169	1671	1.10	41776	31210	262	1.88
Mixed cropping of sorghum and linseed 45 cm rows	1475	57	1587	1.03	39695	28786	242	1.87
Sole sorghum (45cm x 15 cm)	1553	-	1553	1.00	38834	27480	233	1.88
Sole linseed (30 cm x 5 cm)	-	803	1606	1.00	40142	29652	247	1.81
SEm±	56	26	65	0.03	1631	1631	16	0.19
CD (P=0.05)	166	78	193	0.09	4848	4848	47	NS

Sorghum equivalent yield showed marked differences due to intercropping system at varying row proportion and spacing. The SEY was significantly higher (Table 1) in sorghum+ linseed in 1:2 with 30 cm rows as compared to sole crop of sorghum followed by the sorghum+chickpea in 2:1with 45 cm row spacing (1671 kg/ha). The higher SEY in sorghum+linseed (1:2) with 30 cm rows was due to higher yield obtained by both sorghum and linseed and higher market price of linseed (Table 1). These results are in conformity with the findings of Subbian and Selvaraju (2000).

The significantly higher LER was recorded when sorghum intercropped with linseed 30 cm in 1:2 row proportion when compared to sole crop of linseed and sorghum. The higher LER values in the above intercropped treatments were due to higher yield of component crops in relation to their sole crops. This was evident by higher combined seed yield per plant of both the crops per unit area (Table 1). The higher combined seed yield could in turn related to the fact that component crops differed in utilization of growth resources and converting them more efficiently into yield components resulting in higher yield/plant and yield/unit area. These results confirmed by Gautham *et al.* (2004). They reported that intercropping of sorghum with legumes resulted in higher LER than sole crop. Similarly, Tanwar *et al.* (2011) reported that intercropping systems of linseed with chickpea were found more LER and advantageous than sole cropping.

Significantly higher gross returns was recorded in sorghum+linseed in 1:2 with 30 cm rows (₹ 45,566/ha) which was on par with sorghum + chickpea (2:1) 45 cm rows (₹ 41,776/ha) and sorghum + linseed (1:1) 30 cm rows (₹ 41,321/ha). Similar results obtained by Gautam *et al.* (2004). They reported that gross returns was highest under soybean+ sorghum intercropping system of 1:2 row ratio followed by soybean+sorghum in 4:2 row ratio. Significantly lowest gross returns was noticed in sorghum + linseed (1:2) 22.5 cm rows (Table 1).The higher gross returns in sorghum could be attributed to higher yields of sorghum and linseed yield.

Significantly higher net return was recorded in sorghum+linseed in 1:2 with 30 cm rows (₹ 34,348/ha) and which was on par with sorghum + chickpea (2:1) 45 cm rows (₹ 31,210/ha) and sorghum + linseed (1:1) 30 cm rows (₹ 29,876/ha). The higher net return from these treatments was mainly because of higher yield level of both the crops and higher market price of component crop as compared to other treatment combinations. Similarly Biru Amedie (2004) reported the highest net returns in sorghum+soybean intercropping. Significantly lowest net return was noticed in sorghum+linseed (1:2) 22.5 cm rows (Table 1). Higher B: C was recorded in sorghum + linseed (1:2) 30 cm rows this could be attributed to lower cost of cultivation (Table 1). The higher economical advantage of these intercropping systems was due to higher grain yield from intercrops besides higher market price. The results are in conformity with the findings of Subbian and Selvaraju (2000), Angadi *et al.* (2004) and Biru Amedie *et al.* (2004).

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Effect of ethrel spray on ISF induction in pistillate line of castor SKP-84

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(Received: December, 2014; Revised: May, 2015; Accepted: June, 2015)

ABSTRACT

Reducing the number of interspersed staminate flowers (ISF) in female line is an important breeding objective in castor. An experiment was carried out to investigate the effect of ethrel spray on the level of ISF induction in pistilate lines in castor. Male line (SKI-215) and pistillate line (SKP-84) were grown in 4:1 ratio. Ethrel was sprayed at 0.1 per cent in pistillate line. Ethrel treated pistillate line exhibited significantly less number of the ISF in primary spikes. In addition, ethrel spray lead to reduced length of primary spike, increased spike compactness, early induction of flowering, early spike development, stunted stigma growth and reduced plant canopy.

Keywords: Castor, Ethrel, Interspersed Male Flower, Monoecious, Pistillate line, Stunted stigma

Castor (*Ricinus communis* L.) is an important industrial oilseed crop in the world. It is monoecious in nature and its sex expression is very sensitive to environmental factors. Hormones have been reported to play central role in control of sex expression in variuos monoecious crops. Ethylene (Meilian *et al.,* 2011), NAA (Naphthaleneacetic acid) and 6-BA (6- Benzylaminopurine) have been reported to promote femaleness in many crops like castor, cucurbits, *Cannabis* spp. etc. Hormones regulate the sex expression either directly or indirectly. The enhancement of femaleness by auxin possibly occurs through the induction of ethylene biosynthesis (Kumar *et al.,* 2009) in response to auxin. There are also evidences to suggest that higher concentration of ethyl hydrogen 1-propyl phosphate (4,000 to 16,000 ppm) promotes transformation of female into male flower (Philipos and Narayanaswamy, 1976). Some antagonistic compounds like silver and cobalt ions, which reduce ethylene concentration in tissue, leading to formation of male or bisexual flower in place of female ones (Ram and Sett, 1980). Genetic purity of hybrid plays pivot role in castor seed productivity and genetic purity of hybrid depends on pistillateness of female parent line. Reducing number of ISF in parental female line leads to increase in the genetic purity of hybrid seed and reduces the cost of roguing. Present investigation was carried out to access the role of ethrel in reducing the ISF in female parent of castor.

The experiment was conducted in seed production plot of castor hybrid GCH-7 at Regional Research Station, Anand Agricultural University, Anand, Gujarat in *rabi,* 2011. Pistillate line "SKP-84" and male line "SKI-215" were sown in 4:1 ratio (4 pistillate lines and 1 monoecious male line) with inter row spacing of 120 cm and intra row spacing of 60 cm. A total of 28 pistillate blocks were maintained in the field. Each block consisted of around 333 plants of SKP-84 genotype, grown in 4 lines. Ethrel 0.1% was sprayed on the pistillate line at 30 days after sowing (Ankaiah *et al*., 2011). Ethrel was applied in alternate blocks (14 blocks) and rest of the blocks were kept as control (14 blocks: no spray). Plants showing ISF were observed and counted twice (15 days interval) on 48 days after sowing and 63 days after sowing. Off-type plants and ISF plants were removed after observations to maintain purity in seed production plot.

There was significant reduction in occurrence of ISF in the pistillate lines treated with 0.1% ethrel as compared to control treatment. Number of pistillate plants with ISF in ethrel treated blocks was 35, whereas in control, it was 81. This trend continued during the later stage of roguing too, during which 52 plants in ethrel treated blocks showed ISF, whereas 124 plants exhibited ISF in non treated blocks (Table 1). In total (both the roguing in combination), 1.9% and 4.4% plants were observed to contain ISF in Ethrel treated and control plants, respectively.

Morphological changes associated with reduced spike yield like short-compact spike, early flowering, stunted stigma and less seeds setting per inflorescence were also observed in the primary spike of ethrel sprayed pistillate lines (Fig. 1). Reduction in spike seed yield was also reported in *Jatropha curcas* (Makwana *et al.,* 2010). It was observed that application of GA_3 hormone increased number of female flowers at low concentration (10 to 100 ppm). However, at higher concentration (1000 ppm) there was increase in number of female flowers but fruit yield decreased. Fig. 2 also emphasizes that ethrel spray reduced

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Fig. 1. Comparison between primary spike of pistillate line of ethrel spray (0.1 %) and control.
Ethrel sprayed spikes were short, compact, early flowering and had stunted stigma

canopy of pistillate line (SKP-84) compared to control. It can also be seen (Table 1) that number of ISF increased in gradient manner from Block-1 to Block 14 in both control and ethylene treated pistilate lines, this unidirectional increase may be due to wind direction, which had created specific different microclimate at both the ends of the experiment. This needs to be substantiated with further studies.

From the present study it is concluded that 0.1% ethrel spray significantly reduced the ISF in primary spike in pistillate lines of castor. However, this change was accompanied with negative yield traits. Optimization of ethrel spray by studying the effect of various concentration of ethrel on ISF induction should be undertaken to reduce the negative yield effect.

Table 1 Number of ISF in control and ethrel sprayed (0.1%) pistillate blocks

Blocks (Replication)	3/11/2011 (ISF) (48 days after sowing)		16/11/2011 (ISF) (63 days after sowing)	
	Ethrel	Control	Ethrel	Control
1	1	3	0	2
2	1	3	0	2
3	1	1	1	3
4	2	4	1	3
5	1	5	3	9
6	2	8	4	9
7	1	7	3	10
8	1	4	3	9
9	3	7	9	10
10	4	8	9	15
11	4	7	6	15
12	4	7	6	15
13	5	8	3	11
14	5	9	4	11
Total ISF	35	81	52	124
Treatment MS	75.57*		185.14*	
SEm±	0.30		0.53	
CD (P=0.05)	0.92		1.63	

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Fig. 2. Comparison between ethrel sprayed vs. control pistillate block. Ethrel sprayed block has less canopy (which can be seen as wide gap between two rows) as compared to control

Effect of phyllosphere and spike mycoflora on castor gray mold incited by *Amphobotrys ricini*

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(Received: June, 2015; Revised: June, 2015; Accepted: June, 2015)

ABSTRACT

Gray mold of castor incited by *Amphobotrys ricini* is an economically important disease causing heavy losses during capsule formation stage under high humid conditions. The phyllosphere and spike mycoflora were isolated from castor and tested for their bioefficacy against gray mold under laboratory and greenhouse conditions. The mycoflora isolated were identified based on morphological characters as species of *Acremonium, Aspergillus, Choanephora, Cladosporium, Fusarium, Macrophomina* and *Penicillium.* Among the mycoflora tested *in vitro,* highest inhibition of the test pathogen was recorded with *Acremonium* species. Greenhouse evaluation of phyllosphere and spike mycoflora by detached spike method has shown that inoculation of detached spikes with *Penicillium* spp. 24 hours prior to pathogen inoculation has significantly reduced gray mold severity compared to control.

Keywords: *Amphobotrys ricini,* Castor, Gray mold, Phyllosphere mycoflora, Spike mycoflora

India is the leading producer of castor (*Ricinus communis* L.) in the world contributing to 65% of share in world castor production. India exports 4 lack tonnes of castor oil earning 40 billion rupees in foreign exchange (SEA, 2014). Castor is known to be infected by fungal and bacterial diseases at different crop growth stages reducing its productivity. Among these, one of the most destructive diseases of castor, primarily infecting inflorescence and racemes, is gray mold, caused by the fungus, *Amphobotrys ricini* (N.F. Buchw.) Hennebert. Castor phyllosphere and spikes provide a habitat for microorganisms termed the phyllosphere and the inhabitants are called epiphytes (Inacio *et al.,* 2002). These epiphytes can promote plant growth and both suppress and stimulate the colonization and infection of tissues by plant pathogens (Lindow and Brandl, 2003). Species of *Trichoderma, Gliocladium, Ulocladium* and *Sporidesmium* isolated from phylloplane have been found antagonistic to *Botrytis* species and were utilized in their management (Lee *et al*., 2004; Zhang *et al*., 1996). Hence, the knowledge of phyllosphere and spike mycoflora is important for management of plant pathogens in view of the adverse effects of chemical fungicides on environment. In the present investigation, isolation of phyllosphere and spike mycoflora of castor and testing their efficacy against *A. ricini* under laboratory and greenhouse conditions was attempted.

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The mycoflora associated with castor leaves was isolated following modified leaf washing technique (Deb *et al.,* 1999). Ten fresh, healthy castor leaves were collected at random from College Farm, Rajendranagar, Hyderabad and research fields of Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad, in a polythene bag and brought to the laboratory. Five discs were cut from each leaf with the help of 5mm sterile cork borer. As such 50 leaf discs were cut and transferred to a conical flask containing 100 ml sterile water blank. The discs were thoroughly agitated for 20 minutes using a Neolab Vortex mixer. Serial dilutions were prepared in the standard way and the dilutions (10^{-3} and 10^{-4}) were plated in Petri dishes containing potato dextrose agar and the inoculated Petri dishes were incubated in a BOD incubator at 25±1°C. Four replicates were maintained for all the dilutions tested. The Petri plates were observed daily and the fungal colonies obtained were transferred to PDA slants for further use.

The fungi associated with the castor spikes were isolated using the serial dilution plate method (Aneja, 2001). Fresh, healthy spikes were collected in a sterile polythene bag and brought to the laboratory. The spikes were cut into small pieces with the help of a sterile stainless steel blade. Out of this, ten grams of spike tissue was weighed in a single pan electronic balance and transferred to conical flask containing 100 ml sterile water blank. The contents were thoroughly agitated for twenty minutes using Neolab Vortex mixer. Serial dilutions were prepared in the standard way and the dilutions (10^{-3} and 10^{-4}) were plated in Petri dishes containing PDA and the inoculated Petri dishes were incubated in BOD incubator at 25±1°C. Four replicates were maintained for all dilutions. The Petri plates were observed daily and the fungal colonies obtained were transferred to PDA slants for further use.

The fungi isolated from phyllosphere and spikes of castor were screened for antagonism against *A. ricini* under *in vitro* conditions on oat meal enriched medium by following dual culture technique (Mortan and Sproube, 1995). Three replications were maintained for each treatment. The per cent growth reduction of the test pathogen was calculated when the growth of the pathogen was full in the control plates by using the formula of Vincent (1927).

The fungal antagonists were screened for their biocontrol potential against *A. ricini* using detached spike assay in a closed polythene humid chamber. Racemes/spikes were collected from castor plants (cv. DCH-519) and were kept in conical flasks containing 2% sucrose solution and are arranged on a green house bench in a randomized complete block design and replicated thrice. Racemes were sprayed with conidial suspension (10^7conidia/ml) of potential antagonists and inoculum (10^6conidia/ml) of *A. ricni* was sprayed 24-h after pathogen inoculation. Racemes sprayed with water alone or inoculated with spore suspension (10^6 conidia/ml) of *A. ricini* alone served as healthy and inoculated controls. Treated racemes were transferred to polythene humid chamber with fogging devices in which temperature and humidity were maintained at 22±2°C and relative humidity at 90%. Per cent infected capsules in each treatment were calculated when maximum number of capsules was infected in control using the formula:

Per cent infected capsules =

$$\frac{\text{Number of infected capsules in a raceme}}{\text{Total number of capsules in a raceme}} \times 100$$

The disease progress in various treatments was assessed using the disease severity scale given by Mayee and Datar *et al.* (1996) when maximum disease severity is observed in inoculated control.

Ten fungi were isolated and based on their morphological characters, they were identified up to genus level as *Acremonium, Aspergillus, Choanephora, Cladosporium, Fusarium, Macrophomina* and *Penicillium.* Among the fungi isolated, *Aspergillus* was found to be the most abundant one on phyllosphere and racemes of castor. *Aspergillus* species were identified based on morphology as *A. flavus, A. fumigatus, A. niger* and *A. terreus.* These results are in accordance with Singh *et al.* (2014), who observed that in castor *Aspergillus fumigatus* is the dominant species on phyllosphre followed by *Alternaria alternata* and species of *Mucor, Curvularia, Fusarium, Helminthosporium, Penicillium* and *Cercospora*.

However, the microbial diversity of phylloplane is known to be influenced by plant age, species, micro- and macro-habitat, changes to environmental factors and position of leaf on the plant (Talley *et al*., 2002). For example, five species of fungi *viz., Alternaria ricini, Aspergillus fumigatus, Cercospora ricinela, Curvularia clavata* and *Fusarium* spp. were dominant on castor (Family, Euphorbiaceae) phylloplane during summer season and *Emericella nidulans, Leveillula taurica* and *Melampsora ricini* were predominant during winter season. Maximum number of fungi was isolated from castor phylloplane during March and April and minimum numbers during December to January in Jorhat, Assam, India (Borgohain *et al*., 2014).

The native mycoflora isolated from phyllosphere and racemes of castor were screened for their antagonistic potential against *A. ricini* by dual culture technique. Data in the Table 1 indicated that all fungi were effective in inhibiting the mycelial growth of *A. ricini*. Highest inhibition (56.85%) of the test pathogen was recorded with *Acremonium* spp. compared to all other treatments. This is followed by *Macrophomina* spp. which inhibited the pathogen to an extent of 39.07%. *Choanephora* spp., *Aspergillus fumigatus* and *Aspergillus niger* were found to be on par with each other by inhibiting mycelial growth by 34.26, 33.89 and 33.33%, respectively indicating that there is no significant difference between these treatments. The isolates, *Cladosporium* spp., *Fusarium* spp., *Aspergillus flavus* and *Penicillium* spp. showed 26.11, 24.44, 23.15, 22.40% inhibition, respectively. *Aspergillus terreus* recorded least (20.56%) inhibition of mycelial growth of *A. ricini* compared to all other treatments.

Table 1 *In vitro* evaluation of phyllosphere and spike mycoflora of castor in inhibiting the mycelial growth of *A. ricini*

Treatment	Per cent inhibition of mycelial growth
Acremonium spp.	56.85 (48.92)*
Aspergillus terreus	20.56 (26.95)
Aspergillus flavus	23.15 (28.73)
Fusarium spp.	24.44 (29.56)
Aspergillus niger	33.33 (35.25)
Aspergillus fumigatus	33.89 (35.57)
Penicillium spp.	22.40 (28.22)
Choanephora spp.	34.26 (35.81)
Macrophomina spp.	39.07 (38.66)
Cladosporium spp.	26.11 (30.70)
CD (P=0.05)	2.85
SEm (±)	1.35
CV (%)	4.91

*Figures in the parenthesis are angular transformed values

Tirupathi *et al.* (2006) tested the efficacy of phylloplane mycoflora *viz., Trichoderma* spp., *Penicillium* spp., *Aspergillus* spp., *Curvularia* spp., *Fusarium* ssp., and *Alternaria* spp., against *A. ricini.* The highest disease inhibition of pathogen was obtained with *T. viride* and *Penicillium digitatum.* In the present investigation, was found least effective against *A. ricini* under laboratory conditions. This type of variation in parasitic potential within different isolates of *Penicillium* spp. might be due to inherent genetic variations within the species which have been well established and documented by Dennis and Webster (1971).

Ten fungal antagonists were evaluated under green house conditions for their efficacy against *Botrytis* gray rot of castor using detached spike technique. The results are presented in Table 2. Results reveal that all the treatments have significantly reduced the per cent infected capsules compared to inoculated control. The per cent infected capsules were minimum in racemes pre-inoculated with *Penicillium* spp. (7.33%) which was significantly superior to all other treatments. This was followed by raceme sprays with *Aspergillus flavus* (15.00%), *Acremonium* spp. (16.33%) and *Aspergillus niger* (33.33%). *Aspergillus flavus* and *Acremonium* spp. were statistically at par with each other. There was no significant difference between the treatments of raceme spray with *Fusarium* spp. (41.67%) and *Cladosporium* spp. (41.67%). The per cent infected capsules were highest in racemes sprayed with *Aspergillus terreus* (50.33%), *Choanephora* spp. (58.67%), *Aspergillus fumigatus* (70.67%) and *Macrophomina* spp. (85.33%).

Table 2 Greenhouse evaluation of castor phyllosphere and spike mycoflora in reducing the gray mold disease caused by *A. ricini*

Treatments	Mean per cent infected capsules	Per cent reduction over control	Severity rating
Acremonium spp.	16.33 (23.72) *	82.50	4
Aspergillus terreus	50.33 (45.17)	46.07	6
Aspergillus flavus	15.00 (22.71)	83.93	4
Fusarium spp.	41.67 (40.18)	55.35	6
Aspergillus niger	33.33 (35.15)	64.29	5
Aspergillus fumigatus	70.67 (57.25)	24.28	7
Penicillium spp.	7.33 (15.36)	92.15	3
Choanephora spp.	58.67 (50.01)	37.14	7
Macrophomina spp.	85.33 (68.14)	8.57	9
Cladosporium spp.	41.67 (40.15)	55.35	6
Control	93.33 (75.04)	0.00	9
CD (P=0.05)	7.12		
SEm (±)	2.40		
CV (%)	9.66		

*Figures in the parenthesis are angular transformed values

The results are in agreement with Tirupathi *et al.* (2006), who evaluated phyllosphere mycoflora against castor gray mold incited by *B. ricini.* Phylloplane mycoflora *viz., Trichoderma* spp., *Penicillium* spp., *Aspergillus* spp., *Curvularia* spp., *Fusarium* ssp., and *Alternaria* spp. were evaluated against castor gray mold under green house conditions. Under *in vitro* experiments highest disease inhibition of pathogen was obtained with *T. viride* and *Penicillium digitatum.* Under glass house conditions, foliar spray with *Trichoderma* spp. ($1x10^6$ spores/ml) prior to pathogen inoculation recorded minimum incidence of gray mold compared to control. In the present study, *Penicillium* spp. was found effective under green house conditions which may be due to the species variation or strain differences existing within the fungus.

To conclude, the phyllosphere and spike mycoflora have inhibitory effect on castor gray mold pathogen, *A. ricini.* However, the phyllosphere and spike colonization potential and the bioefficacy of phyllosphere and spike mycoflora under field conditions need to be studied for effective management of castor gray mold disease.

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Impact of farmer field school on extent of adoption of improved practices by groundnut farmers

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(Received: May, 2015; Revised: June, 2015; Accepted: June, 2015)

ABSTRACT

The present study was conducted in Chittoor district of Andhra Pradesh to know the impact of Farmer Field School (FFS) on extent of adoption of improved practices by groundnut farmers. The sample consisted of two groups of participants and non-participants (120 each group) making a total sample size of 240 farmers. The study followed expost-facto research method. The results revealed that half of the participant farmers were in the medium adoption category followed by high and low adoption categories whereas, less than half (45.83%) of non-participant farmers were in the medium adoption category followed by low and high adoption categories, respectively. Majority of the participant farmers had adopted the improved practices taught in FFS when compared to non-participant farmers. The 't' value (11.27) also indicated that there was significant mean difference between participant and non-participant farmers of FFS about adoption of improved practices of groundnut. It is concluded from the study that the season long FFS programme had positive impact on adoption of improved practices in groundnut by the participant farmers.

Keywords: Adoption, Farmer Field School, Groundnut, Impact

Farmer Field School (FFS) is a community based, practically oriented, field study programme, involving a group of farmers, facilitated by extension personnel. FFS aims to affect farmer's knowledge, which can be interpreted broadly to include the possession of analytical skills, critical thinking and ability to make better decisions, as well as familiarity with agricultural practices, adoption of new technologies and understanding of interactions within the agricultural ecosystem (Ali and Haider, 2012). Improved knowledge is, in turn, reflected in farmers' cultivation practices, input management, and crop yields. FFS approach should be encouraged as an intensive teaching method to enhance adoption of critical technologies (Gopala *et al*., 2012). Groundnut was major crop in Chittoor district of Andhra Pradesh grown in area of 1.62 lakh ha with a production of 1.91 lakh tonnes and with an average yield of 864 kg/ha. Government of Andhra Pradesh started FFS programme in the name of Polambadi with an objective of reducing cost of cultivation and increase the productivity duly empowering the farmers to take economical decisions by adopting integrated crop management practices. Department of Agriculture organized about 805 FFSs from 2009 to 2012 in groundnut in Chittoor district of Andhra Pradesh to improve the knowledge levels and to motivate the farmers towards adoption of improved practices. Hence the present study was conducted to find out the impact of FFS on extent of adoption of improved practices by groundnut farmers.

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The present study was conducted in Chittoor district of Andhra Pradesh during 2012-13. The study followed *expost-facto* research method. Twelve villages from twelve mandals of Chittoor district were selected randomly for the study. 120 participant and 120 non-participant farmers of groundnut FFS at the rate of ten from each village were selected randomly, thus making a sample size of 240 farmers. Adoption is the acceptance and practical application of a particular recommended practice. To measure the extent of adoption, an interview schedule was prepared with thirty recommended groundnut practices in consultation with the scientists of RARS and Professors of S.V. Agricultural College, Tirupati. Thirty recommended practices of groundnut prepared in Telugu language were administered to both participant and non-participant farmers of groundnut FFS. The relevant information with regard to adoption of improved practices in groundnut were collected, scored, quantified, categorized, tabulated and interpreted using statistical methods like mean, standard deviation, and 't' test.

Based on the total score, the participant and non-participant farmers of FFS were classified in to three categories namely low, medium and high based on mean and standard deviation as measure of check. The extent of adoption of participant and non-participant farmers of FFS with regard to improved practices in groundnut was presented in the Table 1.

It could be seen from the Table 1 that half of the participant farmers (50.0%) of groundnut FFS were in the medium adoption category followed by high (26.67%) and low (23.33%) adoption categories whereas less than half

(45.83%) of non-participant farmers were in the medium adoption category followed by low (35.00%) and high (19.17%) adoption categories, respectively.

It was observed that there was significant difference in adoption of participant and non-participant farmers of groundnut FFS. Adoption is a decision to make full use of an innovation as the best course of action available. The mean adoption score (54.80) of participant farmers was higher than that of non-participant farmers (21.90). It was due to after observing the results in experimental plot during FFS programme, the participant farmers might have got confidence on the new innovations of groundnut cultivation and so adopting the same in their fields. The continuous interaction of participant farmers with FFS officials and experts or subject matter specialists during the season long field study resulted in gaining knowledge and skills about groundnut cultivation might have also contributed to adoption of the same. Lack of technical guidance, lack of contact with extension personnel, low mass media exposure and extension participation may be the reason for lower adoption of improved practices in groundnut by the non-participant farmers. The findings are similar to that of Rajeev Raghuvanshi *et al.* (2012), Rao *et al.* (2012), Shabnam (2011) and Sreenivasulu (2011).

Independent 't' test was carried out to assess the significant difference in mean adoption between participant and non-participant farmers of groundnut FFS programme. It is observed from the Table 1 that calculated 't' value (11.27) is greater than that of 't' table value at 0.01 level of probability. Thus it is clear that there was a significant mean difference between adoption of participant and non-participant farmers of FFS about improved practices of groundnut. It was due to the fact that the season long FFS programme had positive impact on adoption of improved practices in groundnut by the participant farmers.

Table 1 Distribution of participant and non-participant farmers of groundnut FFS based on their extent of adoption

Category	Participant farmers (N=120)		Non-participant farmers (N=120)		t-value	p-value
	F	%	F	%		
Low adoption	28	23.33	42	35.00	11.27**	0.00
Medium adoption	60	50.00	55	45.83		
High adoption	32	26.67	23	19.17		
Total	120	100	120	100		
Mean	54.80		21.90			
SD	23.43		18.53			

** Significant at 0.01 level; F- Frequency; % - Per cent

The extent of adoption (adoption behavior) in terms of full adoption, partial adoption, discontinued and non adoption with respect to thirty package of practices of groundnut by participant and non-participant farmers of FFS was studied (Table 2). The thirty package of practices were grouped in to 16 sub heads and each sub head explained in detail as given below.

About 38.34% of participant farmers were fully adopting summer ploughing practice, followed by 33.33% partial adoption, 20% discontinued and 8.33% are not adopting the practice. Reduction in pest and disease incidence, reduction in weed problem and improved yields were the reasons for full adoption of summer ploughing practice by the participant farmers. Shabnam (2011) and Yashwanth Kumar Naik (2010) reported that cent per cent of FFS participants were fully adopting summer ploughing practice.

Table 2 Extent of adoption of improved practices in groundnut by participant farmers of FFS (N=120)

Technology	Extent of adoption							
	Full adoption		Partial adoption		Discontinued		Non adoption	
	F	%	F	%	F	%	F	%
Summer ploughing	46	38.34	40	33.33	24	20.00	10	8.33
Soil testing	33	27.50	48	40.00	25	20.83	14	11.67
Selection of suitable improved varieties	70	58.33	50	41.67	0	0.00	0	0.00
Germination test	54	45.00	28	23.33	16	13.33	22	18.34
Optimum seed rate	66	55.00	24	20.00	15	12.50	15	12.50
Seed treatment	109	90.83	11	9.17	0	0.00	0	0.00
Optimum time of sowing	85	70.83	35	29.17	0	0.00	0	0.00
Recommended spacing	15	12.50	61	50.83	0	0.00	44	36.67
Seed drill (bullock drawn or tractor drawn)	14	11.67	18	15.00	0	0.00	88	73.33
Integrated Nutrient Management (INM)	39	32.50	28	23.33	11	9.17	42	35.00
Crop rotation	50	41.67	27	22.50	0	0.00	43	35.83
Pre and post emergence application of herbicides	39	32.50	33	27.50	0	0.00	48	40.00
Irrigation water management (Check basin or sprinkler method)	56	46.67	24	20.00	0	0.00	40	33.33
Integrated Pest Management (IPM)	42	35.00	23	19.17	19	15.83	36	30.00
Harvesting and threshing (use of digger and thresher)	0	0.00	0	0.00	0	0.00	120	100.00
Post-harvest (Drying of pods and storage)	64	53.33	23	19.17	0	0.00	33	27.50

F- Frequency; %- Percentage

With respect to soil testing, only 27.50% of participant farmers were adopting soil testing. Forty per cent were partially adopting followed by 20.83% discontinued and 11.67% were not adopting the practice. Delay in soil test reports and unable to calculate fertilizer doses based on soil test results were the reasons for partial adoption by the participant farmers. Sreenivasulu (2011) reported that 69% of FFS participants were fully adopting soil testing.

Majority (58.33%) of participant farmers were fully adopting and 41.67% partially adopting the suitable improved groundnut varieties. None of them were under non adoption and discontinued categories. The reasons expressed by the participant farmers of groundnut for full adoption were high yielding than traditionally used varieties, tolerant to pest and diseases, suitable for their farming situation and uniform maturity.

Majority (45.00%) of participant farmers were fully adopting the germination test before sowing followed by 23.33% partially adopting, 18.34% not adopting and 13.33% discontinued the practice, respectively. The reasons for full adoption were assured seed quality and reduction of seed cost expressed by participant farmers. Shabnam (2011) reported that more than half (54.17%) of FFS participants were fully adopting germination test before sowing of the crop.

Majority of participant farmers (55.00%) were fully adopting, 20% were partially adopting and 12.50% each were under non adoption and discontinuation. Optimum seed rate ensures higher yields, reduces pest and disease incidence and overcomes climatic aberrations were the reasons expressed by the participant farmers of groundnut for full adoption. Shabnam (2011) reported that cent percent of FFS participants were fully adopting recommended seed rate.

Majority (90.83%) of participant farmers were fully adopting and 9.17% were partially adopting seed treatment practice. None of the participant farmers were falls under non adoption and discontinuation categories. Reduces pest and disease incidence, cheapest and easiest method for controlling pest and diseases, reduces incidence of sucking pests and bud necrosis, reduces cost of cultivation and reduces incidence of root grub were the reasons expressed by the participant farmers for full adoption. Sreenivasulu (2011) reported that 64% of FFS farmers fully adopting seed treatment practice.

The adoption behavior of participant farmers with respect to optimum time of sowing was majority (70.83%) of them were under full adoption followed by 29.17% were under partial adoption. None of them were under either non adoption or discontinued categories. The reasons expressed by the participant farmers for full adoption of this practice were optimum time of sowing leads to more yield and reduces or escapes incidence of few pest and diseases. Sreenivasulu (2011) reported that 87% of FFS participants were fully adopting optimum time of sowing.

With respect to spacing 12.50% were fully adopting, 50.83% were partially adopting and 36.67% were not adopting the practice. None of the participant farmers were discontinued the practice. The reasons for partial adoption were non availability of seed drills and difficult to maintain exact spacing with traditional method of sowing given by participant farmers.

The adoption behavior of the participant farmers with respect to use of seed drill was only 11.67% full adoption, 15% partial adoption and 73.33% non adoption. None of the participant farmers were discontinued the practice. Non availability of seed drills in the village and not aware of seed drills were the reasons expressed by participant farmers for non adoption.

In case of participant farmers, full adoption of INM was 32.50%, partial adoption was 23.33%, discontinuation was 9.17% and non adoption was 35%. The reasons expressed by the participant farmers of groundnut for full adoption of INM were higher yields are possible with low cost of cultivation, crop withstands drought, reduces pest and disease incidence, reduces micro nutrient deficiencies and improves soil physico-chemical and biological properties of soil. Yashwanth Kumar Naik (2010) reported that only 4% of FFS participants of groundnut were fully adopting and 63% of FFS participants were partially adopting INM practices, respectively. Shabnam (2011) reported that 62.63% of FFS participants were fully adopting INM practices.

Majority (41.67%) of participant farmers had full adoption, 22.50% had partial adoption and 35.83% had not adopted the crop rotation. None of them were under discontinuation category. Participant farmers of groundnut expressed that improves yields, reduces pest and diseases, improves soil nutrient status and overcomes price fluctuation in the market were the reasons for full adoption.

With respect to usage of herbicides, 32.50% of participant farmers fully adopting, 27.50% partially adopting, 40% non adoption and none of them discontinued. Timely control of weeds is possible, cost of weeding is reduced, improved yields and reduced pest and disease infestation were the reasons for full adoption by the participant farmers of groundnut.

Majority (46.67%) of participant farmers fully adopting, 20% partially adopting and 33.33% had non adopting irrigation water management. None of them under discontinued category. Optimum use of irrigation water through sprinklers, improved yields and uniform flowering and maturity of pods were the reasons expressed by participant farmers of groundnut for full adoption. Yashwanth Kumar Naik (2010) reported that 6% of FFS participants were fully adopting and 27% were partially adopting water management in groundnut.

Thirty five per cent of participant farmers had full adoption, 19.17% had partial adoption, 15.83% had discontinuation and 30% had non adoption of IPM whereas, none of the non-participant farmers were fully adopting the IPM, but only 4.17% were partially adopting the practices of IPM. It was due to the fact that the participant farmers had more knowledge on IPM practices like sowing of trap and guard crops, pest and disease identification, identification of beneficial insects and their advantages, use of pheromone traps and bio-pesticides etc. Because of continuous and weekly participation in the FFS classes might have influenced them to adopt IPM practices in groundnut. The similar results reported by Dinpanah *et al.* (2010). The reasons expressed by the participant farmers of groundnut for full adoption of IPM practice were reduces pest and diseases, reduced chemical pesticide usage, incidence of *Spodoptera* or red hairy caterpillar is noticed in the egg stage itself and controlled at that stage before it damages the crop and groundnut cultivation is possible without using chemicals. Yashwanth Kumar Naik (2010) reported that 12.4% of FFS participants were fully adopting and 43.8% were partially adopting IPM practices in groundnut. Shabnam (2011) reported that 46.50% of FFS participants were fully adopting IPM practices.

Cent per cent of participant and non-participant farmers were not adopting the use of digger for harvesting and thresher for stripping of groundnut pods. Unaware of the implements/machinery, non-availability of the implements/ machinery, tractor is required for operation and high cost of machinery were the reasons expressed by the participant farmers for non adoption.

More than half (53.33%) of participant farmers were under full adoption, 19.17% under partial adoption, 27.50% under non-adoption with respect to drying and storage. None of the participant farmers discontinued the practice. Long storage life, reduction in storage pests and diseases, possible to use as seed for next season, and maintenance of quality seed is possible were the reasons behind full adoption of this practice by the participant farmers of groundnut.

Extent of adoption of improved practices in groundnut was more in the case of participant farmers when compared to non-participant farmers of groundnut FFS. It was due to the participation of participant farmers of groundnut in season long FFS programme and it might have influenced the adoption of improved cultivation practices. It is concluded from the study that the season long FFS programme had positive impact on adoption of improved practices in groundnut by the participant farmers.

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OBITUARY

Dr. Pellakuru Subba Reddy
(1937-2015)

Plant Breeding discipline, in particular groundnut (peanut) breeding, lost a distinguished scientist, an honest and efficient administrator when Dr. Pellakuru Subba Reddy, known as Dr. P.S. Reddy, died on May 22, 2015. Dr P.S. Reddy was born on the 1st July, 1937 in Makhtapuram, Nellore district, Andhra Pradesh. He completed his Bachelor's degree in Agriculture in 1960, Masters degree in 1963 and Ph.D. degree under the guidance of Dr. D'Cruz in the year 1967. He was appointed as Assistant Oilseeds Specialist at the Andhra Pradesh Agricultural University, Rajendranagar (now known as ANGRAU) in 1967 and continued in that position till as an Assistant Professor in 1974. He moved to ICAR in 1979 as the Project Coordinator (Groundnut) at the National Research Centre on Groundnut (NRCG, now known as Directorate of Groundnut Research, DGR) in Junagadh and in 1984 Dr. Reddy was appointed as the first Director of NRCG. After 10 years of service at NRCG he was posted as the Project Director at Directorate of Oilseeds Research, Rajendranagar (DOR, now known as the Indian Institute of Oilseeds Research, IIOR) in 1995 and he remained in that position until his retirement in 1997.

Dr. Reddy is recognized for his significant contributions to oilseeds research and development. During his brief tenure at ANGRAU he developed the popular sunflower hybrid APSH-11 and three popular groundnut cultivars Kadiri-71-1, Kadiri-2, and Kadiri-3. The Kadiri-3 was released for general cultivation in several states in India and it was also released in the countries Myanmar, Tanzania and Zambia through combined efforts of ICRISAT and National Institutes. The most popular advanced breeding lines from ICRISAT, ICGS 11 and ICGS 44 were derived from Kadiri-3. Dr. Reddy was chiefly responsible for establishing laboratory and office buildings, staff quarters and a guest house at NRCG in Junagadh. His tireless efforts had resulted in the allotment of over 100 hectares of land, by the Gujarat Agricultural University, for NRCG on-farm research. During his tenure at NRCG he was responsible for release of the groundnut cultivar Girnar-1. His contributions towards establishment of administrative building, trainees hostel, staff quarters and glass houses at IIOR are commendable. So he was referred as "you are destined to build" by Dr. Paroda, the then Deputy DG of ICAR. These achievements by Dr. Reddy at NRCG and IIOR stand as an eloquent testimony for his visionary skills and as an able administrator, with impeccable integrity. Dr. Reddy had published over 150 research papers and 15 technical bulletins. A monograph on groundnut published by ICAR was edited by Dr. Reddy later translated into Vietnamese and published by the Government of Vietnam. He co-authored book entitled "Cytogenetics and Genetics of Groundnut". He visited Soviet Union, Bangladesh, Indonesia, Philippines and China.

Dr. Reddy was kind hearted, modest and known for his impeccable integrity. Dr. Reddy is survived by his wife, Suguna, and two daughters. It is undoubtedly an irreparable loss not only for the agriculture fraternity but also for his family members. Every person who was acquainted with Dr. P.S. Reddy and especially the staff of IIOR and members of oilseeds society, deeply mourn his death and earnestly pray the Almighty that, the departed soul may rest in peace.

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