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CONTENTS

Special Article

Powdery mildew disease in sunflower : A review

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ABSTRACT

Sunflower (*Helianthus annuus* L.) is one of the most important oilseed crops in the world. It is introduced in India during seventies and has occupied an important position in the oilseed economy of the country. The area under sunflower has reached to a maximum of 2.5 million ha during 1994 which declined drastically within the last two decades to 6.9 lakh ha (2014-15). Among the production constraints, vulnerability of the released cultivars to diseases at both vegetative and flowering stages played a major role compelling farmers to switch over to alternate crops. Of the various diseases, alternaria leaf blight, downy mildew and sunflower necrosis diseases attack the crop during vegetative stage while powdery mildew infects the crop from flowering to post flowering and seed formation stages. Powdery mildew is the economically important disease of the tropical regions but has not been witnessed on sunflower in India till the recent past. In India, powdery mildew was reported in high intensity (80%) during the year 2006-07 on *rabi* crop in some areas around Bengaluru and Raichur which increased over the years. Currently, the disease is observed on the crop in all growing situations *viz., kharif, rabi* and spring recording 30-75 per cent disease severity and causing yield losses to the tune of 20-50 per cent necessitating research for development of management strategies. Intensive research work on sunflower powdery mildew is being carried out at Indian Institute of Oilseeds Research, Hyderabad and University of Agricultural Sciences, Bengaluru and disease management practices are being worked out at various AICRP sunflower centres. This review presents the information on the distribution, economic importance, symptomatology, epidemiology, disease cycle, sources of resistance and management strategies for powdery mildew disease on sunflower.

Keywords: *Helianthus annuus*, Management, Powdery mildew, Sunflower

Sunflower (*Helianthus annuus* L.) is an important oil seed crop of the family Asteraceae. Sunflower has shown distinct superiority over other oilseed crops owing to its wider adaptability to different agro-climatic conditions, highest oil production per unit area, short duration, high yield potential, ability to withstand drought, photoperiod insensitivity, lower seed rate, high seed multiplication ratio and high quality edible oil (Sindagi and Virupakshappa, 1986).

Sunflower is a rich source of edible oil (40-52%) having anticholesterol properties due to the presence of polyunsaturated fatty acids (55-65% linoleic acid and 20-30% oleic acid) which are known to reduce the risk of coronary diseases (Joksimovic *et al*., 2006). Apart from its edible properties, sunflower also has many commercial uses as protein source and confectionery, feed and fuel, in the manufacture of fine paints, soaps, cosmetics, etc. In pharmaceutical industry, it is used as a diuretic and for treating certain disorders of the respiratory tract.

Large scale cultivation of sunflower in India started only in 1972 with the introduction of high yielding open pollinated varieties from USSR and Canada. The development of early maturing variety Morden as well as the first sunflower hybrid, BSH-1 in 1980 provided the required fillip to expand sunflower cultivation in the country (Seetharam, 1984). Sunflower has attained a prime position in the oilseed economy of the country. During 2013-14, the area under sunflower cultivation in India was 0.691 million ha, with a total annual production of 0.547 million tonnes and productivity of 729 kg/ha. Sunflower is largely confined to southern parts of the country comprising the states of erstwhile Andhra Pradesh, Karnataka, Maharashtra and Tamil Nadu. These four states contribute about 90 per cent of total acreage and 78 per cent of total production. In the recent past, the area has expanded under *rabi* and spring cultivation in Northern India and in rice fallows.

Profitable cultivation of sunflower is limited by the vulnerability of the released varieties and hybrids to multiple diseases and pests. Gulya and Masirevic (1991) listed 80 pathogens causing diseases on sunflower. However, sunflower was free from diseases when introduced in India during early 1970s. Even during early 1980s it was not much affected by diseases. The popularity of the crop among farmers resulted in larger area under the crop and as a consequence many diseases caused by fungi and viruses have co-evolved with sunflower. *Alternaria* blight incited by

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Alternariaster helianthi emerged as a major threat to sunflower cultivation during late 1980's. During 1997, sunflower necrosis disease caused by tobacco streak virus belonging to Ilar virus group was reported which spread rapidly causing severe yield losses. Along with these diseases, downy mildew and rust were also posing problems in sunflower cultivation but in restricted regions (Maharashtra) and seasons. Overall, the diseases in sunflower account for an average yield loss of 25-40 per cent (Shankergoud *et al*., 2006).

During the past decade, powdery mildew (white mould) has become one of the major diseases on sunflower in India. Among the diseases, powdery mildew caused by *Golovinomyces cichoracearum* (DC) V.P. *Heluta* var. *cichoracearum* (1988) (formerly *Golovinomyces cichoracearum* DC. ex *Meret,* 1805) has been considered as an economically important disease in the tropical regions. It affects most of the commercial cultivars under present cultivation and it has been reported from different parts of the world.

Powdery mildew was rarely observed before 2006, however, severe foliar (80%) infections of powdery mildew were observed during 2006 at Challakere and Chitradurga districts in Karnataka (Anonymous, 2007). At present, the situation has become rather alarming and the disease is seen regularly in all sunflower growing areas of the country in moderate to severe form. The loss due to powdery mildew is proportionate to the disease severity and varies considerably depending on the variety or cultivar, age and stage of the plant growth at which the disease occurs. Initially, the disease on sunflower was observed during *rabi* and spring seasons under conditions of cool weather, high relative humidity and in shady areas. Of late, the infection levels have become so high and the disease is seen even on crop cultivated during rainy and post rainy seasons. Powdery mildew flourishes when the days are warm to hot, the nights are cool with dew formation on the foliage. Conditions that favour sunflower also favour the powdery mildew growth. High inoculum in the field coinciding with favourable environmental conditions leads to early infections causing severe losses.

GEOGRAPHICAL DISTRIBUTION

Powdery mildew since long has been known as an obligate biotroph that infects a wide range of angiosperms in different parts of the world. Linnaeus (1767) established the genus Erysiphe while, De Candolle (1802) described many species. Kapoor (1967) reported that *G. cichoracearum* causes powdery mildew on 230 species belonging to 50 genera of the family Asteraceae (Fig. 1).

Powdery mildew of sunflower has a worldwide distribution and was reported first from USA in 1928 (Anonymous, 1928). Later, the disease was reported from different parts of the world like USSR (Zelle, 1933), Argentina (Anonymous, 1947), Chile (Sackston, 1956), Australia (Milddleton, 1971), Bulgaria (Shopov, 1976), Italy (Lorenzini and Triolo, 1980), Romania (Puscasu, 1980; Docea *et al*., 1981; Ivancia *et al*., 1992), Mexico (Diaz Franco, 1983), Florida (Kolte, 1985), Greece (Thanassoulopoulos, 1987), China (Yang *et al*., 1988), California (Gulya *et al*., 1991), Pakistan (Bhutta *et al*., 1993), Serbia (Masirevic and Jasnic, 2006), Taiwan (Chen *et al*., 2008) and Uganda (Anangya and Biruma, 2010).

Fig. 1. World distribution of *Golovinomyces cichoracearum* (Source: http://www.cabi.org/dmpd/)

In India, the disease was first reported from Bombay province (Patel *et al*., 1949), later from Rajasthan (Prasada *et al*., 1968), West Bengal (Goswami and Dasgupta, 1981) and Punjab (Bains *et al*., 1996). Singh and Bedi (1995) reported powdery mildew of sunflower caused by *G. cichoracearum* for the first time from Punjab and observed that none of the six cultivars and hybrids screened under natural epiphytotic conditions were immune, but infection was least on the variety Mega 363.

The distribution of the disease is worldwide but occurs in great intensity in tropical areas of the world. *Golovinomyces cichoracearum* f.sp. *helianthi* (syn *Erysiphe cichoracearum* DC ex Meret) is reported on sunflower from all continents. *Sphaerotheca fuliginea* (*Schlecht* ex Fr) Pollachi (= *S. humuli* (DC) Burr. var. *fuliginea* Salm.) was first reported from China in 1932 and later found on sunflower in Africa, Asia, Europe and South America (Saliman *et al.,* 1982; Braun, 1995). *Leveillula taurica* (Lev.) Arn is reported in restricted regions and only from China, India, the former Soviet Republic and the middle East.

ECONOMIC IMPORTANCE

Powdery mildew infection on sunflower causes early senescence during the flowering and grain formation stages and causes significant reduction in the yield in tropical areas (Zimmer and Hoes, 1978). Powdery mildew causes up to 15 per cent stunting and 81 per cent reduction in yield under green house conditions (Saliman *et al*., 1982). Yield loss was found proportional to the disease severity and the crop stage at which it occurred (Diaz Franco, 1983). Powdery midew

infection on sunflower causes early senescence during the flowering and seed formation stages and causes significant reduction in the yield in tropical areas (Zimmer and Hoes, 1978). The disease is severe on the crop cultivated under both rainfed and irrigated conditions. In a survey in 1989, powdery mildew was found in sunflower fields in California, USA (Gulya *et al*., 1991). A high frequency (70-100%) of *G. cichoracearum* infection was observed on 25 sunflower hybrids in Romania. A field survey on powdery mildew in seven districts of Karnataka recorded 30-74% disease severity (Dinesh *et al*., 2010). The seed yield losses were up to 20.5 and 52.6 per cent at the disease severity levels of 30 and 64 per cent, respectively (Anonymous, 2011). Powdery mildew is a polycyclic disease and yield reduction is mainly due to the reduced photosynthetic activity, physiological changes and increased rate of senescence.

SYMPTOMATOLOGY

Powdery mildew caused by *G. cichoracearum* appears after flowering when the lower leaves start to senescence. Unlike most fungal pathogens, powdery mildew fungi grow epiphytically on plant surfaces and hyphae are confined to the upper leaf surfaces which spread to lower surfaces under severe conditions. The disease begins as minute discoloured specks on leaves from which powdery mass radiates on all the sides. All the aerial parts of the host are covered with white powdery mass containing mycelia and conidia of the fungus (Singh, 1984). It is easily recognizable as white to grey powdery growth on upper surfaces of older (lowest) leaves which enlarge in size, coalesce and develop to cover the entire leaf area. The distinctive white powder on the leaves is composed of fine threads of fungal vegetative tissue (mycelium) and light coloured mats of asexual spores. Gradually the infection extends to petiole, stem and other aerial parts including capitula and reduces the vigour of the host plant.

In the temperate regions, powdery mildew usually is not observed until flowering and the disease intensity is seldom of any economic importance. However, with regular occurrence of the disease, infection is observed even on cotyledonary leaves of the susceptible cultivars and also on vegetative shoots of perennial *Helianthus* species. In Taiwan, powdery mildew infection on sunflower caused severe yellowing on the blade, petiole, stem, and calyx leading to serious defoliation (Chen *et al*., 2008). With progression of the season, microscopically visible black pin head sized dots scattered over the white mildew areas seen which are the overwintering chasmothecia (syn. *Cleistothecia*) that contain asci and ascospores. Heavily infected leaves lack lustre, curl, become chlorotic, dry up and shed prematurely. Losses due to powdery mildew occur mainly due to reduced photosynthetic efficiency.

Symptoms caused by the three powdery mildew fungi on sunflower are almost similar except for few subtle differences (Kolte, 1985). *G. cichoracearum* and *P. xanthii* infection initially appear as white to grey spots on the upper surface of older leaves. Subsequently, the superficial mildew mycelium spreads over the entire leaf surface and gives a powdery appearance due to the continuous production of conidia. However, *Leveillula*-infected sunflower is observed to have pale green to yellow round spots on the upper surface of the leaves which coalesce to cover the entire leaf surface. On the underside of the affected leaves powdery gray to purple covering of mycelium and conidia is found.

CAUSAL ORGANISM

Two different genera of powdery mildew fungi *viz*., *Sphaerotheca fuligenea* (Schlecht. Ex. Ft.) Pollacci and *Erysiphe cichoracearum* DC. f.sp. *helianthi* Jacz are reported on sunflower in India (Patel *et al.,* 1949; Prasada *et al.,* 1968; Goswami and Dasgupta, 1981) and Taiwan (Chen *et al.,* 2008).

G. cichoracearum is an obligate biotrophic fungus belonging to the Kingdom - Fungi; Phylum - Ascomycota; Class - Filamentous/Leotiomycetes Ascomycetes, Leotiomycetidae; Order - Erysiphales; Family - Erysiphaceae; Genus - *Erysiphe*; Species - *cichoracearum*. The fungus has been reported to be an ectoparasite with superficial mycelium, which is hyaline, branched and septate besides haustoria in epidermal host cells. Conidia are oval/barrel shaped, single celled, hyaline and measure 28-60 x 11-28µ in size, produced in long or short chains. Cleistothecia measure 60-90 x 25-50 µ and contain 10-30 asci. Each oval ascus contain one to two elongate to oval ascospores measuring 20-30 x 12-60 µ in diameter (McKeen *et al*., 1966). Conidia germinate optimally at 20-25°C under conditions of high humidity within two to four hours after falling on the leaf. Under optimal conditions, infection will lead to the production of more spores within five to seven days. Short life cycle and airborne nature of the spores lead to rapid spread of the pathogen under favourable conditions.

It is reported that at least three genera of powdery mildews *viz., G. cichoracearum* (=*Erysiphe cichoracearum*), *Leveillula taurica* (=*Leveillula compositarum*) and *Podosphaera xanthii* Castagne Braun & Shishkoff (=*Sphaerotheca fuliginea* auct p.p.) are the causative agents of powdery mildew in sunflower of which *G. cichoracearum* is of most common occurrence in all the continents (Fang, 1973; Saliman *et al.,* 1982; Yang *et al.,* 1988; Gulya *et al.,* 1991; Anonymous, 1994; Braun, 1995; Chen *et al.,* 2008). The three fungi can be distinguished from each other based on the chasmothecia morphology (teleomorph) and conidial characters (anamorph). Formation of chasmothecia is favoured by old leaves, low host nutrition, low humidity and

temperatures (Gulya *et al.,* 1997) (Table 1). Specialized hyphae are absent in these genera and the features of the holomorphs of the three genera are presented. Conidia of *G. cichoracearum* resemble that of *P. xanthii* but differ in production of appressoria in the former and forked germ tubes in the latter (Kapoor, 1967). *Leveillula* differs from the other two genera in that the mycelium is not limited to the epidermis, but also ramifies throughout the mesophyll (Gulya *et al.,* 1997). *G. cichoracearum* is the more prevalent pathogen on sunflower and with limited host range but *P. xanthii* with short lived and wind dispersed conidia has no host specificity and infects many other plants (Kuo *et al*., 1991). *G. cichoracearum* is reported to infect *H. tuberosus, H. scaberimum* and other *Helianthus* species (Kolte, 1985).

Table 1 Distinguishing features of the holomorphs of the genera causing powdery mildew on sunflower

Species	Holomorph genus	Mycelium	Conidiogenesis	Fibrosin body	Chasmothecial appendages/ diameter	No. of asci/ chasmothecium	Conidia type and size
Golovinomyces cichoracearum	Golovinomyceteae	External	Catenate	Absent	Myceloid and unbranched 90-135 µ	Multiple (2-3)	Monomorphic 25-45 x 14-26 µ
Podosphaera xanthii	Cystotheceae	External	Catenate	Present	Myceloid/dichotomously branched 65-100 µ	Multiple (8)	Monomorphic with fibrosin bodies 25-45 x 14-26 µ
Leveillula taurica	Phyllactinieae	Internal/ external	Single	Absent	Myceloid and unbranched 13-250 µ	Multiple (2)	Large, dimorphic 25-95 x 14-20 µ

Morphological studies: Identification of powdery mildew was largely based on the teleomorph (sexual stage) along with the morphology of the chasmothecium (syn. cleistothecium) and its appendages. As morphology of teleomorph is not conserved, identification of powdery mildew includes attributes of the anamorph (asexual stage) as well. Accordingly, the former teleomorphic genus *Erysiphe* has been grouped into the new holomorphic genus *Golovinomyces*. Conidia (asexual spores) are produced in chains on specialized hyphae called conidiophores which arise from the epiphytic hyphae. The hypha was tubular, septate in nature with nipple shaped appressoria. At frequent intervals, multiseptate conidiophores produced which are unbranched, septate and the conidia are hyaline, single celled, ellipsoid, borne in long chains on short conidiophores. These conidiophores contain two nuclei, either in the basal cell or immediately above it, indicating the capability of both the cells to generate conidia. The conidia are monomorphic, barrel shaped, uninucleate, colourless and measure 23.04-32.16 x 13.92-18.00 µm with an average size of 26 x 17 µm. Conidia germinate by producing simple germ tube with conidial size of 10 x 21.8 µm with 1:2 ratio of width to length.

Molecular characterization: According to Gulya *et al*. (1997), the two species *L. taurica* and *S. fuliginea* create similar symptoms as that of *G. cichoracearum* but they have a limited geographical range and can be easily distinguished from each other based on morphological characters. Classical identification methods based on microscopic analysis and spore trapping are labour intensive and require considerable experience in differentiating the morphologies of the powdery mildews (Grote *et al*., 2002). Chen *et al*. (2008) have developed a relatively easy and effective technique based on ITS sequence of rDNA for reliable detection and differentiation of the powdery mildew genera. The internal transcribed spacer (ITS) of nuclear ribosomal DNA regions was amplified from powdery mildew of sunflower using the powdery mildew specific ITS universal primer pair PN23 (5'-CACCGC CCG TCG CTA CTA CCG-3')/PN34 (5'-TTGCCG CTT CAC TCG CCG TT -3'). Pairs of primer, S1 (5'- GGA TCA TTA CTG AGCGCG AGG CCC CG -3')/S2 (5'- CGC CGC CCTGGC GCG AGA TAC A -3'), G1 (5'- TCC GTAGGT GAA CCT GCG GAA GGA T -3')/G2 (5'-CAA CAC CAA ACC ACA CAC ACG GCG -3'), and L1 (5'- CCC TCC CAC CCG TGT CGA CTCGTC TC -3')/L2 (5'- CTG CGT TTA AGA GCCGCC GCG CCG AA -3'), that are specific to the ITS regions of *P. xanthii, G. cichoracearum,* and *L. taurica,* to give amplicons of sizes 374, 391 and 454 bp, respectively were designed (Fig. 2).

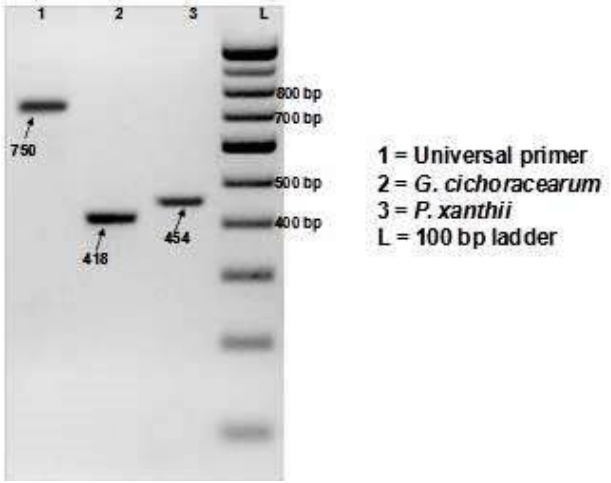

Fig. 2. PCR amplification using primers specific to 1) ITS region of powdery mildew, 2) *G. cichoracearum,* 3) *P. xanthii,* L represents 100 bp ladder

Multiplex PCR method by using combination of primer pairs is also a rapid, simple and effective technique to detect and differentiate powdery mildews (Chen *et al.,* 2008).

Screening methods: The following are the different screening methods employed to screen sunflower genotypes against powdery mildew disease.

- **Dusting conidia with camel hair brush**: Leaves of the test plants are moistened by sprinkling water. Powdery mildew conidia are slowly dusted on leaf blades of young plants by using camel hair brush.
- **Spraying of spore suspension**: A spore suspension is prepared by detaching heavily sporulating leaves and washing them with a spray of 100 ml of water and filtered through a double layer of cheese cloth. The suspension is then diluted to a spore concentration of 4 x 10^3 conidia/ml *G. cichoracearum.* This spore suspension has to be freshly prepared as and when required and sprayed on to the plants with an atomizer.
- **Swabbing with cotton**: Cotton is dipped in the conidial suspension prepared (4 x 10^3 conidia/ml) and gently rubbed on the leaves of plants to be tested.
- **Blotter paper method**: A blotter paper is dipped in the conidial suspension (4 x 10^3 conidia/ml) and gently placed on the leaves of the test plants.
- **Shaking infected leaves on healthy plants**: The infected leaves carrying conidia are shaken over healthy plants.
- **Dipping the leaves in spore suspension**: Leaves of healthy plants grown in glasshouse are dipped in spore suspension (4 x 10^3 conidia/ml).
- **Touching the leaves of test plants with infected leaves**: Leaves of the healthy plants are touched with infected leaves with full of conidia of *G. cichoracearum*.
- **Stapling method**: Infected leaves are stapled on to healthy leaves with the adaxial surfaces in contact with each other.

Disease assessment/Scoring scale: In general, on cultivated sunflower the powdery mildew reaction could be classified as strong (very high infection all over the plant), weak (infection on the lower 1/3 of the plant with weak spread to the top leaves) and no symptoms. Different disease scoring scales were used for estimation of powdery mildew infection in sunflower *viz*., 0-3 scale (Saliman *et al*., 1982; Bosko *et al*., 2012), percentage of leaf area infected (Jan and Chandler, 1985; Rojas-Barros *et al*., 2004; 2005; Gulya *et al*., 1991) and a 0-5 scale (McCarter 1993; Dinesh *et al*., 2009).

However, screening of wild *Helianthus* species, interspecific derivatives, core germplasm and exotic germplasm showed wide variability in the reaction of cultivars to powdery mildew. Hence, for scoring the powdery mildew incidence, a 0-9 disease scoring scale was developed (Prathap Reddy *et al*., 2013) (Table 2).

Table 2. Scale for scoring of powdery mildew incidence

Severity of disease on different position of the leaves			Scale	Category
Bottom	Middle	Top		
High	High	High	9	Highly susceptible
High	High	Medium	8	Highly susceptible
High	High	Low	7	Susceptible
High	Medium	Medium	6	Susceptible
High	Medium	Low	5	Susceptible
High	Low	Low	3	Moderately resistant
Medium	Medium	Medium	4	Moderately resistant
Medium	Medium	Low	4	Moderately resistant
Medium	Low	Low	2	Resistant
Low	Low	Low	1	Highly resistant
Nil	Nil	Nil	0	Immune

0 = no infection, Low = < 10% infection, Medium = 11-30% infection, High = 31-100% infection

With regard to disease infection level, the material was scored as 0= no infection on leaves; low (L) - if leaves had < 10% infection; moderate (M) - if leaves had 11-30% infection, and high (H) - if leaves had 31-100% infection. As the material was from diverse genetic backgrounds exhibiting significant variations in qualitative and quantitative characters, infection was observed on the whole plant or confined till the middle leaves or only to the lower leaves. Hence, a scale was developed based on the level of infection on the bottom, middle and top leaves. Powdery mildew severity was scored at 10-days-interval from 45 days of sowing till plant maturity. This new scale allows researchers to have reliable estimate of the disease based on the percentage of leaf area infected as well as the spread of

the disease on the plant. This scale is particularly important in scoring for the disease in mapping populations where the resistance is polygenically controlled.

DISEASE CYCLE

Being an obligate ascomycete, the fungus is strictly restricted to living host plants and is devoid of saprophytic life stages. Conidia are short lived and the pathogen overwinters through chasmothecia and survives through perennial sunflower plants. The minute chasmothecia are formed within the mycelial mat as the host tissues mature. Under favourable conditions of warm and humid weather, the chasmathecium absorbs water and cracks open to release the asci. Each ascus has 8 ascospores and the microscopic ascospores are carried by wind to healthy plant tissues where they germinate and cause infection. A mycelia mat is formed and chain of conidia on conidiophores are seen within a few days, completing the disease cycle. In conditions where the host plants and powdery mildew fungi grow simultaneously and continuously throughout the year, the chasmothecia are not produced and only the conidia (the *Oidium* stage) are formed. Being polycyclic in nature, new infection cycles are produced continuously.

The conidia and ascospores that land on the leaf surface germinate and produces the nipple shaped appressorium on the plant surface. A fine hypha develops from the bottom of the appressorium which pierces the cuticle and penetrates the host directly and forms the haustoria (feeding structures) in the epidermal cells. The haustoria are ellipsoidal with branches on each ends and are located in the cells without rupturing the host plasma membrane. Additional haustoria are formed in other epidermal cells. The fungus develops a dense branched network of hyphae on the infected plant surface. From this hyphal matrix, short erect branches (conidiophores) develop more or less perpendicular to the surface hyphae. The first complete cell of the conidiophores is termed as the foot cell and it subtends one or more additional cells which terminates in barrel-shaped conidium. Conidial production is basauxic when each new conidium forms at the base of the previous conidium with the oldest conidium at the top. Successive conidia are formed, one each day which remain attached in chains giving the characteristic white powdery appearance. The conidia eventually break away and dispersed singly or in short chains predominantly through wind to new infection sites. Conidia of *G. cichoracearum* on lettuce were reported to be dispersed 200 km in California (Schnathrost, 1959). The intimate relationship develops for nutrition from host cells. *G. cichoracearum* has a wide host range, and infects the members of family Asteraceae, Cucurbitaceae, Solanaceae and Malvaceae.

The disease cycle including production of conidia, their release, germination, infection, and the production of a new generation of conidia may be as short as 72 to 96 hours. Hence, if left uncontrolled, powdery mildew being polycyclic quickly becomes an epidemic under favourable conditions of cool, damp nights followed by warm, dry days. The pathogen survives through cleistothecia containing ascospores in the off-season and when suitable host plants are grown, the ascospores germinate to cause fresh infection. The fungus produces conidia, which are wind disseminated causing secondary spread. The conidia are capable of germinating even under dry conditions with low humidity and hence the secondary infection takes place very rapidly.

EPIDEMIOLOGY

The variation of disease incidence is influenced by several climatic factors like temperature, relative humidity, distribution and amount of rainfall, the microclimate build up besides cultural practices like sanitation and suitable management practices. Conditions that favour powdery mildew include presence of infected tissue on the plant, vigorous, succulent plant growth, warm temperatures, dry days followed by nights with high humidity. The age of the crop and the cool nights concomitant with dry weather situation is favourable for the powdery mildew disease to attain severity. Cool temperature coupled with low relative humidity is reported to cause severe epidemics of powdery mildew of sunflower (Kolte, 1985). In India, continuous cropping of sunflower during *kharif, rabi* and summer seasons over the years has also resulted in build up of the inoculum and perpetuation of the pathogen.

When conidia or ascospores fall on the leaf/plant surface, they start germinating in 3 hours or less, reaching a maximum within 24 hours. The optimum temperature for germination is 32°C; the minimum about 5°C; and the maximum about 35°C. A relative humidity in the range of 25 to 99 per cent is ideal for spore germination. Free moisture is detrimental to the spore germination of the powdery mildew fungi. The thin-walled conidia are short lived (from several hours to a day or two) upon release and their life span is dictated by temperature and relative humidity. The peak of conidial abstriction in powdery mildew of sunflower is reported to be between 8 AM and 2 PM as evident from the periodic catching of dislodged spores for several days (Kolte, 1985).

The weather conditions most favourable for conidial production, maturation, release and spread, germination, and infection includes repeated day-night cycles in which the nights are cool (about 16°C) and damp with a relative humidity of 90 to 99 per cent and the days are warm (25-27°C) and dry with a relative humidity of 40 to 70 per cent. Hence, epidemics of powdery mildew are reported to be most common in the spring and fall.

Effect of various factors on conidial germination of *G. cichoracearum*: Air pollution and climate change particularly longer growing seasons may result in significant changes in the distribution of powdery mildew and in their effects on host species leading to production of greater number of chasmothecia and higher powdery mildew populations in succeeding growing seasons (Glawe, 2008). Studies were carried out at UAS, Bengaluru to assess the optimal conditions for promoting the conidial germination of *G. cichoracearum* are presented below:

Temperature: Conidial germination was studied at different temperatures *viz*., 4°C to 40°C. Powdery mildew conidia was dusted on a dry clean slide and the slide was placed in moist chambers and incubated at different temperatures *viz*., 4°C, 10°C, 15°C, 20°C, 25°C, 30°C, 35°C and 40°C in thermostatically controlled incubators for 24 hours. The per cent germination was calculated by counting the number of spores germinated to total number of spores observed under each microscopic field. The perusal of the data shows that the per cent conidial germination ranged from 0.0 to 81.33 per cent at different temperature levels. Maximum germination was observed at 25°C (81.33%), followed by 20°C (42.67%) and 30°C (40.33%) while it was minimum (4.0%) at 35°C. None of the conidia germinated at 5°C and 40°C. This showed that the temperature range of 20-30°C is favoured for the germination of conidia with the optimum being 25°C.

Relative humidity: Different levels of relative humidity (10, 20 30, 40, 50, 60, 70, 80, 90 and 100 per cent) were maintained in desiccators containing various proportions of potassium hydroxide with distilled water. The Petri dishes containing conidia on clean dry glass slide were then placed in desiccators containing different concentrations of potassium hydroxide and incubated in an incubator at 22°C for 24 hours and the per cent germination was calculated as described. The conidial germination ranged from 11.3 to 74 per cent at different relative humidity levels tested. The highest germination of 74 per cent was observed at 90 per cent relative humidity and lowest of 11.3 per cent at a relative humidity of 10 per cent. It was observed that the optimum relative humidity range of 70-100 per cent is required for good germination of conidia (61.7 to 74.0%) under laboratory conditions.

Severity of powdery mildew of sunflower was found to be influenced by environmental factors, which prevailed during crop growth period. During *kharif,* rainfall is detrimental because it removes conidia and disrupts the mycelium and free water causes poor and abnormal germination of conidia. The coincidence of the favourable period (i.e., dry spell after rain) with stage of the crop led to considerable boost in disease severity during *rabi*. It was also observed that the disease severity reduced during rainy days and gets aggravated when there was dry spell after rain. Correlation studies were carried among weather factors *viz.,* temperature, rainfall and relative humidity with disease severity (%) of powdery of sunflower in highly susceptible hybrid KBSH 44. During *kharif,* negative relationship existed between disease severity (%) and temperature (-0.471), rainfall (-0.502) and relative humidity (-0.502). During *rabi* there was a positive relationship between disease severity (%) and rainfall (+0.421) and relative humidity (+0.973), while a negative relationship existed with temperature (-0.672). The pooled data of both seasons indicated negative relationship between disease severity (%) and temperature (-0.436), rainfall (-0.510) and relative humidity (-0.435).

During *kharif* the multiple regression co-efficient for temperature, rainfall and relative humidity was 0.39, 0.008 and -0.152, respectively, whereas during *rabi* the regression co-efficient for these weather parameters were 2.9, -0.077 and 3.74. The pooled regression co-efficient for both the seasons for temperature (-13.3), rainfall (0.029) and relative humidity (-2.73).

The multiple regression equation worked out considering the dependent variable (Y) as disease severity (%) with weather parameters temperature, rainfall and relative humidity indicated that the extent of contribution from the independent variables temperature, rainfall and relative humidity was lower in *kharif* (41.9%) compared to *rabi* (99.3%). The multiple regression models indicated in Table 3 facilitates the estimation of disease severity for the expected values of temperature, rainfall and relative humidity in *kharif* and *rabi*, respectively.

Table 3 Multiple linear regression equation of per cent disease severity of powdery mildew of sunflower in relation to weather parameters

Season	Multiple linear regression equation
Kharif	$Y = 5.8 + 0.39\ X_1 - 0.152\ X_2 + 0.008\ X_3$
Rabi	$Y = -239 + 2.79\ X_1 + 3.74\ X_2 - 0.077\ X_3$
Pooled	$Y = 546 - 13.3\ X_1 - 2.73\ X_2 + 0.029\ X_3$

X_1: Temperature (ºC), X_2: Relative humidity (%), X_3: Rainfall (mm)

Osmoticum: The 0.5, 1, 1.5, 2, 2.5 and 3 per cent sucrose solutions were prepared by dissolving different quantities of sucrose in 100 ml distilled water and the distilled water served as control. Two drops of the different concentrations of sugar solution were placed in a cavity slide and conidia were dusted on the slide. The slide was placed in moist chambers and incubated at room temperature for 24 hours and the per cent germination was calculated. The data revealed that the conidial germination of 62.7 to 81.0 per cent was favoured by the different sucrose concentrations tested. Maximum conidial germination of 81 per cent was

recorded in 1.5 per cent sucrose solution followed by 2 percent (78%), 2.5 percent (73.3%), 1 percent (72%) and 0.5 percent (62.7%). The lowest conidial germination was in distilled water (42.3%). Thus, the germination of conidia of *G. cichoracearum* was enhanced by using 1 to 2 per cent concentration of sucrose solution.

Effect of storage conditions on viability of conidia: The investigation on viability and survival of *G. cichoracearum* was undertaken to obtain information about the perpetuation of the pathogen during the off-season. The freshly harvested powdery mildew infected leaves of sunflower were collected and stored in polythene bags under different storage conditions *viz.,* refrigerated (4-5 °C), under tree shade (15-20 °C), room temperature (21-28 °C) and field condition (28-30 °C) in separate lots. Per cent germination of conidia on each type of leaf was recorded before preserving the samples. The viability of conidia of each type of leaf under different storage conditions were regularly examined by checking germination under microscope.

The conidial germination at different weekly intervals was recorded and presented in Table 4. The results revealed that the conidia remained viable up to 10 weeks when stored under field conditions. Whereas, they remained viable up to 11 weeks at room temperature. The conidia remained viable up to 13 weeks when the infected leaves were kept under tree shade. However, under refrigerated conditions, the conidia were viable up to 17 weeks. This indicated that the conidia of powdery mildew pathogen were short lived on the host debris under natural conditions.

Table 4 Effect of different storage conditions on the viability of conidia of *G. cichoracearum*

Storage Conditions	Conidial germination at different weekly intervals																			
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Field	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Room	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-
Refrigerator	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
Tree shade	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-

Date of sowing: A field experiment was conducted during *kharif* and *rabi* 2009 at Zonal Agricultural Research Station, UAS, Bengaluru to assess the progress of powdery mildew at different sowing dates. A total of 13 different sowing dates from June 2009 were taken up and the severity of powdery mildew was recorded at 35, 42, 49, 56 and 63 days after sowing. The meteorological data for the experimental period was collected and correlated with powdery mildew severity. The results indicated that very low (2-5%) severity of powdery mildew was observed during *kharif*. During *rabi*, in the 1st date of sowing (i.e., 25th September) the disease severity at 35 DAS was 30 per cent and reached 92 per cent at 63 DAS. Similar trend was noticed when the crop was sown between 12th October to 10th November. In the crop sown on 23rd November and 12th December the disease severity at 35 days after sowing (DAS) was 20 per cent and increased to 75 and 63% , respectively. In the crop sown on 23rd December the disease at 63 DAS was 59 per cent. The dates of sowing particularly from June to September, the disease was not observed, whereas sowing from last week of September to last week of November disease initiation started earlier and reached maximum (Karuna *et al*., 2013c).

INTEGRATED DISEASE MANAGEMENT

Previously powdery mildew disease has not been considered to be of an economic importance (Kolte, 1985). But of late, powdery mildew has become an epidemic and warranting management. Powdery mildew infection on sunflower occurs when the crop is at flowering or seed formation stages when fungicides are seldom used. Hence, reducing the likelihood of the disease outbreak is more effective than trying to control the disease once it is established. Some of the management practices that need to be followed to prevent infection are given hereunder:

Cultural practices: Sunflower cultivation should be taken up in areas that receive full sunlight during most of the day and should be avoided in situations of high humidity. Irrigating the crop in the morning limits the build-up of humidity in the crop during the night. High plant densities, low air circulation and overcrowding should be avoided as it leads to heavy infection. Crop rotation should be followed for control and preventing the spread of the disease. Late season application of nitrogen fertilizer should be avoided to limit the production of succulent tissue making the plant vulnerable to infection. As the fungus overwinters as chasmothecia, the plant debris at the end of the season should be removed and destroyed to reduce the inoculum available to start new infections. Different agronomic practices *viz*., alteration in date of sowing, inter and mixed cropping and nutrient management are helpful in reducing the disease spread.

Host plant resistance: Serious economic losses due to powdery mildew infection in the tropics necessitates

development of resistant cultivars. Sources of resistance to powdery mildew have been identified mostly in the wild sunflowers and their derivatives (Table 5). In the annual wild species *Helianthus debilis*, the resistance was governed by a partial dominant gene and the interspecific hybrid (PM1) between *H. debilis* and *H. annuus* was registered as a source of resistance to powdery mildew (Jan and Chandler, 1988). The studies till date report the resistance sources from wild species while reports on sources of resistance in cultivated germplasm are lacking. However, it is interesting to note that some of the diploid annuals that are easily crossable with cultivated sunflower (*H. debilis, H. praecox* and *H. bolanderi*) confer resistance to the pathogen (Saliman *et al*., 1982; Jan and Chandler, 1988; Rojas-Barros *et al*., 2004; Christov, 2008; Prathap Reddy *et al*., 2013) which could be exploited in the programmes aimed at breeding for resistance to powdery mildew in sunflower. Among five cultivated hybrids (KBSH-1, KBSH-41, KBSH-42, KBSH-44 and KBSH-53) developed from Karnataka, KBSH-53 recorded least (4.1%) powdery mildew incidence while KBSH-44 was highly susceptible (61%) (Karuna *et al*., 2012; Karuna *et al*., 2013b). For the determination of morphological basis of resistance, histopathological and histochemical studies and changes in cell permeability were estimated in the leaf samples of healthy and infected susceptible (KBSH-44) and resistant (KBSH-53) sunflower hybrids grown under glass house conditions. The studies revealed differences in the levels of nucleic acids and proteins in healthy and diseased tissues and also between the resistant and susceptible hybrids with the depletion being drastic in the infected susceptible hybrid, KBSH-44 (Karuna *et al*., 2014).

Table 5 Sources of resistance in wild *Helianthus* species to powdery mildew

Sources of resistance	Reference
H. atrorubens, H. californicus, H. ciliaris, H. debilis, H. decapetalus, H. laciniatus, H. laevigatus, H. microcephalus, H. resinosus, H. rigidus, H. simulans and *H. smithii* showed resistance at field The two annuals *H. bolanderi* and *H. praecox* subsp. *praecox* showed resistance under artificial inoculation assays Two annual species *H. debilis* Nutt. ssp. *silvestris, H. divaricatus* and the perennial species *H. strumosus* showed resistance under both field and artificial inoculation conditions.	Saliman *et al.,* 1982
Interspecific hybrids between *H. giganteus, H. hirsutus, H. divaricatus, H. salicifolius* and cultivated sunflower	Skoric, 1984
H. debilis ssp. *debilis*	Jan and Chandler, 1985
PM1 derived from interspecific hybridization between *H. debilis* Nutt. and *H. annuus* L.	Jan and Chandler, 1988
H. debilis ssp. *debilis*, *H. debilis* ssp. *vestitus, H. argophyllus*	Rojas-Barros *et al.,* 2004; 2005
3 accessions of *H. tuberosus*	McCarter, 1993
Five perennial wild species, *H. decapetalus, H. laevigatus, H. glaucophyllus, H. ciliaris, H. tuberosus, H. resinosus* and one annual species *H. debilis*	Christov, 2008
H. tuberosus, H. praecox, H. bolanderi and *H. praecox*	Acimovic, 1998
Field resistance in *H. decapetalus, H. divaricatus, H. laevigatus, H. californicus, H. eggertii, H. laetiflorus, H. resinosus, H. salicifolius, H. silphoides, H. smithii, H. glaucophyllus, H. microcephalus, H. multiflorus*	Bosko *et al.,* 2012
H. argophyllus, H. agrestis, H. debilis, H. praecox, H. angustifolius, H. atrorubens, H. rigidus, H. salicifolius, H. pauciflorus, H. resinosus; Two interspecific derivatives HIR-1734-2, RES-834-3 Exotic lines PI 642072, EC-537925	Prathap Reddy *et al*., 2013

Biological control: The grubs and beetles of *Illeis cincta* (Fabricius) (Coleoptera: Coccinellidae) (ladybird beetle) have been identified as mycophagous on powdery mildew caused by *G. cichoracearum* (Karuna *et al.,* 2013a). Both the adults and the grubs were found feeding on the powdery mildew conidia. The hyperparasite, *Cicinnobolus cesatii* is often found to parasitize the conidial stage of the mildew (Chona and Munjal, 1956; Patwardhan, 1965).The development of cleistothecial stage of the fungus on sunflower under Indian conditions appear to be governed by the presence or absence of the hyperparasite. During the monsoon season in the vicinity of Pune area of India, the mildew was parasitized by *Cicinnobolus* sp., preventing the formation of cleistothecia, whereas in winter season, the mildew remain free from any infection of hyperparasite and it grows rapidly leading to the formation of cleistothecia.

Chemical control: When symptoms just appear, application of wettable sulphur dust at 25-30 kg/ha or calixin (0.1%) or karathane (0.2%) or benlate (0.2%) effectively controls the disease. Under high incidence of powdery mildew, two sprays of difenoconazole (0.05%) or propiconazole (0.1%) at 45 and 60 days after sowing are effective which reduced disease severity by 46 to 87 per cent and increased the seed yields up to 31 to over 100 per cent.

WAY FORWARD

The future line of research priorities are as follows:

- Genetics and inheritance of resistance to powdery mildew in different resistant donors including wild *Helianthus* species needs to be determined.
- Introgression of resistance from the identified resistant donors into promising parental lines.
- Molecular mapping and tagging of powdery mildew resistance genes as a prelude for molecular breeding and marker assisted selection (MAS) in sunflower.
- Biochemical, transcriptome and proteome profiling has to be done for identification of differentially expressed genes and proteins in resistance cultivars for deployment in agronomically desirable cultivars through conventional, molecular breeding and transgenic approaches.
- Taxonomic identity of the causal organism and mapping of distribution in different regions and seasons using morphological and molecular tools.
- Variability in powdery mildew needs to be characterized using morphological, virulence and molecular techniques to study the existence of physiological races.

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Enhanced recovery of oil from *Jatropha curcas* L. seeds

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ABSTRACT

Jatropha curcas L. is a popular and potential tree borne oilseed exploited for biofuel, however, extraction of oil from whole seeds incurs oil loss due to adsorption of considerable amount of oil to the oil cake. To minimize the oil loss, seeds were decoated using a seed decoater which separates the whole seeds into shell and kernel. Seeds with 15 per cent of the shell removed and with 40 per cent of the shell removed were compared with whole seeds for oil extraction. The oil present in the oil cake was estimated and analysed for its physico-chemical properties. The average oil recovery from the whole seed was about 23.16 per cent. Removal of 15 per cent shell increased the oil recovery to 24.6 per cent and further removal of 40 per cent shell resulted in 25.41 per cent oil recovery. The oil present in the oil cake was reduced from 10.08 to 8.93 and 7.61 per cent in the 15 per cent shell removed and 40 per cent shell removed seeds, respectively. However, the physico-chemical properties of oil from oilcake did not vary significantly. From a commercial point of view, this study helped to enhance oil recovery and displayed the significance of seed processing technique.

Keywords: Decoater, *Jatropha curcas,* Oil expeller, Oilseed, Processing

Renewable energy is derived from natural processes that are replenished constantly. It has an important role in providing modern energy access to the billions of people in developing countries that continue to depend on more traditional sources of energy. The need for alternative energy sources that combine environmental friendliness with biodegradability, low toxicity, renewability, and less dependence on petroleum products has been greater today than ever before. One such energy source is referred to as "Biofuel" (Akoh *et al.,* 2007). According to Wiggins *et al.* (2008), cultivation of non-food biofuel crops could represent an opportunity for poor countries to benefit from the growing demand for biofuels and the role of plant based oils have become indispensable for fuel requirements. India has enormous potential of oilseeds of tree origin like mahua (*Madhuca latifolia*), neem (*Azadirachta indica*), simarouba (*Simarouba glauca*), karanja (*Pongamia pinnata*), jatropha (*Jatropha curcas*), punna (*Calophyllum inophyllum*), kusum (*Schleichera oleosa*), etc., which can be grown and established in the wastelands under varied agro-climatic conditions.

In general, seeds are pressed or grounded for extraction of oil and the whole seeds along with seed coat are fed in the hopper for oil extraction. However, it is reported that the oil content in seed coat is negligible as almost all oil is stored in the seed kernel (Jongschaap *et al*., 2007). However, the seeds are pressed as such along with seed coat for giving sufficient friction during grinding. The oil recovery through grinding or pressing was observed to be low when compared to solvent extraction method which helps in almost absolute oil recovery. Extraction efficiencies of conventional methods seldom exceed 80 per cent, compared to solvent extraction methods which achieve over 98 per cent (Bargale, 1997). The major reason for the loss of oil on extraction by pressing or grinding is retention of oil within the seed coat particles which goes into oilcake. Hence removal of seed coat is preferred as it helps to minimize extraction loss and improve the extraction efficiency as any tough seed coat has been reported to interfere with grinding process (Bachmann, 2001).

In many oilseeds such as sunflower and neem, removal of seed coat is known to improve the oil recovery. Comparison of oil yield from whole seeds and kernels of *Jatropha curcas* have shown that it is essential to separate the shell or seed coat from seed in order to maximize oil recovery. However, availability of suitable decoating equipment for different seed species has been a limitation. Hence an existing seed grinding mill was suitably modified for removing the seed coat of *Jatropha curcas* seeds. The efficiency of this seed coater in improving the oil recovery has been discussed in this study. Whole seed and partly shell removed samples were assessed for oil recovery using solvent extraction by Soxhlet and as well as oil expeller.

MATERIALS AND METHODS

Collection and seed extraction: Black pulpy fruits of *Jatropha curcas* were collected from Attapady (11° 14' N ; 76° 48' E), Kerala, South India and the seeds were extracted manually. The seeds were analysed for initial moisture content after surface drying for half an hour under shade (30±1°C; RH 65 ± 2%).

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Determination of seed moisture content: The seeds were tested for moisture content on fresh weight basis by oven dry method (ISTA, 1999). About 5g of seed samples were taken in triplicates and determined the exact wet weights. The seeds were dried in a hot air oven at 103°C for 17 hours. The sample seeds were then cooled in desiccators and the dry weight was found. The moisture content was calculated using the following formula,

$$\text{Moisture content (\%)} = \frac{\text{(Initial weight - Dry weight) g}}{\text{Initial weight (g)}} \times 100$$

The fresh or initial seed moisture content estimated inclusive of seed coat was found to be 9.09 per cent.

Drying seeds to target seed moisture content (MC): The fresh seeds were dried to a target moisture content of 6 per cent under shade (30±1°C; RH 65 ± 2%) for ten days as suggested by Anandalakshmi *et al*. (2008). The target weight for drying the seeds was determined using the formula given by DFSC (1999).

$$\text{Target weight (kg)} = \frac{\text{(100 - Initial moisture content)}}{\text{(100 - Target moisture content)}} \times \text{Weight of the seed bulk}$$

Seed decoater: An existing seed grinding mill was modified to break open the seed and separate the shell covering the kernel. In this grinding mill, the seed is broken by milling technique while the separation of shell from kernel is through air suction. The prototype is driven by a 1hp motor and about 10 kg seed per hour can be processed by this seed decoater. The suction pressure can be regulated to remove shell in different proportions. In the present study, two seed bulks were made by removing 15 per cent and 40 per cent shell.

Seed coat or shell removal: Seed subsamples were put in the seed decoater equipment to remove about 15 per cent as well as 40 per cent of the shell by regulating the suction pressure. Four replications each with 10 kg of seed was used for each treatment. Shell weight equal to 15 kg and 40 kg were removed from 10 kg of seeds for 15 and 40 per cent shell removal treatments, respectively. After removal of the shell in different proportions, the samples were put in oil expeller to assess the oil recovery. One seed bulk without removing the shell was taken as control (Fig. 1).

Oil extraction by Power Ghani: In the power ghani (mechanical expeller), the mortar is firmly fixed to the ground. The oil is released by friction and pressure as the pestle rotates. The extracted oil runs out of a small aperture at the base of the mortar. About 100 kg seed per day is its usual throughput.

Fig. 1. Seed decoating of *J. curcas* in different shell proportions for oil extraction

In this study, each seed subsample was divided into four replicated samples each weighing about 10 kg for oil extraction. Each sample was preheated over a shallow pan for 10 minutes as suggested (Bachmann, 2001) and fed into the power ghani for extraction of oil (Fig. 2). The extracted oil was collected, allowed to stand for about 7 days to remove moisture, filtered and then weighed. The oil cake was collected after each extraction process, dried under shade for 10 days and weighed. The oil present in the oil cake was estimated separately by solvent extraction method using Soxhlet apparatus. Each sample was replicated four times and the extraction was carried out separately for each replication. The oil was characterized for its physico-chemical properties such as viscosity, specific gravity, refractive index, acid value, saponification value and peroxide value as per standard methods.

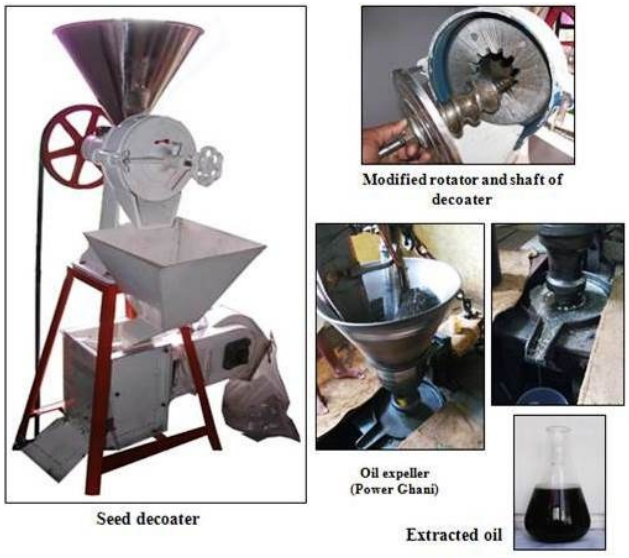

Fig. 2. Seed decoater prototype and oil extraction in power ghani

Estimation of oil content: The seeds were ground using mortar and pestle and 20g of coarse seed powder was taken for oil extraction. Commonly used solvent extraction method in Soxhlet apparatus was applied, using petroleum ether (boiling point: 40 to 60°C) as solvent for extraction of oil as

per AOAC 920.39C method (AOAC, 2007). In the present study, whole seeds were used for oil extraction. After six continuous hours of extraction, the solvent was recovered by simple distillation and the residual oil was allowed to cool in desiccator and weighed. The percentage of oil in the sample was calculated as follows:

$$\text{Percentage oil yield} = \frac{\text{Weight of the extracted oil}}{\text{Weight of the seed sample}} \times 100$$

Characterization of oil

a. Determination of specific gravity: Specific gravity was measured at 25°C using the specific gravity bottle based on AOCS method Cc 10a-25 (AOCS, 1993). The specific gravity was calculated using the following equation:

$$\text{Specific gravity} = \frac{\text{Weight of bottle and oil sample - Weight of empty bottle}}{\text{Weight of bottle and water - Weight of bottle}}$$

b. Determination of viscosity: The specific viscosity (at 30°C) of oil samples was measured using Engler Viscometer and expressed in Degree Engler (°Engler) according to ASTM D1665-98 (2003) standard. Viscosity of oil is defined as the ratio of time of flow for 50 ml of oil in seconds using an Engler viscometer at a selected temperature to the time of flow, in second, for an equal volume of water at 25 °C.

c. Determination of refractive index: Refractive index of oil was determined using the Abbe refractometer. The refractometer was first standardized to 1.3333 using distilled water at a temperature of 30°C. This water was cleaned off with tissue paper and replaced with about 0.5 g of oil sample. The dark and light regions of the refractometer were adjusted to meet at an intercept of a crossbar before the readings were taken (Ringler and Maroti, 1994).

d. Determination of acid value: The oil samples were subjected to chemical characterization for acid value (Cox and Pearson, 1962; AOAC, 2007) an important indicator of vegetable oil quality (Kardash and Tur'yan, 2005). Acid value is expressed as the amount of potassium hydroxide (in milligrams) necessary to neutralize free fatty acids contained in 1 g of oil.

Acid value was determined for each oil sample by dissolving 0.20g of each oil in 2.5 ml of 1:1 v/v ethanol: diethyl ether solvent and titrating with 0.1N sodium hydroxide (NaOH) while swirling using phenolphthalein as indicator. Calculation is as follows,

$$\text{Acid value} = \frac{\{56.1 \times N \times V\}}{W}$$

Where,
N = Normality of NaOH used
V = Volume (ml) of NaOH used
W = Weight of sample used

e. Determination of saponification value: Saponification value which is a measure of fatty acid chain length in oils was determined (Horowitz, 1975; AOAC, 2007) and expressed in milligrams of potassium hydroxide absorbed per gram of oil, 1g of each oil was dissolved in 12.5 ml of 0.5% ethanolic potassium hydroxide and the mixture refluxed for 30 minutes. 1 ml of phenolphthalein indicator was added and the hot soap solution titrated with 0.5N hydrochloric acid. A blank determination was also carried out under the same condition and saponification value determined using the following equation,

$$\text{Saponification value} = \frac{56.1N\ (V1 - V2)}{W}$$

Where,
N = Normality of hydrochloric acid used
V_1 = Volume of hydrochloric used in test
V_2 = Volume of hydrochloric acid used in blank
W = Weight of oil used (1g)

f. Determination of peroxide value: Peroxide value was determined (Cox and Pearson, 1962; AOAC, 2007) and expressed in milli Eq per kg of oil is an index of fatty acid oxidation. For peroxide value, 1g of each oil sample was weighed into a 200 ml conical flask then 25 ml of 2:1 v/v glacial acetic acid chloroform solvent was added 1 ml of saturated potassium iodine was then added and mixture left in the dark for 1 minute. Next, 30 ml of water was added and the mixture titrated with 0.02N thiosulphate solution using 5 ml starch as indicator. A blank determination was similarly carried out. Peroxide value was calculated from the equation,

$$\text{Peroxide value} = \frac{\{100\ (V_1 - V_2)\ \text{mg/kg}\}}{W}$$

Where,
W = weight of sample
V_1 = volume (ml) of thiosulphate used in test
V_2 = volume (ml) of thiosulphate used in blank

Statistical analysis: The experiments were carried out in completely randomized design in 4 replications. One-way ANOVA was applied to test the significance of seed coat removal at 5% level of confidence using GENSTAT 5.0.

RESULTS AND DISCUSSION

The whole seed and the decoated seeds with different proportions of shell were pressed and the oil was extracted. The statistical significance in seed oil, oilcake, percent of oil in oilcake, physicochemical characteristics of the oil extracted from the whole seed, 15 and 40 per cent shell removed seed bulk are given in Table 1. Seed samples processed to remove the shell in two different proportions of 15 and 40 per cent showed that the weight of extracted oil was significantly high in 15 as well as 40 per cent shell removed seed bulk than the whole seed bulk (Table 2). It works out to be 23.16 per cent to 25.41 per cent oil recovery for 15 and 40 per cent shell removal treatments, respectively. The increase in the oil recovery due to removal of shell was observed to be statistically significant.

Table 1 ANOVA for seed coat removal on oil recovery and oil characteristics in *J. curcas*

Character	Mean square	F ratio	F probability
Weight of extracted oil	0.051906	40.06	<.001
Oil recovery %	5.1906	43.06	<.001
Oil cake weight (kg)	18.264280	7562.85	<.001
Per cent oil present in oil cake	6.10745	503.71	<.001
Viscosity at 30°C	0.1333E-03	NS	NS
Specific gravity	0.1333E-05	NS	NS
Refractive index (nD)	0.1333E-03	NS	NS
Acid value (mg of KOH/g oil)	0.004137	3.00	0.125
Saponification value (mg of KOH/g oil)	0.6557	2.14	0.173
Peroxide value (milliEq/kg oil)	0.013333	3.00	0.125

NS = Non-significant

Table 2 Efficacy of seed coat removal using seed decoater on oil recovery in *J. curcas*

Treatments	Weight of extracted oil	Oil recovery %	Oil cake weight (kg)	% Oil present in oil cake	Weight of oil cake alone (kg)	Weight of oil in cake (kg)
Whole seed	2.316	23.16	7.615	10.08	6.847	0.768
15% shell removed	2.460	24.60	5.955	8.93	5.423	0.532
40% shell removed	2.541	25.41	3.375	7.61	3.118	0.257
SEd	0.0255	0.245	0.0347	0.0779		
CD (P=0.05)	0.0623	0.555	0.085	0.1905		

SEd. =Standard error of deviation; CD =Critical difference

The weight of oilcake was more in the whole seed than other seed bulks. The oil present in the oil cake was reduced from 10.08 to 8.93 and 7.61 per cent in the 15 per cent shell removed and 40 per cent shell removed seed bulks. The oilcake was assessed for oil content using solvent extraction by soxhlet and the weight of oil and oilcake alone was determined. The oil present in the oil cake was less in the 40 per cent shell removed fraction than the whole seed fraction. The physico-chemical characteristics of the oil recovered in these three different fractions were tested. There was no significant difference in viscosity, specific gravity, refractive index, acid value, saponification value and peroxide value among the treatments (Tables 3 and 4).

Table 3 Effect of seed coat removal using seed decoater on physical characteristics of Jatropha oil

Treatment	Viscosity at 30°C	Specific gravity	Refractive index (nD)
Whole seed	9.32	0.878	1.462
15% shell removed	9.32	0.877	1.462
40% shell removed	9.33	0.878	1.462
SEd	0	0	0
CD (P=0.05)	NS	NS	NS

SEd =Standard error of deviation; CD =Critical difference; NS =Non-significant

Table 4 Effect of seed coat removal using seed decoater on chemical characteristics of Jatropha oil

Treatment	Acid value mg of KOH	Sap. value mg of KOH	Peroxide value milli Eq/kg
Whole seed	2.02	203.36	1.2
15% shell removed	2.02	203.36	1.1
40% shell removed	2.08	204.06	1.2
SEd	0.0263	0.391	0.0471
CD (P=0.05)	NS	NS	NS

SEd =Standard error of deviation; CD =Critical difference; NS =Non-significant

Jatropha seeds contain about 30-35 per cent oil in seed kernel. In general, seed coat does not contain substantial oil (Jongschaap *et al*., 2007; Dunford, 2009). However during extraction through screw or pressing type of expellers, some amounts of shell are required to provide friction required inside the expellers. During this process, substantial amount of oil is retained within oilcake. Although total removal of shell affects the oil extraction process, the proportion of shell can be reduced to improve the oil recovery. The experiment conducted with 15 and 40 per cent shell removal showed significant improvement in oil recovery.

Small-scale, hand-operated expellers can extract 1 litre of oil for every 5.0 to 5.5 kg of seed and engine-driven screw presses can extract 1 litre of Jatropha oil from every

4 kg of dried seed (Henning, 2008; Achten *et al*., 2008). Jongschaap *et al*. (2007) stated that about 19-22 per cent of oil recovery can be done from the dry whole seed while the seed kernel has 30 per cent oil. The seed bulk used in the present investigation was observed to contain 34 per cent oil content when estimated by solvent extraction method. The same seedlot has given only 23.16 per cent oil when pressed in an oil expeller which is equal to extraction efficiency of 68 per cent. Removal of 15 and 40 per cent of the seed coat resulted in recovery of 24.6 and 25.41 per cent oil which are equal to 72 and 75 per cent extraction efficiency respectively. Studies showed 60-65 per cent extraction efficiency in mechanical press type of oil extraction and efficiency varies with the type of expeller (Pathak *et al*., 1988).

Improvement of the extraction efficiency is of paramount importance as the process is done at industrial scale. During large scale processing, pre-heating and solvent extraction are known to increase the extraction efficiency (FAO, 2010). The seeds are preheated prior to oil extraction in power ghani and the oil which is left out in oil cake is extracted through solvent extraction method. The oil remaining in the oilcake is also a measure of expeller efficiency.

In the present study, about 10 per cent of the oil could not be extracted due to various reasons including retention of oil within the shell particles. Similarly, the oil content of sunflower is given as 35.45 per cent (weight basis) and in the extraction of oil by screw press, 60 to 70 per cent of the oil from meal is recoverable (Chakraventy, 1988). It is reported that, an oil-rich seed such as sesame seed or groundnut yields about 5 per cent less oil in a ghani than in a modern expeller, mainly because of insufficient pressure and Ghani oilcake carries about 15 per cent residual fat, about twice that of screw-press oilcake (Achaya, 1993). In the present study, the oil left out in the oilcake was estimated and observed that reducing the shell proportion in the seed bulk has reduced the retention of oil in oilcake to a significant extent. Removal of seed coat during oil extraction was recommended by Bachmann (2001) as it improves extraction efficiency by reducing the quantity of tough seed coat which is reported to interfere with grinding process. Removal of shell is reported to also increase the oil production efficiency, capacity of the extraction equipment and reduces wear in the expeller as the husks are abrasive (Dunford, 2009). In this study, the quantity of oil present in the oilcake was observed to reduce from 10 to 7.6 per cent when the 40 per cent shell was removed. This demonstrates that shell retains oil during pressing. In many oilseeds such as sunflower and neem, removal of seed coat is known to improve the oil recovery. In sunflower partially dehulled seeds with only 10 per cent residual hull are used for mechanical pressing followed by solvent extraction (Grompone, 2005).

The quality of the oil extracted with different proportions of the shell showed no significant variation. Similar study carried out in Ghana to establish the optimum conditions for the extraction of oil from *Allanblackia floribunda* nuts and also assess the quality and stability of both the crude pressed oil (CPO) and solvent extracted oil (SEO) showed that there were no significant differences in the quality parameter such as refractive index, specific gravity, iodine value, saponification value, peroxide value, free fatty acid, acid value and ester value (Wilfred *et al*., 2010).

The oil extraction efficiency has been improved by 7 per cent through removal of 40 per cent of the shell using seed decoater. Removal of seed coat helped to check loss of oil through adsorption by seed coat that otherwise goes untapped along with the oil cake. Deployment of seed decoater in processing Jatropha seeds prior to small or large scale oil extraction maximizes the oil recovery and minimizes economic loss. Standardizing similar techniques for other tree borne oilseeds can improve gains and support large scale programs on TBO utilization.

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Performance of sunflower (*Helianthus annuus* L.) hybrids under West Bengal condition

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ABSTRACT

An experiment on the performance of various sunflower hybrids was carried out at Pulses and Oilseed Research Station (PORS), Berhampore during *rabi* (winter) 2013-14 under Initial Hybrid Trial (IHT) of AICRP (Sunflower) with 12 hybrids. Among the 12 hybrids, two hybrids WBSH-2021 and WBSH-2034 developed at PORS, Berhampore during winter 2012-13 were included in the trial. The experiment was laid out in Randomized Complete Block Design having four replications, with each sub plot size of 4.5 x 3.0 m^2. Statistical analysis of the data showed significant differences for all the parameters except days to 50% flowering, days to maturity and 100-seed weight. It was observed that WBSH-2021 registered 31%, 25% and 66% more seed yield and 30%, 29% and 70% more oil yield than the three check hybrids. Under zone-III, WBSH-2021 recorded 16%, 7% more seed yield and 11%, 15.3% more oil yield than the check hybrids DRSH-1 and KBSH-44, respectively. Based on the performance of the IHT the hybrid WBSH-2021 was promoted to Advanced Hybrid Trial (AHT) of AICRP (Sunflower).

Keywords: Hybrids, Performance, Sunflower, West Bengal

After soybean, sunflower (*Helianthus annuus* L.) is the second important source of vegetable oil in the world. In India, it is mostly grown in the states of Karnataka, Maharashtra, Andhra Pradesh and Tamil Nadu with potential scope of growing in non-traditional areas like West Bengal (Dutta, 2011). In West Bengal, sunflower is second important oilseed crop after rapeseed-mustard during *rabi* (winter) season. Due to short winter spell and delayed sowing of rapeseed-mustard the production is drastically reduced due to infestation of pest and diseases in most of the years. Sunflower being a photoperiod neutral crop has wide scope to replace rapeseed-mustard cultivation with high yield potentiality. Keeping this in mind the hybrid sunflower programme was initiated at Pulses and Oilseed Research Station (PORS), Berhampore during 2003-04 (Dutta *et al.,* 2011). Several hybrids were produced at PORS, Berhampore and tested under All India Coordinated Research Project (AICRP) on Sunflower network since 2007-08. Among the hybrids two hybrids WBSH-2021 and WBSH-2034 were nominated for testing under AICRP trial and evaluated at 16 locations under four zones across the country. The present study was aimed to evaluate the performance of the two hybrids with respect to yield and yield components and to identify the best hybrid suitable for West Bengal condition to overcome the problem of unavailability of quality hybrid seed of sunflower.

MATERIALS AND METHODS

In order to study the performance of various hybrids, an experiment was carried out during *rabi* (winter) 2013-14 at PORS, Berhampore, West Bengal. The experiment comprised of 12 hybrids including checks received from Directorate of Oilseeds Research, Rajendranagar, Hyderabad and planted on 8th November 2013. The experimental design was Randomized Complete Block Design having four replications, with each sub plot size of 4.5 x 3.0 m^2. The row/plot were five in number with row spacing of 60 cm and plant to plant spacing was 30 cm. Uniform dose of fertilizer @ 60 kg N, 90 kg P_2O_5 and 60 kg K_2O per ha was applied. Sunflower seeds were planted by putting three seeds per hill and after emergence one plant per hill was maintained. Observations were recorded on ten randomly selected plants from each plot of all replications to record data on the following characters *viz*., plant height (cm), final plant stand ('000 per ha), 50% flowering (days), maturity (days), head diameter (cm) and 100-seed weight (g). Seed yield (kg/ha), oil content (%) and oil yield (kg/ha) were estimated on plot basis. The mean values were subjected to statistical analysis.

RESULTS AND DISCUSSION

Growth and development: The statistical analysis revealed that final plant stand (Table 1) differed significantly by various hybrids of sunflower. KBSH-71 produced maximum final plant stand of 92.3 ('000/ha). Lowest plant stand was observed by the hybrid RSFH-10-600 (39.5 '000/ha). Plant height of 12 hybrids showed that RSFH-10-600 had highest plant height (192 cm) closely followed by DRSH-1 (191 cm). Local check hybrid showed lowest plant height (125 cm) followed by WBSH-2021 (128 cm) and WBSH-2034 (131 cm). Since dwarf plant height is a desirable characteristic (Gvozdenovic *et al*., 2005) for sunflower to avoid lodging,

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WBSH-2021 (128 cm) and WBSH-2034 (131 cm) are promising in this respect. Table 1 also shows comparison of various sunflower hybrids in terms of 50% flowering (days) and maturity (days) (Anonymous, 2015). Statistical analysis of the data showed that both the characters were non-significant for all the hybrids of sunflower. However, maximum 50% flowering (days) was recorded in hybrid RSFH-10-600 (93 days) which was closely followed by LSFH-176 and KBSH-44 (91 days). The minimum days to 50% flowering was recorded in KBSH-71 (75 days) followed by KBSH-72 (78 days). Among the hybrids, RSFH-10-600 recorded highest maturity (124 days) followed by KBSH-44 (121 days). WBSH-2021 and WBSH-2034 showed 119 days to maturity.

Table 1 Final plant stand, plant height (cm), 50% flowering (days) and maturity (days) of various sunflower hybrids in West Bengal condition

Hybrids	Final plant stand ('000/ha)	Plant height (cm)	50% flowering (days)	Maturity (days)
WBSH-2021	63.8	128	85	119
WBSH-2034	80.2	131	86	119
S-2216	82.7	133	90	117
KBSH-72	86.9	146	78	109
LSFH-176	74.5	160	91	120
KBSH-71	92.3	133	75	105
LSFS-2351	58.1	166	84	116
RSFH-10-600	39.5	192	93	124
CSFH-12235	67.7	146	82	113
DRSH-1 (C)	65.9	191	87	117
KBSH-44 (C)	75.9	163	91	121
LSFH-171(LC)	88.4	125	79	110
Mean	73.0	151	85	116
SEm ±	6.1	4	1.0	1.0
CD (P=0.05)	17.7	13	3.0 (NS)	2.7 (NS)
CV (%)	16.8	5.8	2.4	1.7

C - Check LC - Local Check; NS - Non-significant

Yield and yield components: Table 2 presented comparative performance of various yield attributes of 12 hybrids. The character head diameter non-significantly affected by various hybrids of sunflower. However maximum head diameter (28 cm) was recorded in hybrid RSFH-10-600 followed by WBSH-2021 (24.9cm). While minimum head diameter was observed in local check hybrid LSFH-171 (20.7 cm) followed by CSFH-12235 (20.8cm). Data reported in table 2 demonstrated the comparative effect of different sunflower hybrids on 100-seed weight differed significantly. Maximum 100-seed weight of 7.7 g was observed in hybrid DRSH-1 while KBSH-71 showed minimum 100-seed weight (5.8 g). Pirani and Gato (1995) reported significant variation for 1000-seed weight and other agronomic traits due to various sunflower hybrids (Anonymous, 2015).

Statistical analysis of data on seed yield revealed that highest seed yield of 3245 kg/ha was observed in hybrid WBSH-2021 followed by WBSH-2034 with 3110 kg/ha. The check hybrid DRSH-1 and KBSH-44 recorded seed yield of 2415 and 2590 kg/ha, respectively. The local check hybrid LSFH-171 recorded seed yield of 1959 kg/ha (Table 2). In terms of percentage increase of seed yield WBSH-2021 registered 34, 25 and 66 per cent more seed yield over the check hybrids DRSH-1, KBSH-44 and local check LSFH-171.WBSH-2034 recorded 29, 20 and 59 per cent more seed yield over the three check hybrids. Although oil content (%) of 12 hybrids was statistically non-significant the highest oil yield was recorded in WBSH-2021 followed by WBSH-2034. WBSH-2021 registered 30, 29 and 70 per cent more oil yield over the check hybrids DRSH-1, KBSH-44 and local check LSFH-171.WBSH-2034 recorded 23, 22 and 61 per cent more oil yield over the three check hybrids.

Under zone-III the performance of WBSH-2021 and WBSH-2034 was best among all the hybrids (Table 3). WBSH-2021 and WBSH-2034 recorded 2246 and 2106 kg/ha seed yield, respectively. Whereas, the check hybrids DRSH-1 and KBSH-44 recorded 1943 and 2106 kg/ha seed yield, respectively, WBSH-2021 registered 16 per cent more seed yield over DRSH-1 and 7 per cent more seed yield over KBSH-44 under zone-III. WBSH-2021 also registered 11 and 15.3 per cent more oil yield than the two check hybrids under zone-III (Anonymous, 2015).

Based on the overall performance of WBSH-2021 (Table 2 and 3) under various locations and zones across the country, the entry was promoted to Advanced Hybrid Trial under AICRP Sunflower.

Table 2 Yield and yield components of various sunflower hybrids in West Bengal condition

Hybrids	Head diameter (cm)	100-seed weight (g)	Seed yield (kg/ha)	Oil content (%)	Oil yield (kg/ha)
WBSH-2021	24.9	6.5	3245	38.5	1249
WBSH-2034	22.3	6.6	3110	38.0	1181
S-2216	22.0	6.1	2426	43.6	1055
KBSH-72	21.6	7.2	1692	41.5	701
LSFH-176	23.9	7.4	1496	34.6	518
KBSH-71	21.4	5.8	2380	41.0	978
LSFS-2351	24.3	7.1	2508	38.4	962
RSFH-10-600	28.0	7.5	1867	36.7	685
CSFH-12235	20.8	6.0	2180	39.7	865
DRSH-1 (C)	23.3	7.7	2415	39.9	964
KBSH-44 (C)	22.7	6.5	2590	37.4	967
LSFH-171(LC)	20.7	6.6	1959	37.5	735
Mean	23.0	6.7	2322	38.9	905
SEm ±	1.1	0.3	135	0.5	54.6
CD (P=0.05)	3.2 (NS)	0.8	389	1.5 (NS)	156.9
CV (%)	9.7	8.7	11.7	2.7	12.1

C - Check LC - Local Check; NS - Non-significant

Table 3 Performance of WBSH-2021 and WBSH-2034 under Zone-III

Hybrids	Seed yield (kg/ha)	% increase over checks		Oil yield (kg/ha)	% increase over checks	
		DRSH-1 (C)	KBSH-44 (C)		DRSH-1(C)	KBSH-44 (C)
WBSH-2021	2246	16	7	816	11	15.3
WBSH-2034	2106	8.4	-	754	2.4	6.5
DRSH-1 (C)	1943	-	-	736		
KBSH-44 (C)	2106	-	-	708		

C - Check

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Evaluation of herbicides for effective weed control in irrigated castor *(Ricinus communis* L.)

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ABSTRACT

An experiment was conducted to evaluate the efficacy of weed management practices using pre-emergence (pendimethalin and trifluralin) and post-emergence herbicides (quizalofop-ethyl and fenoxaprop-ethyl) along with weed free and unweeded check in castor (cv. GCH-6) under irrigated conditions at Main Oilseeds Research Station, Junagadh Agricultural University, Junagadh for three consecutive years during *kharif* 2010 to 2012. The experiment was conducted in randomised block design with three replications on medium clay soils with pH 7.9. The experimental field was infested with grasses and broad leaved weeds *viz., Echinochloa colonum, Eluropus villosus, Dactyloctenium aegyptium, Brachiaria* sp., *Cyperus rotundus, Commelina benghalensis, Digera arvensis, Indigofera glandulosa* and *Amaranthus viridis.* The highest castor seed yield during the study period was found in weed free control (4429, 2546 and 2581 kg/ha during year I, II and III, respectively). Similarly, pooled mean of seed yield (3183 kg/ha) was highest in weed free control. Among the herbicidal treatments, trifluralin @ 1.0 kg a.i./ha followed by post-emergence application of quizalofop-ethyl @ 0.05 kg a.i./ha at 25 days after sowing (DAS) recorded highest seed yield (3005 kg/ha) due to lower dry weight of weeds (374 kg/ha), higher weed control efficiency (85.9%) at 75 DAS and lower weed index (5.5%). This treatment resulted in higher gross returns (₹ 120208/ha), net returns (₹ 90398/ha) and B:C ratio (3.0). However, this was at par with application of pendimethalin @ 1.0 kg a.i./ha followed by post-emergence quizalofop-ethyl @ 0.05 kg a.i./ha at 25 DAS.

Keywords: Castor, Fenoxaprop-ethyl, Pendimethalin, Quizalofop-ethyl, Trifluralin, Weed control

Castor (*Ricinus communis* L.) is an important industrial oilseed crop grown in *kharif* season under rainfed conditions. Castor yield depends on several agronomic factors. Among them, weed management plays an important role in castor production. Castor plant is very sensitive to competition with weeds. As castor is initially slowly growing and with wider spacing is prone to heavy weed infestation. After 30 to 40 days of germination, the weeds may emerge and adversely affect the growth and yield of castor. The problem can be further aggravated by unpredictable weather conditions. The frequent and continuous rainfall cannot permit to enter in the field for hand weeding or inter culturing operations. Herbicides are the best option for weed management in extensive castor fields where labour is unavailable or expensive, but this option is being limited by only few recommended herbicidal control measures. An important property of an herbicide is the selectivity to control weeds without being toxic to the crop. Some post-emergence herbicides are non-selective for castor (e.g. glyphosate, paraquat, bentazon and 2,4-D) and can be applied using hoods (Maciel *et al.,* 2008); however, this method inefficient because only weeds growing between rows can be reached, and there is a risk of injury to the crop. The finding of chlorimuron-ethyl as an herbicide selective to castor plants when applied in post-emergence (Valdinei *et al.,* 2012) made possible the development of efficient herbicidal weed management techniques for this oilseed crop. The pre-emergence herbicides selective to castor (alachlor, trifluralin, pendimethalin, and clomazone) are efficient against monocotyledon species, but they have lower efficiency against broad leaved plants (Maciel *et al.,* 2007). Quizalofop-ethyl herbicide was found to be selective against perennial and annual grass weeds in many crops. The objective of present experiment was to evaluate the efficacy of some pre and post-emergence herbicides alone and in combination for effective weed control in castor.

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MATERIALS AND METHODS

An experiment was conducted at Main Oilseeds Research Station, Junagadh Agricultural University, Junagadh during *kharif* 2010, 2011 and 2012. The soil of experiment site was medium black, clayey in texture with low available nitrogen (165 kg/ha), low available phosphorus (21 kg/ha) and high available potash (322 kg/ha). An experiment was laid out in randomized block design with eight treatments and three replications. Gross plot size was 6.0 x 5.4 m and net plot was 4.8 x 3.6 m. The crop was sown at 90 x 60 cm spacing and fertilizer dose 75 kg/ha N and 50 kg/ha P_2O_5 was applied. Castor hybrid, GCH 6 was sown with seed rate of 5 kg/ha. Other cultural practices and plant protection measures were followed as per recommendations. The treatments consisted of : T_1: Trifluralin@ 1 kg a.i./ha as pre-emergence followed by one IC at 40 DAS, T2: Pendimethalin @1 kg a.i./ha as pre-emergence followed by one IC at 40 DAS, T_3: Quizalofop-ethyl @ 0.05 kg a.i./ha as post emergence, T_4: Fenoxaprop-ethyl @ 0.05 kg a.i/ha as post emergence, T_5:

Trifluralin@ 1 kg a.i./ha as pre-emergence followed by quizalofop-ethyl @ 0.05 kg a.i./ha as post emergence, T_6: Trifluratin@ 1 kg a.i./ha as pre-emergence followed by fenoxaprop-ethyl @ 0.05 kg a.i/ha as post-emergence, T_7: Pendimethalin@ 1kg a.i./ha as pre-emergence followed by quizalofop-ethyl @ 0.05 kg a.i./ha as post-emergence, T_8: Pendimethalin@ 1 kg a.i./ha as pre-emergence followed by fenoxaprop-ethyl @ 0.05 kg a.i/ha as post emergence, T_9: Weed free and T_{10}: Unweeded control. Herbicides were dissolved in 500 litres water and pre-emergence herbicide was sprayed with knapsack sprayer using flat fan nozzle at 2 days after sowing as soil application. The post-emergence herbicide was sprayed 25 days after sowing. Data on weed biomass were recorded 75 days after sowing using 0.25 m^2 quadrat placed at 4 places in each plot at random and weed observations were recorded in each quadrat. Growth and yield attributing as well as yield of castor were recorded following standard practices. The weed control efficiency (WCE) and weed index (WI) was worked out. The weed control efficiency was calculated as:

$$WCE = \frac{DWC - DWT}{DWC} \times 100$$

Where, DWC = Dry weight of weeds in unweeded control plot
DWT = Dry weight of weeds in treated plot

The weed index was derived as:

$$WI = \frac{X - Y}{X} \times 100$$

Where, X = yield from hand weeded plot
Y = yield from weed treated plot for which WI is to be calculated

Data was subjected to analysis of variance Tukey test (5%) for comparison of means.

RESULTS AND DISCUSSION

Effect on weeds: The dominant weed flora in the experimental field were narrow leaved weeds *viz., Echinochloa colonum* (21%), *Eluropus villosus* (20%), *Dactyloctenium aegyptium* (7%), *Brachiaria* spp. (9%) and *Cyperus rotundus* (7%). The broad leaved weeds *viz., Commelina benghalensis* (12%), *Digera arvensis* (14%), *Indigofera glandulosa* (6%) and *Amaranthus viridis* (4%) was also marked their presence in good numbers. The predominance of grassy and sedge weeds during *kharif* season have also been reported by Gowda *et al.* (2002) and Singh *et al.* (2013).

Significantly lowest dry weight of weeds was found in application of pendimethalin @ 1kg a.i./ha as pre- emergence followed by quizalofop-ethyl @ 0.05 kg a.i./ha as post emergence (354 kg/ha) which was remained at par with trifluralin @ 1 kg a.i./ha as pre-emergence followed by quizalofop-ethyl @ 0.05 kg a.i./ha as post emergence, trifluralin @ 1 kg a.i./ha as pre-emergence followed by fenoxaprop-ethyl @ 0.05 kg a.i/ha as post-emergence, pendimethalin@ 1kg a.i./ha as pre-emergence followed by fenoxaprop-ethyl @ 0.05 kg a.i/ha as post-emergence and trifluralin @ 1kg a.i./ha as pre-emergence followed by IC at 40 DAS (Table 1). At 75 DAS, weed control efficiency of pendimethalin @ 1kg a.i./ha as pre-emergence followed by quizalofop-ethyl @ 0.05 kg a.i./ha as post-emergence recorded higher (86.6%) which was closely followed by trifluralin @ 1 kg a.i./ha as pre-emergence followed by quizalofop-ethyl @ 0.05 kg a.i./ha as post-emergence (85.9%). Lowest weed control efficiency among herbicide application was recorded in application of fenoxaprop-ethyl @ 0.05 kg a.i/ha as post-emergence only (45.5%). Better response of quizalofop-ethyl in controlling narrow-leaved weeds might be due to the fact that the herbicide belongs to aryloxyphen-oxypropionates (AOPP) class is readily absorbed and translocated to meristematic region and exert herbicide activity. It acts by inhibiting the enzyme Acetyl Coenzyme-A carboxylase (ACCase) in susceptible species (Burton, 1997). The lowest weed control efficiency was recorded by unweeded treatment. This might be due to the continuous competition of castor crop with the obnoxious weed species for nutrient and moisture. Ramkrishna *et al.* (1990) and Dubey *et al.* (2010) observed the similar trend in efficacy of herbicide in groundnut crop and Singh *et al.* (2013) in castor crop.

Effect on crop: All the weed control treatments significantly improved the yield and yield attributing parameters over unweeded control (Table 1). The results of the present experiment showed that the weed free condition recorded significantly higher seed yield and remained comparable with pre-emergence application of trifluralin 1 kg ai/ha followed by post-emergence application of quizalofop-ethyl 0.05 kg a.i./ha as well as pre-emergence application of pendimethalin 1 kg a.i./ha followed by post-emergence application quizalofop-ethyl 0.05 kg a.i/ha during 2010, 2011 and 2012. Unweeded check resulted in lowest seed yield (1593 kg/ha). The better yield with the pre and post-emergence herbicidal treatment was due to more branches, longer spikes, more capsules per spike, more spikes per plant as compared with unweeded check and other herbicidal treatments (Table 2). The pooled analysis over three years (2010 to 2012) revealed that weed free conditions recorded highest seed yield (3183 kg/ha). The weed free treatment remained at par with pre-emergence application of trifluralin @ 1 kg a.i./ha followed by post-emergence application of quizalofop-ethyl @ 0.05 kg a.i./ha (3005 kg/ha), pre-emergence application of pendimethalin 1 kg a.i/ha followed by post-emergence application of quizalofop-ethyl 0.05 kg a.i /ha (2935 kg/ha). Higher seed yield was due to realization of better growth

(plant height, branches/plant and internodes/plant) and yield attributes (capsules/spike and length of spike) (Table 1 and 2). The unweeded control treatment recorded lowest seed yield (1593 kg/ha). This caused severe competitive stress on crop plants for growth resources and led to inferior yield attributing traits hence had minimum seed yield. These results are in close conformity with the earlier findings of Roy *et al.* (2003), Sasikala *et al.* (2007), Dubey *et al.* (2010), Bhale *et al.* (2012) and Malunjkar *et al.* (2012) in groundnut crop,Valdinei *et al.* (2012) and Singh *et al.* (2013) in castor crop.

Economics: Gross returns, cost of cultivation, net returns and B:C ratio of different treatments were worked out on the basis of current market prices of castor inputs used (Table 3). The results indicated that gross returns (₹ 127323/ha), net returns (₹ 95030/ha) and B:C ratio (2.9) was higher in weed free treatment in pooled results. It was closely followed by herbicide treatments trifluralin @ 1 kg a.i./ha + post-emergence application of quizalofop-ethyl @ 0.05 kg a.i./ha and pendimethalin 1 kg a.i/ha. + post-emergence application of quizalofop-ethyl 0.05 kg a.i /ha.

Table 1 Effect of different weed control treatments on seed yield, dry weed weight, weed index and WCE in castor

Treatments	Seed yield (kg/ha)				Dry weed weight at 75 DAS (kg/ha)	Weed index (%)	Weed control efficiency (%)
	2010	2011	2012	Pooled			
Trifluralin @ 1kg a.i./ha as pre-emergence + IC at 40 DAS	3338	1882	1929	2383	582	25.1	78.0
Pendimethalin @ 1kg a.i./ha as pre-emergence + IC at 40 DAS	3379	1737	1809	2308	676	27.5	74.5
Quizalofop-ethyl @ 0.05 kg a.i./ha as post-emergence	3509	1608	1699	2272	1277	28.6	51.8
Fenoxaprop-ethyl @ 0.05 kg a.i/ha as post-emergence	3236	1634	1489	2120	1445	33.4	45.5
Trifluralin @ 1 kg a.i./ha as pre-emergence followed by quizalofop-ethyl @ 0.05 kg a.i./ha as post-emergence	4273	2324	2419	3005	374	5.5	85.9
Trifluralin @ 1 kg a.i./ha as pre-emergence followed by fenoxaprop-ethyl @ 0.05 kg a.i/ha as post-emergence	3596	1816	1750	2387	577	25.0	78.2
Pendimethalin @ 1kg a.i./ha as pre-emergence followed by quizalofop-ethyl @ 0.05 kg a.i./ha as post-emergence	4082	2223	2500	2935	354	7.7	86.6
Pendimethalin @ 1kg a.i./ha as pre-emergence followed by fenoxaprop-ethyl @ 0.05 kg a.i/ha as post-emergence	3581	1787	1809	2393	494	24.8	81.3
Weed free	4429	2546	2581	3183	0	---	100.0
Unweeded control	2640	1107	1032	1593	2654	49.9	-
SEm±	247	81	104	60.3	99	-	-
CD (P=0.05)	734	242	310	179	295	-	-

Table 2 Effect of different weed control treatments on yield attributes in castor (pooled data of three years)

Treatments	Plant height (cm)	No. of spikes/ plant	No. of branches/ plant	No. of internodes/ plant	Capsules/ spike	Length of main spike (cm)
Trifluralin @ 1kg a.i./ha as pre-emergence + IC at 40 DAS	84.0	7.4	4.3	19.8	59.8	42.1
Pendimethalin @ 1 kg a.i./ha as pre-emergence + IC at 40 DAS	79.3	7.0	4.5	19.6	65.2	43.9
Quizalofop-ethyl @ 0.05 kg a.i./ha as post-emergence	83.2	7.4	4.7	19.3	59.0	42.8
Fenoxaprop-ethyl @ 0.05 kg a.i/ha as post-emergence	77.4	5.7	4.2	19.8	55.7	42.9
Trifluralin @ 1 kg a.i./ha as pre-emergence followed by quizalofop-ethyl @ 0.05 kg a.i./ha as post-emergence	80.0	8.3	5.2	20.0	69.3	47.3
Trifluralin @ 1 kg a.i./ha as pre-emergence followed by fenoxaprop-ethyl @ 0.05 kg a.i/ha as post-emergence	79.8	7.5	5.0	19.4	60.8	44.6
Pendimethalin @ 1kg a.i./ha as pre- emergence followed by quizalofop-ethyl @ 0.05 kg a.i./ha as post-emergence	81.8	8.1	5.7	19.7	70.2	46.7
Pendimethalin @ 1kg a.i./ha as pre- emergence followed by fenoxaprop-ethyl @ 0.05 kg a.i/ha as post-emergence	84.3	8.1	5.1	20.1	66.3	45.4
Weed free	88.6	9.1	5.9	19.9	76.2	49.0
Unweeded control	71.9	4.8	3.6	18.7	48.3	36.0
SEm±	2.2	0.5	0.31	0.2	3.0	1.5
CD (P=0.05)	6.7	1.5	0.9	0.84	8.9	4.6

Table 3 Economics of different weed control treatments in castor (pooled data of three years)

Treatments	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
Trifluralin @ 1kg a.i./ha as pre-emergence + IC at 40 DAS	30210	95327	65117	2.2
Pendimethalin @ 1kg a.i./ha as pre-emergence + IC at 40 DAS	30658	92335	61677	2.0
Quizalofop-ethyl @ 0.05 kg a.i./ha as post-emergence	28593	90895	62302	2.2
Fenoxaprop-ethyl @ 0.05 kg a.i/ha as post-emergence	27946	84781	56835	2.0
Trifluralin @ 1 kg a.i./ha as pre-emergence followed by quizalofop-ethyl @ 0.05 kg a.i./ha as post-emergence	29810	120208	90398	3.0
Trifluralin @ 1 kg a.i./ha as pre-emergence followed by fenoxaprop-ethyl @ 0.05 kg a.i/ha as post-emergence	29162	95481	66319	2.3
Pendimethalin @ 1kg a.i./ha as pre-emergence followed by quizalofop-ethyl @ 0.05 kg a.i./ha as post-emergence	30258	117397	87139	2.9
Pendimethalin @ 1kg a.i./ha as pre-emergence followed by fenoxaprop-ethyl @ 0.05 kg a.i/ha as post-emergence	29611	95702	66091	2.2
Weed free	32293	127323	95030	2.9
Unweeded control	26893	63711	36818	1.4

Market price of castor seed - ₹40 /kg; Labour charges - ₹100 /day; Trifluralin - ₹1400 /litre;
Pendimethalin - ₹ 425 /litre, Quizalofop-ethyl - ₹1300 /litre; Fenoxaprop-ethyl - ₹1500 /litre

It could be concluded that the weed management of castor crop was satisfactory with herbicidal treatment schedule combining pre-emergence herbicides (pendimethalin or trifluralin) and a post-emergence herbicides (quizalofop-ethyl or fenoxaprop-ethyl) applied at 25 days after emergence. The post-emergence herbicide significantly increased castor seed yield complementing the weed control of pre-emergence herbicides. Trifluralin @ 1 kg a.i./ha as pre-emergence application followed by quizalofop-ethyl @ 0.05 kg a.i./ha as post emergence (at 25 days after sowing) application or pendimethalin @ 1 kg a.i/ha as pre-emergence followed by quizalofop-ethyl @ 0.05 kg a.i/ha as post emergence application seemed to be more beneficial with high productivity and economic returns.

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Requirement of phosphorus and its use efficiency by sunflower (*Helianthus annuus* L.) in high phosphorus soils

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ABSTRACT

Field experiments were conducted during *kharif* 2008, 2009 and 2010 to find out the phosphorus requirement to sunflower crop grown in a soil with high initial available phosphorus (110-119 kg P_2O_5/ha). Three years pooled data revealed that application of 100% recommended dose of P_2O_5 (RDP) resulted highest seed yield of 12.18 q/ha. The seed yield increased significantly by about 9.51, 11.75, 12.50 and 13.62 per cent due to application of 25 (11.74 q/ha), 50 (11.98 q/ha), 75 (12.06 q/ha) and 100 (12.18 q/ha) per cent RDP, respectively over control (10.72 q/ha). However, the differences in seed yields observed at 50, 75 and 100% RDP are narrow and imperceptible. The per cent phosphorus derived from fertilizer (% Pdff) and phosphorus-use efficiency decreased significantly from 21.10 to 19.93 per cent and 24.19 to 6.67 per cent, respectively due to increase in P level from 25 to 100% RDP, whereas the fertilizer P uptake and soil P uptake increased from 1.58 to 1.75 kg/ha and 5.93 to 7.03 kg/ha, respectively with increase in P level from 25 to 100% RDP. The extent of saving in P fertilizer in these soils is ranged from 75 to 100 per cent depending upon the P build up in the soil.

Keywords: High P-soil, Per cent Pdff, P-levels, P-utilization, Sunflower

Long term fertilization experiments conducted by Indian Council of Agricultural Research across the country have indicated accumulation of applied phosphorus in different soils over time when optimal/supra optimal doses of either P alone or in combination with other fertilizers were made to the crops (Nambiar, 1994). Recent surveys conducted in Andhra Pradesh and work of private research organizations point out that large areas were found to contain high available P. On the other hand, loss of higher available P from top soil into water bodies results in eutrophication of water bodies and this can become a serious environmental issue albeit, locally. These observations point out that there is a need to develop appropriate technologies to use this accumulated soil P pools. One of the means by which this issue can be addressed is to re-recommend the P requirements on these soils. Alternatively, package can also be worked out to reduce the recommended P to crops in these soils having accumulated P.

In the past, while studying the use efficiency of applied P fertilizer with the help of ^{32}P isotope, researchers have usually selected soils having low available P and then gave appropriate recommendations to different crops under different conditions. However, the use efficiency of applied P in soils having higher accumulated available P need to be reassessed for developing the fertilizer P recommendations to soils of this type. Sunflower is one of the most important oilseed crop in Andhra Pradesh and is generally believed to be a heavy feeder of nutrients. Under these conditions, an attempt has been made to find out the actual requirement of P to sunflower in high P soils, the extent of P fertilizer saving that is possible from the current recommended dose to sunflower grown on these soils and the use efficiency of applied P employing isotope ^{32}P.

MATERIALS AND METHODS

Field experiments were conducted consecutively during *kharif* 2008, 2009 and 2010 at Agricultural College Farm of Acharya N.G. Ranga Agricultural University, Rajendranagar, Hyderabad. The initial characteristics of the experimental fields as determined following standard procedures (Tandon, 1993) are presented in table 1. The soils were normal without any salt problem. The soils were low in available N and high in available P_2O_5 and K_2O. Five levels *viz*., 100, 75, 50, 25 and 0 per cent of recommended dose of P_2O_5 (RDP) for sunflower (RDP-60 kg P_2O_5/ha) were imposed as treatments. Each treatment plot was divided into two parts i.e., main plot and micro plot separated by a small bund. The microplots were laid out in such a way that they were blocked on both sides by main plots. Recommended dose of N (120kg/ha) and K_2O (40 kg/ha) were applied uniformly to all the treatment plots. Part of N and P_2O_5 as per treatment was supplied through DAP. Balance of N and K_2O were applied through urea and MOP. The entire dose of P_2O_5 and K_2O were applied at the time of sowing while the nitrogen was applied in three equal splits as recommended i.e., at sowing, bud initiation stage and flowering stage. The phosphorus in DAP was tagged with ^{32}P radioisotope @ 12.95 MBq (0.35mCi)/g P_2O_5 and applied to the crop in microplots and untagged DAP was applied in the main plots. The treatments were replicated five times in randomized block design. The crop was grown duly following the standard package of practices. The crop in the main plot was used exclusively for recording

yield while the crop in the microplots was used for estimating the chemical constituents. Radioassay of ^{32}P in plant samples was carried out as per the procedure given by IAEA (1990). The radiation counting was done with a Geiger-Muller counter (Model- RCS 4207A). Phosphorus use efficiency by using the radioisotopes was derived by adopting the following steps:

a) P-uptake (kg/ha) : Seed yield (kg/ha) X % P content / 100
b) P-ppm : % P content X 16
c) ml /mg P : 1000 / P-ppm
d) Counts/Second : Reading from Geiger Muller counter/Sec
e) Counts/mg/sec : Counts/sec X ml/ mg P
f) Per cent phosphorus derived from fertilizer (%Pdff) :
Counts/mg/sec of plant/Counts/mg/sec of fertilizer
g) Fertilizer P uptake (kg/ha) : % Pdff X P-uptake (kg/ha) / 100
h) % P use efficiency : Fertilizer P uptake X 100 / Dose of applied fertilizer

Table 1 Initial soil characteristics of experimental field

Characteristics	2008-09	2009-10	2010-11
pH	8.1	8.1	8.2
EC (dS/m)	0.22	0.24	0.28
Organic Carbon (%)	0.23	0.24	0.26
Available Nitrogen (kg/ha)	238	223	206
Available Phosphorus (kg P_2O_5/ha)	110	114	119
Available Potassium (kg K_2O/ha)	442	448	454

RESULTS AND DISCUSSION

Dry matter yield: The dry matter yield of sunflower at flowering stage as influenced by varied levels of P fertilizer application in P-accumulated soils is presented in table 2. The pooled analysis of three years (2008-2010) data indicated that the increased application of P fertilizer to sunflower crop on high P soils did not affect the dry matter yield at flowering stage in these high P soils having available P_2O_5 in the range of 110 to 119 kg/ha. However, the mean dry matter yield increased by 7.19, 9.76, 9.15 and 9.97 per cent when P was applied @ 25, 50, 75 and 100% RDP, respectively over control. Highest dry matter yield (2140 kg/ha) was recorded with application of 100% RDP over other levels of P. These observations pointed out that there is a possibility of reducing the recommended dose of P fertilizer to sunflower crop on soils with high initial available P. These results also corroborate earlier findings of Senanayake *et al.* (1991) for rice and Balwinder Singh and Bishnoi (1998) for sunflower who reported that the dry matter yield response to applied P fertilizer is low when available P in soil is high.

P-content and uptake by dry matter at flowering stage: The P-content and uptake (Table 2) by sunflower dry matter at flowering stage increased due to different levels of added P fertilizer. Three years pooled analysis of data indicated that highest mean P-content (0.41%) and uptake (8.77kg/ha) were observed when P was applied @ 100% RDP to sunflower crop. However, the mean P content and uptake recorded at all levels of P application in these high P soils were statistically on par. It is observed that though the soils were high in initial available P_2O_5, the content of P in dry matter tend to increase with incremental P application within recommended dosage and recorded highest P with 100% RDP. Thus, application of different levels of P to a high P soil invariably did not affect the P content or its uptake by sunflower crop. Similar results were reported by Surendra Babu *et al.* (2005) in sunflower.

Table 2 Effect of Phosphorus levels on dry matter yield of sunflower at flowering stage in high P soils (Three years pooled data)

Treatments	Dry matter yield (kg/ha)	P-content (%)	P-uptake (kg/ha)
100% RDP	2140	0.41	8.77
75% RDP	2124	0.39	8.28
50% RDP	2136	0.38	8.12
25% RDP	2086	0.36	7.51
Control	1946	0.36	7.01
Mean	2086	0.38	7.94
CD(P=0.05)	NS	NS	0.54

Per cent P derived from fertilizer (Pdff): The radioassay data for different P fertilizer parameters are presented in table 3. The per cent P derived from the fertilizer in sunflower plants at flowering stage is affected by the level of P fertilizer application. The mean per cent Pdff tended to decrease gradually at the higher levels of P application when compared to that of lower levels of P application. In the past, when experiments were conducted on a nutrient deficient soil with different levels of that fertilizer nutrient, it was observed that the percent nutrient derived from the fertilizer was higher with the increasing levels of fertilizer application due to its higher availability in soil (Sonali Mazumdar *et al*., 2004) . However, in the present study where in high P soils the per cent Pdff in the plants tended to decrease from 25 to 100% RDP indicating that sufficient levels of available P is already existing in the soils as reflected by availability status. At the same time, it is also observed that with the increased P application to these soils, the contribution from the native soil P also became a major contributor in higher P fertile soil for crop requirement and the data on soil P uptake by plants presented in table 3 reflect the same.

Fertilizer P uptake: Pooled analysis of three years data indicated that the mean fertilizer P uptake (Table 3) followed the trend similar as that of total P uptake (Table 2) which was more influenced by the yield. Similar results were reported by Surendra Babu *et al*. (2005) in sunflower crop.

P-use efficiency: The applied P fertilizer use efficiency of three years pooled analysis data (Table 3) by sunflower

plants was significantly affected by P fertilizer application. The mean P utilized by sunflower ranged from 6.67 to 24.19 per cent due to different levels of its application. The use efficiency of applied P fertilizer was significantly decreased with increase in P application. P utilization was higher (24.19 %) when supplied @ 25% RDP as compared to that of 100% RDP (6.67%). Similar results were reported by Venkata Reddy *et al.* (1997). Thus, the present investigation clearly indicated that the % Pdff by sunflower is getting reduced with enhanced application of P in high P soils in contrast to what is being generally observed in low P soil and at the same time, the use efficiency of applied P tend to remain same like that of in low P soil.

Table 3 Effect of phosphorus levels on per cent P derived from fertilizer, fertilizer P uptake, per cent P utilization and soil P uptake by sunflower at flowering stage in high P soils (Three years pooled data)

Treatments	% Pdff	Fertilizer P uptake (kg/ha)	% P utilization	Soil-P uptake (kg/ha)
100% RDP	19.93	1.75	6.67	7.03
75% RDP	20.39	1.69	8.59	6.59
50% RDP	20.64	1.68	12.79	6.44
25% RDP	21.10	1.58	24.19	5.93
Mean	20.51	1.67	13.06	6.49
CD(P=0.05)	NS	NS	0.96	0.54

Seed and stover yield: Three years pooled data revealed that application of 100% RDP resulted highest seed yield of 12.18 q/ha (Table 4). The seed yield increased significantly by about 9.51, 11.75, 12.5 and 13.62 per cent due to application of 25 (11.74 q/ha), 50 (11.98 q/ha), 75 (12.06 q/ha) and 100 (12.18 q/ha) per cent RDP, respectively over control (10.72 q/ha). However, the differences in seed yields observed at 50, 75 and 100% RDP are narrow and imperceptible. It clearly indicates that there is no need of application of 100% RDP to sunflower in P-accumulated soils if soil available P_2O_5 is in between 110-119 kg/ha. At the same time, application of either 25% RDP or 50% RDP resulted in similar yield indicating that at least 75% of RDP to sunflower crop can be reduced to obtain yields similar like that of 100% RDP in this high P soils. There is a need of application of only a booster dose of 25% RDP is required to obtain maximum yields. Thus in these soils the extent of saving in P fertilizer is ranged from 75 to 100 per cent depending upon the P build up in the soil. Similar trend in case of stover yield of sunflower also (Table 4). Ramesh Babu (2003) while working with different high-P group soils indicated that it is possible to reduce P application from current RDP of rice by 25% in soils having initial available P_2O_5 range of 50 to 70 kg/ha without reducing the yields.

P-content and uptake by seed and stover: Mean P-content and uptake by sunflower seed was influenced by application of reduced levels of phosphorus in P-accumulated soils (Table 4). Mean P-content and uptake by seed was highest at 100% RDP. Decrease in P content and uptake was noticed at lower levels of P application in seed of sunflower. Similar trend was noticed in case of stover of sunflower also (Table 4).

Table 4 Effect of phosphorus levels on seed yield, stover yield and P- uptake by sunflower in high P soils (Three years pooled data)

Treatments	Seed yield (q/ha)	Stover yield (q/ha)	P-uptake by seed (kg/ha)	P-uptake by stover (kg/ha)	Total P uptake (kg/ha)
100% RDP	12.18	24.86	7.31	2.24	9.55
75% RDP	12.06	24.12	7.11	2.41	9.52
50% RDP	11.98	23.02	7.07	2.53	9.60
25% RDP	11.74	22.12	6.81	1.99	8.80
Control	10.72	19.34	6.00	1.93	7.93
Mean	11.74	22.69	6.86	2.27	9.13
CD(P=0.05)	0.64	1.78	0.44	0.14	

Current investigation indicated that to obtain optimum yields in sunflower application of 25% recommended dose of phosphorus as a booster dose will be sufficient in P accumulated soils if available P_2O_5 was in between 110-119 kg/ha. Thereby reduce the cost of chemical P fertilizer input from the current level of general recommendation.

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Productivity and nutrient use of sunflower (*Helianthus annuus* L.) in sequential cropping system in Vertisols

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ABSTRACT

Field experiments were conducted on fixed plot for three consecutive years during 2009-12 on medium Vertisols at Hyderabad. The experimental site was clay soil with a soil pH and organic carbon of 7.7 and 0.51 per cent, respectively. The productivity and sustainability of *rabi* sunflower was assessed under three cropping sequences in rainy (*kharif*) and winter (*rabi*) seasons *viz.,* fallow-sunflower; sunflower-sunflower and soybean-sunflower and four nutrient management practices. The *kharif* crops were grown as rainfed and *rabi* sunflower was grown with one irrigation at sowing. The highest seed yield (1412 kg/ha) of sunflower was recorded in soybean-sunflower system followed by fallow-sunflower (1185 kg//ha) system. Continuous cropping of sunflower resulted in lowest yield (983 kg/ha). N and P uptake of *rabi* sunflower succeeding either soybean or fallow was higher compared to continuous cropping. Significantly higher and comparable seed yield, stalk yield were obtained with the application of recommended dose of major nutrients in conjunction with farm yard manure (FYM).

Keywords: Cropping sequence, Fallow, Nutrient uptake, Soil fertility, Soybean, Sunflower

Sunflower is an important oilseed crop with high quality edible oil. Owing to its short duration and wider adoptability, it has great potential for diversification of major cropping systems in the country. Improper crop management in terms of crop rotation and nutrition are the major limitations for realizing higher yields especially in traditional sunflower growing areas of Karnataka, Andhra Pradesh, Maharashtra and Tamil Nadu. Currently, the crop is grown in an area of 69 lakh ha with a production of 55 lakh t. (2013-14). Compared to the world average productivity of about 1320 kg/ha, the national average productivity of 791 kg/ha is low due to its production under sub-optimal agro-ecological conditions. About 60% of the crop is grown under Vertisols. Dynamic cropping systems take advantage of crop sequencing and synergism (Tanaka *et al.,* 2005). To optimize the benefits of cropping systems on crop parameters, it is important to understand the effects of previous crops on current crop production. Continuous cropping of sunflower has resulted in declining yield and sustainability in traditional sunflower growing areas of the country.

The main objective of the present investigation was to assess the performance of *rabi* sunflower under three cropping systems and possibility of reducing nutrient requirements of sunflower through integration of legumes or fallow in the cropping system and provide appropriate nutrient management practices that could lead to higher yield. Keeping this in view, nutrient management studies were initiated with three crop sequences *viz.,* fallow-sunflower; sunflower-sunflower and soybean-sunflower in Vertisols.

MATERIALS AND METHODS

Field experiments were conducted on fixed plot during 2009-12 for three consecutive years at IIOR-ICRISAT Farm, Hyderabad, on medium Vertisols. The experimental site was clay soil with a soil pH, organic carbon, available nitrogen, available phosphorus and potassium of 7.7, 0.51 per cent, 148 kg/ha, 15 kg/ha and 772 kg/ha, respectively. Sunflower (Hybrid: KBSH-1) was grown under three cropping sequences in rainy (*kharif*) and post-rainy (*rabi*) seasons *viz*., fallow-sunflower; sunflower-sunflower and soybean (JS-335)-sunflower in main plots and four nutrient management practices (no manure, 50% recommended NPK, 100% recommended NPK, 100% recommended NPK + FYM @ 5t/ha) in sub-plots in split-plot design with four replications. The experimental site was fertilized with 60: 60: 30 kg NPK through urea, single super phosphate and muriate of potash, respectively. The seeds of sunflower were hand dibbled with spacing of 60 x 30 cm on ridges and furrows. The *kharif* crops were grown under rainfed conditions and *rabi* sunflower was grown with one irrigation at sowing. Gross and net plot size of 6x5.4 m and 4.8x4.8 m were maintained. Growth and yield parameters (plant height, stem girth, 100-seed weight) were recorded on five random plants in net plot and average of five plants at harvest during each year was recorded. The seed weight, stalk weight and total biomass yield was recorded on net plot basis at harvest and reported as kg/ha. The nutrient content (N and P) of plant samples and oil content (%) in seed was determined by using standard procedures. The oil yield (kg/ha) was determined as seed yield (kg/ha) x oil content (%)/100. Similarly, N and P

uptake was determined. Harvest Index (H.I) was determined as follows: H.I= Economic yield/biomass yield x 100. The pooled analysis of data during study period (2009-12) is reported.

RESULTS AND DISCUSSION

The growth and yield parameters of sunflower differed due to different cropping sequences and nutrient management practices. The growth characters (plant height, stem girth and 100-seed weight), seed yield and stalk yield of sunflower varied significantly due to various cropping sequences and nutrient management practices. The pooled analysis of data over three years (2009-10 to 2011-12) indicated that the growth parameters did not differ significantly. The highest seed yield (1412 kg/ha) was recorded in soybean-sunflower system followed by fallow-sunflower (1185 kg//ha) system. Continuous cropping of sunflower resulted in significantly the lowest yield (983 kg/ha). Among nutrient management practices, the highest seed yield was recorded with 100% recommended NPK + FYM application (1471 kg/ha). There was about 43 per cent yield reduction in no fertilizer control compared to 100% NPK. The stalk yield followed similar trend as that of seed yield. The biomass yield was not influenced significantly due to cropping sequences. Numerically the highest biomass yield (4127 kg/ha) was recorded in soybean-sunflower cropping sequence. Different nutrient management schedules influenced the biomass yield of *rabi* sunflower significantly. The highest biomass yield (4585 kg/ha) was recorded with application of 100% recommended NPK+FYM followed by application of 100% recommended NPK only. Significantly the lowest biomass yield (3258 kg/ha) was recorded in control. The harvest index ranged between 28.7-40.6 per cent due to different nutrient management practices (Table 1). The effect of *kharif* legumes on productivity and economics of *rabi* sunflower at Latur, Maharashtra indicated that both mungbean-sunflower and urdbean-sunflower sequence recorded similar higher yields/sunflower equivalent yields and higher net returns and were significantly superior over fallow-sunflower (Aglave *et al*., 2009). Oilseed-based crop sequences help to utilize the residual fertility and provide ideal crop rotations. The long term fertilizer trial on sunflower based sequences in Alfisols at Hyderabad revealed that groundnut and castor are efficient in utilizing the residual fertility from preceding sunflower. Sunflower yields at 50% recommended fertilizer application, in sunflower-groundnut sequence were similar to that of 150% recommended fertilizers in sunflower-sunflower crop sequence. A saving of 50% of N to safflower was possible when preceding *kharif* crop was greengram compared to sorghum or fallow (Sudhakara Babu and Hegde, 2011).

Table 1 Performance of sunflower under nutrient management in crop sequences in Vertisols (Pooled means of 3 years)

	Plant height (cm)	Stem girth (cm)	Head diameter (cm)	100-seed weight (g)	Seed yield (kg/ha)	Stalk yield (kg/ha)	Biomass yield (kg/ha)	Harvest index (%)	Oil content (%)	Oil yield (kg/ha)
Crop sequences - *Kharif-Rabi*										
Fallow-sunflower	188	7.4	13.9	4.13	1185	1585	3988	37.3	39.9	473
Sunflower-sunflower	177	6.9	13.2	3.83	983	1309	3782	33.3	40.5	398
Soybean-sunflower	195	7.4	14.7	4.25	1412	1629	4127	37.0	40.7	575
SEm±	3.3	0.095	0.40	0.048	13.0	21.5	207.3	-	0.422	-
CD (P=0.05)	11.6	0.363	NS	0.176	38.7	64.0	NS	-	NS	-
Nutrient Management										
Control	174	6.5	12.6	3.64	828	1239	3258	28.7	40.3	334
50% NPK	183	7.1	13.5	4.02	1094	1446	3747	33.9	40.2	440
100% NPK	192	7.5	14.3	4.31	1381	1611	4273	37.4	40.6	561
100% NPK+FYM	198	7.9	15.2	4.42	1471	1733	4585	40.6	40.5	596
SEm±	2.17	0.089	0.16	0.065	15.3	18.9	94.5	-	0.338	-
CD (P=0.05)	2.99	0.258	0.52	0.558	43.2	53.3	717	-	NS	-
Interaction										
SEm±	1.52	0.76	0.18	0.033	26.6	32.8	126.3	-	-	-
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	-	NS	-

The oil content was not significantly influenced due to crop sequences and nutrient management schedules. The highest oil yield (575 kg/ha) was recorded in soybean-sunflower sequence followed by fallow-sunflower (473 kg/ha) and lowest (398 kg/ha) was recorded in continuous cropping of sunflower. Among various nutrient management schedules, the highest oil yield (596 kg/ha) was recorded with application of 100% recommended NPK + FYM followed by 100% recommended NPK (561 kg/ha) and lowest oil yield (334 kg/ha) was recorded in control. Oil content (%) being mainly a genetically influenced character was not influenced significantly due to cropping sequences and nutrient management practices.

The nutrient uptake (N and P) by *rabi* sunflower varied due to different cropping sequences. The N and P uptake was highest (43.5 N; 12.3 P kg/ha) in soybean-sunflower system followed by fallow-sunflower (36.7 N; 11.1 P kg/ha) and the lowest was found in continuous cropping of sunflower (27.4 N; 7.4 P kg/ha).

Soil fertility changes: After harvest of sunflower crop, soil analysis data at the end of three cycles indicated that there was no perceptible change in soil pH (8.36 to 8.48) and organic carbon content (0.58 to 0.65%) due to different cropping sequences. Soil available N was found to be low in sunflower-sunflower system than all other systems due to more removal while available N was high in soybean-sunflower and fallow-sunflower due to less removal. As a result, the N and P uptake of *rabi* sunflower succeeding either soybean or fallow was higher compared to continuous cropping of sunflower (Fig. 1 and 2).

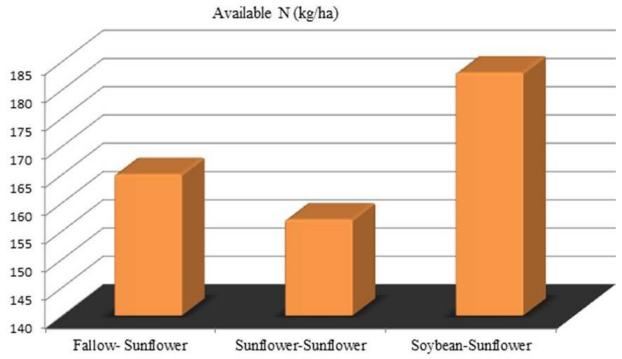

Fig. 1. Available N (kg/ha) in soil as influenced by different cropping sequences

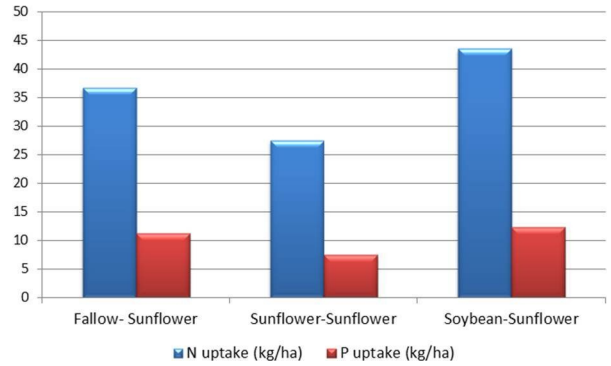

Fig. 2. Nutrient uptake by *rabi* sunflower in different cropping sequences

In Northern Great Plains of USA, the relative seed yield for eight of the 10 crops resulted in synergistic effects when the previous crop was dry pea or lentil, compared with each crop grown on its own residue (Tanaka *et al.,* 2007). Balanced fertilization to rainy season soybean and succeeding winter sunflower involving soybean-sunflower cropping system recorded highest soybean and sunflower seed yield, soybean equivalent seed yield and higher economic returns in Vertisols in semi-arid conditions (Suresh *et al*., 2014).

The study revealed that sunflower succeeding either soybean or fallow gave higher yields compared to sunflower-sunflower in Vertisols. Continuous cropping of sunflower resulted in lowest yields due to greater depletion of nutrients and lower uptake of nutrients by the crop. Significantly higher and comparable seed yield and stalk yield were obtained with the application of full dose of major nutrients in conjunction with FYM.

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Management of *Sclerotinia* rot of rapeseed-mustard through integrated pest management

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ABSTRACT

In vitro studies revealed maximum mycelial growth inhibition (98.5%) of *Sclerotinia sclerotiorum* by *Trichoderma koningii* isolate JMA-11 followed by DMA-8 (90.4%). Extract of *Vitex negundo* and *Melia azedarach* showed 100 per cent and 98.3 per cent inhibition of mycelial growth of *S. sclerotiorum* at 5% concentration followed by 96.7 per cent and 91.7 per cent growth inhibition at 2.5% concentration, respectively. At 1% concentration, 57.6 per cent growth inhibition of the pathogen was shown by *Melia azedarach* followed by 55.6 per cent inhibition with *Vitex negundo.* Fifty nine genotypes of rapeseed-mustard screened under artificial field conditions showed lack of the resistance to *S. sclerotiorum.* However, ten genotypes *viz.,* NRCG-104, NRC-DR-603, HC-0213, HC-0212, HC-9603, HC-9605, BCRS-17, Pusa Swarnim, Kiran, and PBC-9221 belonging to *Brassica carinata* were found to be moderately susceptible. In the integrated disease management, a combination of row spacing 45 cm, 2-3 lower leaf removal at 80 and 100 days after sowing and one spray of companion (0.2%) was found to be best treatment in reducing the disease incidence of *Sclerotinia* rot in *Brassica napus*.

Keywords: Botanicals, IPM, Rapeseed-Mustard, Resistance, *Sclerotinia* rot, *Trichoderma*

Rapeseed-mustard is the third important oilseed crop in the world after soybean [*Glycine max* (L.) Merr.] and palm (*Elaeis guineensis* Jacq.). Rapeseed-mustard group is constituted by seven annual oilseeds belonging to the family *Brassicaceae* (Cruciferae) *viz.,* Indian mustard [*Brassica juncea* (L.) Czern. & Coss.], three ecotypes of Indian rapeseed *viz., toria,* brown sarson and yellow sarson (*Brassica campestris* L. sp. *oleifera*), gobhi sarson (*Brassica napus* L.), Ethiopian mustard or *karan rai* (*Brassica carinata* A. Braun) and taramira (*Eruca sativa* Mill.). Rapeseed-mustard is grown in an area around 6.2 million ha with annual production of 7.36 million tonnes and productivity of 1188 kg/ha in India (Anonymous, 2013). In Himachal Pradesh, the crop is grown over an area of 8.4 thousand ha with a total production of 3.6 thousand metric tonnes. The average productivity of the state is quite low (430 kg/ha) as compared to 1188 kg/ha in India and 1950 kg/ha world over (Anonymous, 2010). Among various biotic constraints limiting production, *Sclerotinia* rot caused by *Sclerotinia sclerotiorum* (Lib.) de Bary has emerged as a serious disease in most of the rapeseed-mustard growing areas of India and Himachal Pradesh (Aggarwal *et al*., 2001). Shukla (2005) recorded 50.88 per cent yield loss in mustard crop due to the *Sclerotinia* rot. It is very difficult to manage this disease, once the pathogen is established in soil as the fungus is known to survive as mycelium in plant debris and mainly as sclerotia in the soil from which the disease initiates. Management of *Sclerotinia* rot with fungicides has been attempted since long time. However, it is difficult to control this disease with fungicides alone because of its wide host range and soil borne nature. Similarly control through host resistance is unsatisfactory because of non-availability of resistant varieties against this disease. Mitigation of such plant disease problems has necessitated a research for alternative means of disease control that are effective and environmental friendly. Present studies have been attempted to identify IPM interventions for management of *Sclerotinia* rot of rapeseed-mustard in an effective manner.

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MATERIALS AND METHODS

In vitro* evaluation of bio-control agents against *Sclerotinia sclerotiorum: Antagonistic activities of seven isolates of *Trichoderma* spp. *viz.,* JMA-11 and DMA-8 of *Trichoderma koningii,* JMA-4 and SMA-5 of *T. harzianum,* SAT-1 and SAT-2 of *Trichoderma* sp. and H-3 of *T. viride* were tested on PDA medium using dual culture technique (Huang and Hoes, 1976). The plates containing PDA medium inoculated with pathogen alone served as control. Three replications were maintained in each treatment and the plates were incubated at 22±2°C. The radial growth of the pathogen and bioagents from the centre of the discs towards the centre of plate was recorded after the control plates were completely covered by the pathogen. Growth inhibition of the pathogen by bioagents over control was calculated by using the following formula suggested by Vincent (1947).

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

Where,
I= per cent inhibition of mycelial growth
C= growth of the pathogen in control (mm)
T= growth of the pathogen in treatment (mm)

Evaluation of plant extracts against *S. sclerotiorum*: Extracts of ten locally available plants like Harad (*Terminalia chebula*), Bahera (*Terminalia belerica*), Amla (*Emblica officinalis*), Safeda (*Eucalyptus globulus*), Silver oak (*Grevillia robusta*), Garlic (*Allium sativum*), Gandla (*Murraya koenigii*), Bana (*Vitex negundo*), Eupatorium (*Eupatorium adenophorum*) and Drek (*Melia azedarach*) were evaluated against the pathogen through poisoned food technique (Nene and Thapliyal, 1993) to identify effective plant extracts. Plant extracts were prepared and purified by procedure described by Ashlesha (2012). Fresh plant materials were utilized for preparing the extract. The plant material (leaves and bulbs) were washed with running water to remove dirt and dried under shade. Dried material was then chopped into small pieces with a sharp knife. The plant material was grinded in grinder cum mixer by adding water in 1:1 w/v ratio to get a fine paste. Equal quantity of methanol was added to the aqueous paste and kept overnight. Then methanol was removed from suspension by treating the mixture in water bath for the time period till methanol from beaker (containing only methanol) was removed. The plant extract was then filtered thrice through Whatman No.1 filter paper. The filtrate thus, obtained was passed through Millipore syringes to remove extra impurities. The plant extracts were then sealed in labeled conical flasks and stored in refrigerator till further use in the experiments.

Different concentrations *viz.,* 1, 2.5, 5 and 10 per cent of extract mixed in PDA medium were poured upto 20ml in each sterilized Petri plate and allowed to solidify. Each Petri plate was centrally inoculated with 5 mm mycelial disc of pathogen cut with the help of sterilized cork borer from the margin of actively growing four days old culture using standard procedures and incubated at 22±2°C. Each treatment was replicated thrice. Mycelial disc of pathogen in plates containing only medium served as control. Regular observations were made and finally colony diameter was measured after the control plates were completely covered by the pathogen. Per cent inhibition of mycelial growth was calculated by using Vincent (1947) formula.

Evaluation of rapeseed-mustard germplasm against *S. sclerotiorum*: Fifty nine genotypes of rapeseed-mustard comprising *Brassica napus* (10), *B. carinata* (14), *B. rapa* (6) and *B. juncea* (29) were artificially screened against *S. sclerotiorum* by the method adopted for field screening of germplasm (Li *et al*., 2007) to find out sources of resistance, if any. The test entries were planted during first week of November in single rows of 3 m length with 30 × 10 cm spacing between rows and plants in two replications. All the recommended agronomic practices were followed for raising the crop.

Pathogen was grown on thick layer of PDA at 22±2°C for 4 days. Five mm mycelial discs of fungus were placed on third internode of plants at the flowering stage. The stem along with the fungal discs was wrapped with a swab of cotton dipped in sterile distilled water. The field was irrigated to create the humid conditions. The degree of resistance or susceptibility towards the *S. sclerotiorum* in different lines was studied by using 0-4 scale where 0 (no disease), 1 (1/4 stem girdled) were rated as resistant and moderately resistant whereas 2 (1/2 stem girdled), 3 (3/4 stem girdled), 4 (> 3/4 stem girdled) as moderately susceptible, susceptible and highly susceptible, respectively.

Effect of leaf removal, row spacing and fungicidal sprays on *Sclerotinia* rot: Integrated effect of removal of 2-3 lower leaves, row spacing and fungicidal sprays was studied against the *Sclerotinia* rot incidence under field conditions in two successive crop seasons of 2010-11 and 2011-12 by using twelve different treatment combinations (Table 1). Field experiment was laid out in a factorial randomized block design in plot size of 3.0 × 2.7 m^2. Sowing was done in first week of November in both the crop seasons and recommended agronomic practices were followed. Data on disease incidence, test weight (weight of thousand seeds) and yield (q/ha) was recorded. All the data of field as well as laboratory experiments were subjected to analysis of variance (Panse and Sukhatme, 1985).

RESULTS AND DISCUSSION

In vitro* evaluation of bio-control agents against *S. sclerotiorum: All the fungal antagonists evaluated in the present study inhibited the mycelial growth of *Sclerotinia sclerotiorum* (Fig. 1 and Table 2). Maximum growth inhibition (98.5 %) was caused by the isolate JMA-11 followed by 90.4 per cent inhibition by DMA-8 both belonging to *Trichoderma koningii,* whereas least inhibition (36.6%) was recorded with *Trichoderma* sp. (SAT-2). The antagonism of *Trichoderma* spp. against *Sclerotinia sclerotiorum* and other phytopathogenic fungi has been well documented by the earlier workers (Chattopadhyay *et al*., 2002; Gaur *et al*., 2010; Sharma *et al*., 2014). *Trichoderma* is considered as fascinating microorganism for biological control because it has different mechanisms of action against plant pathogens which include competition for nutrients, mycoparasitism and antibiosis by hydrolytic enzymes (Castillo *et al*., 2011). It also produces metabolites that promote plant growth. However, efficacy of any biological agent depends on biotic and abiotic factors. Therefore,

proper selection and testing of local strains is important rather using exogenous strains. Present study has resulted in the identification of potential native strains of *Trichoderma* which can be exploited locally for integrated management of *S. sclerotiorum*.

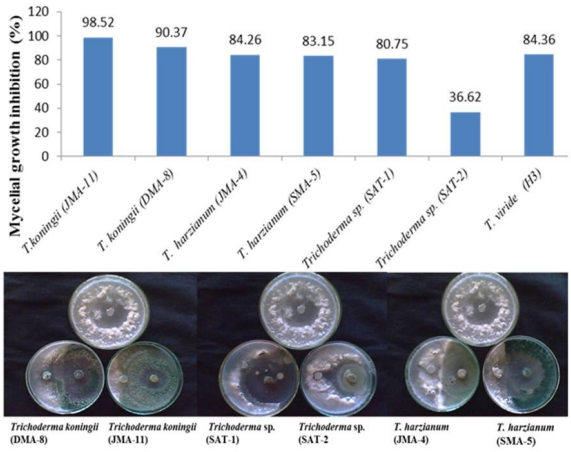

Fig. 1. *In vitro* evaluation of bio-control agents against *S. sclerotiorum*

Evaluation of plant extracts against *S. sclerotiorum*: *In vitro* studies on efficacy of extracats of ten locally available plants at different concentrations revealed that all the tested plant extracts except *Emblica officinalis* and *Terminalia chebula* inhibited the mycelial growth of *S. sclerotiorum* at 1.0% concentration. The inhibition ranged from 41.7 to 57.6 per cent being highest in *Melia azedarach* followed by 55.6 per cent in *Vitex negundo* (Table 3). At 2.5 per cent concentration, *Vitex negundo* showed maximum mycelial inhibition (96.7%) followed by *Melia azedarach* (91.7%) Similarly at 5 per cent concentation, 100 per cent mycelial inhibition was recorded with *Vitex negundo* followed by *Melia azedarach* (98.3%). No growth of pathogen was observed at 10 per cent concentration in any of the plant extract. Antifungal activity of leaf extracts of *Vitex negundo* and *Melia azedarach* has also been observed by earlier researchers (Prince and Prabhakaran, 2011; Jabeen *et al*., 2011). The leaves of *Vitex negundo* and *Melia azedarach* are known to possess chemical constituents like flavonoids, flavones, glycosides, volatile oil, triterpenes and many other compounds with antifungal nature (Ladda and Magdum, 2012; Sharma and Paul, 2013). Earlier workers (Chattopadhyay *et al.,* 2002; Pandey *et al.,* 2011; Yadav *et al.,* 2011) have reported effectiveness of garlic extract against *S. sclerotiorum*. The extracts of *Melia azedarach* and *Vitex negundo* were found superior to garlic for inhibiting mycelial growth of *S. sclerotiorum* in present investigation.

Table 1 Details of treatments on integrated disease management

Treatments	Symbol
Row spacing 30cm	$S_1D_0F_0$
Row spacing 30cm + two sprays of Companion* (0.2%)	$S_1D_0F_2$
Row spacing of 30cm + removal of 2-3 lower leaves on 80DAS	$S_1D_1F_0$
Row spacing of 30cm + removal of 2-3 lower leaves on 80DAS + one spray of Companion (0.2%)	$S_1D_1F_1$
Row spacing of 30cm + removal of 2-3 lower leaves on 80 and 100 DAS	$S_1D_2F_0$
Row spacing of 30cm + removal of 2-3 lower leaves on 80 and 100DAS + one spray of Companion (0.2%)	$S_1D_2F_1$
Row spacing of 45cm	$S_2D_0F_0$
Row spacing 45cm + two sprays of Companion (0.2%)	$S_2D_0F_2$
Row spacing of 45cm + removal of 2-3 lower leaves on 80DAS	$S_2D_1F_0$
Row spacing of 45cm + removal of 2-3 lower leaves on 80DAS + one spray of Companion (0.2%)	$S_2D_1F_1$
Row spacing of 45cm + removal of 2-3 lower leaves on 80 and 100 DAS	$S_2D_2F_0$
Row spacing of 45cm + removal of 2-3 lower leaves on 80 and 100 DAS + one spray of Companion (0.2%)	$S_2D_2F_1$

*Companion (Carbendazim 12 % + Mancozeb 63% WP)

Table 2 *In vitro* evaluation of bio-control agents against *S. sclerotiorum*

Bio-control agent	Source/code	Radial growth of pathogen (mm)	% inhibition*
Trichoderma koningii	Palampur (JMA-11)	0.7	98.5 (84.3)
T. koningii	Palampur (DMA-8)	4.3	90.4 (71.9)
T. harzianum	Palampur (JMA-4)	7.0	84.3 (66.6)
T. harzianum	Palampur (SMA-5)	7.2	83.2 (65.8)
Trichoderma sp.	Kangra (SAT-1)	8.7	80.8 (64.0)
Trichoderma sp.	Kangra (SAT-2)	28.3	36.6 (37.2)
T. viride	Hyderabad (H3)	7.0	84.4 (66.7)
Control		44.7	0 .0 (0.0)
CD (P=0.05)		2.3	3.6

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

Table3 Evaluation of different plant extracts against *S. sclerotiorum*

Plant / Concentration (%)	1	2.5	5	10	1	2.5	5	10
	Mycelial growth (mm)				% Inhibition*			
Amla (*Emblica officinalis*)	90.0	47.2	21.5	0	0.0 (0.0)	47.6 (43.3)	76.1 (71.1)	100 (90.00)
Bahera (*Terminalia belerica*)	52.5	31.5	24.5	0	41.7 (39.3)	65.0 (62.9)	72.8 (68.6)	100 (90.00)
Harad (*Terminalia chebula*)	90.0	23.2	15.5	0	0.0 (0.0)	74.2 (71.6)	82.8(79.8)	100 (90.00)
Safeda (*Eucalyptus globulus*)	43.2	37.5	22.5	0	52.0 (49.8)	58.3 (54.6)	75.0 (71.5)	100 (90.00)
Silver oak (*Grevillia robusta*)	42.0	35.0	20.0	0	53.3 (51.3)	61.1 (57.3)	77.8 (72.4)	100 (90.00)
Garlic (*Allium sativum*)	46.5	38.2	28.5	0	48.3 (45.3)	57.6 (53.6)	68.3 (62.5)	100 (90.00)
Gandla (*Murraya koenigii*)	47.0	34.0	17.0	0	47.8 (43.3)	62.2 (59.2)	81.1 (77.2)	100 (90.00)
Bana (*Vitex negundo*)	40.0	3.0	0.0	0	55.6 (50.2)	96.7 (91.5)	100.0 (94.3)	100 (90.00)
Eupatorium (*Eupatorium* sp.)	45.0	36.5	18.2	0	50.0 (46.8)	59.4 (54.6)	79.7 (74.5)	100 (90.00)
Drek (*Melia azedarach*)	38.2	7.5	1.50	0	57.6 (48.3)	91.7 (86.5)	98.3 (95.4)	100 (90.00)
Control	90.0	90.0	90.0	90.0	-	-	-	-
CD (P=0.05)					1.6	1.2	1.7	0.90

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

Germplasm evaluation: Out of 59 genotypes of rapeseed-mustard evaluated against the disease under artificial field conditions, none was found to have resistance against *S. sclerotiorum*. Ten genotypes *viz.,* NRCG-104, NRC-DR-603, HC-0213, HC-0212, HC-9603, HC-9605, BCRS-17, Pusa Swarnim, Kiran and PBC-9221 were found moderately susceptible. Whereas, 46 genotypes showed susceptible reaction and three genotypes *viz.,* Neelam, BSH-1 and Rohini were found highly susceptible (Table 4). Results of present investigations are in conformity with findings of Sharma *et al.* (2012) who reported that out of fifty six rapeseed-mustard germplasm lines, none of the lines exhibited complete resistance to *Sclerotinia* rot and variety Rohini of *Brassica juncea* was found to be highly susceptible. The limited variation in resistance to *S. sclerotiorum* is not surprising, because of broad host range of the pathogen and aggressive infection process. Partial resistance to *S. sclerotiorum* has been mentioned in some genotypes of *Brassica napus* and *Brassica oleracea* (Dickson and Petzoldt, 1989; Sedun *et al.,* 1991). In *Brassica napus* one of the *loci* associated with aliphatic glucosinolate contents is associated with disease resistance (Zhao and Meng, 2003). Locating effective sources of resistance through screening large number of rapeseed-mustard genotypes against the prevailing pathogen strains in particular geographically distinct area by adopting standard protocols still offers the best long-term prospect for improved management of this disease.

Effect of leaf removal, row spacing and fungicidal sprays on disease: During both the crop seasons of *rabi* 2010-11 and 2011-12 (Table 5), combination of row spacing of 45 cm + two sprays of Companion (0.2%) i.e., $S_2D_0F_2$ and row spacing of 45 cm + removal of 2-3 lower leaves on 80 and 100 DAS + one spray of Companion ($S_2D_2F_1$) resulted in least disease incidence i.e., 1.2, 1.8; 1.6 and 1.8 per cent, respectively. Whereas, 30 cm row spacing + no defoliation + no fungicide spray ($S_1D_0F_0$) showed highest disease incidence of 10.3 and 9.7 per cent during 2010-11 and 2011-12, respectively. Row spacing of 45 cm ($S_2D_0F_0$) alone resulted in less disease incidence as compared to the closer row spacing of 30 cm. Removal of 2-3 lower leaves twice at 80 and 100 DAS was more effective than leaf removal at 80 DAS alone and could compensate one spray of fungicide. Interaction between row spacing + leaf removal was statistically significant in season 2010-11 compared to season 2011-12, where it was non significant. In both the seasons, the interaction between leaf removal + fungicide spray was statistically significant whereas interaction between row spacing + fungicide spray and row spacing + leaf removal + fungicide spray were statistically non-significant. The maximum 1000-seed weight (4.40 and 3.85 g) was obtained in $S_2D_2F_1$ during both the years. Maximum seed yield of 32.10 q/ha was obtained by treatment $S_1D_2F_1$ in year 2010-11 whereas in year 2011-12, the treatment $S_1D_0F_2$ exhibited maximum seed yield (24.9 q/ha).

Out of twelve combinations of row spacing + leaf removal + fungicide spray, a combination of row spacing 45 cm + leaf removal at 80 and 100 DAS + one spray of Companion (0.2%) *viz.*, $S_2D_2F_1$ followed by $S_2D_0F_2$ was found to be the best treatments in reducing the disease incidence. Handoro *et al.* (2002) also found that disease severity was low (6.52%) at wider plant spacing of 45 cm and significantly high in closer spacing of 15 cm (20.87%). Prajapati and Narain (2008) found Bavistin and Companion (Carbendazim + Mancozeb) to be most effective in controlling the pathogen among different groups of fungicides.

Management of *Sclerotinia* rot still remains as a challenging task due to lack of resistance. Since no single method or approach is feasible, viable, stable, effective and economical in dealing with such host-pathogen system, therefore, it is necessary to integrate all the methods of plant

disease control including cultural, chemical and biological to manage the disease effectively. In the present study, a combination of row spacing 45 cm + leaf removal at 80 DAS and100 DAS + one spray of Companion (0.2%) was found to be the best treatment in reducing the disease incidence under field conditions. There is a further scope to integrate native strains of biological control agents like *Trichoderma koningii* and extract of plants like *Vitex negundo* and *Melia azedarach* in the integrated disease management of *Sclerotinia* rot.

Table 4 Evaluation of rapeseed-mustard germplasm against *S. sclerotiorum*

Disease rating scale (0-4)	Reaction	Genotypes
0	Resistant	none
1	Moderately resistant	none
2	Moderately susceptible	NRCG-104, NRC-DR-603, HC-0213, HC-0212, HC-9603, HC-9605, BCRS-17, Pusa Swarnim, Kiran, PBC-9221
3	Susceptible	ONK-I, HPN-1, GSL-I, GS-05-I, GS-05-3, HNS-301, CAN-130, Jayanti, PBC-2006, DLCS-1, DRMR-270, KDH-BS-6, KBS-3, HPBS-I, EC-414293, JD-6, EC-414299, RCC-4, OMK-I, RH-8544, NRC-2, OMK-2, NRC-1, 03-456, IC-347949, 03-218, KBJ-80, GS-05-2, OMK-15, NBPG-24, EC-552608, Bio-902, PHR-2, Varuna, Kranti, JM-1, Divya-33, Divya-22, BIOYSR, NPJ-159, PAC-47, NPJ-127, NPJ-140, RL-1359, EC-399299, GS-05-4
4	Highly susceptible	Neelam, BSH-1, Rohini

Table 5 Integrated management of *Sclerotinia* rot of rapeseed-mustard

Treatments	2010-11			2011-12		
	Disease Incidence (%)	Test weight (g)	Seed yield (q/ha)	Disease incidence (%)	Test weight (g)	Seed yield (q/ha)
$S_1D_0F_0$	10.3(18.7)	4.13	24.69	9.7(18.1)	3.66	20.99
$S_1D_0F_2$	3.6(10.9)	4.33	30.56	1.8(7.8)	3.79	24.90
$S_1D_1F_0$	5.1(13.0)	4.20	27.16	6.3(14.5)	3.65	21.40
$S_1D_1F_1$	3.1(10.1)	4.30	29.32	3.4(10.7)	3.74	22.43
$S_1D_2F_0$	4.2(11.8)	4.23	30.25	4.4(12.0)	3.68	22.22
$S_1D_2F_1$	2.6(9.3)	4.37	32.10	2.4(8.8)	3.77	23.66
$S_2D_0F_0$	7.5(15.8)	4.20	25.31	8.1(16.5)	3.69	20.78
$S_2D_0F_2$	1.2(6.3)	4.33	30.86	1.8(7.8)	3.82	24.28
$S_2D_1F_0$	5.6(13.7)	4.23	26.54	5.9(14.0)	3.74	21.19
$S_2D_1F_1$	4.0(11.5)	4.33	30.25	2.8(9.6)	3.78	22.22
$S_2D_2F_0$	2.6(9.2)	4.33	31.17	3.5(10.7)	3.76	22.02
$S_2D_2F_1$	1.6(7.1)	4.40	31.79	1.8(7.7)	3.85	23.05
CD (P=0.05)		0.11	1.67		0.07	0.83
Row spacing (S)	0.6			0.7		
Leaf defoliation (D)	0.7			0.8		
Fungicide (F)	0.6			0.7		
S x D	1.0			NS		
D x F	1.0			1.1		
S x F	NS			NS		
S x D x F	NS			NS		
CV (%)	7.3			8.2		

Figures in parentheses are arc sine transformation value.

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Viability of sclerotia of *Sclerotinia sclerotiorum* at different depths and durations in soil

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ABSTRACT

Sclerotia of *Sclerotinia sclerotiorum* (Lib.) de Bary obtained from natural infected stem of Indian mustard plants were wrapped in synthetic nets and buried at different depths and durations under screen house and field conditions at CCS Haryana Agricultural University, Hisar. Viability of sclerotia was tested and it declined gradually in screen house and sharply under natural field conditions with the increase in soil depth and duration of burial. A maximum of 91.3 per cent sclerotial germination was found, when sclerotia were placed at soil surface (0 cm) for three months under screen house conditions while 83.8 per cent at same depth and duration under field conditions. A minimum of 8.8 per cent sclerotia germinated when placed below 12.5 cm depth for six months under screen house conditions, while none of the sclerotia germinated, when placed below 5 cm for six months under field conditions.

Keywords: Depth, Sclerotia, *Sclerotinia sclerotiorum,* Viability

Sclerotinia sclerotiorum (Lib.) de Bary, the causal fungus of *Sclerotinia* stem rot disease is a necrotrophic pathogen with worldwide distribution known to infect over 400 plant species and is more common in temperate and sub-tropical regions possessing cool and wet seasons (Purdy, 1979). When the fungus completes its life cycle, sclerotia are formed on all plant parts including stems, roots and inside the pith of the stem of Indian mustard. Sclerotia, the resting structures which allow pathogen to survive for long periods of time under adverse conditions, are formed in the soil and in the stems of the infected tillers at the end of the season. Under severe air borne infection by ascospores, the pathogen does not spare even leaves, floral parts and pods and form sclerotia there also (Rathi *et al.,* 2014). These sclerotia may later released on to soil during harvesting or collected in the harvest seeds that serve as the primary source of inoculum for the next crop season. Sclerotia require prolonged period of moist soil to germinate myceliogenically and/or carpogenically and play a major role in disease cycles as they produce inoculum and are the primary long-term survival structures (Willetts and Wong, 1980); remain viable up to 8 years in soil (Adams and Ayers, 1979). Few studies have quantified sclerotial survival in the field. Henderson (1962) found that the sclerotia of *S. sclerotiorum* were the best source of infection under favourable environmental conditions. The viability of sclerotia on the surface declined rapidly due to the alternate wetting and drying of soil (Maiti and Sen, 1988). Survival was significantly influenced by depth of burial and by sclerotial treatment before burial. About 11-31 per cent of the sclerotia buried deeper than 2.5 cm survived after 30 days, whereas 65-84 per cent of those on the soil surface remained viable (Smith *et al.,* 1989). Since, no sufficient information are available on the survival of *S. sclerotiorum* causing stem rot of mustard at different depths and durations of time under warm dry climate of north-western part of India; hence, the present studies were carried out.

MATERIALS AND METHODS

Sclerotia of *S. sclerotiorum* were collected from infected stems/piths in the month of March, 2013 (Fig. 1). In the first week of April, twenty sclerotia were wrapped in synthetic net and each synthetic net was placed at different depths of 0 cm, 2.5 cm, 5 cm, 7.5 cm, 10 cm and 12.5 cm in surface sterilized earthen pots filled with sterilized field soil (Fig. 2). Pots were arranged in a completely randomized design with four replications. Same bundles were buried at similar different depths in field under natural conditions also (Fig. 3). The synthetic bundles containing sclerotia of four pots and field were taken out at monthly interval starting from first week of July, 2013. Sclerotia were washed in tap water, blot dried and sterilized by dipping in 0.1 per cent mercuric chloride solution for 30 seconds followed by three washing in Petri plates containing sterilized water. Then, sclerotia were transferred into the PDA media and Petri plates were incubated at 21±1ºC. After 7 days, the per cent germination of sclerotia was calculated and data were analyzed statistically.

RESULTS AND DISCUSSION

Gradual reduction in viability of sclerotia (germination percentage) was observed with the increase in soil depth and duration of burial under screen house and field conditions (Table 1). Under screen house conditions, a maximum of

91.3 per cent sclerotial germination was found, when sclerotia were placed at soil surface (0 cm) for three months in comparison to a minimum germination of 38.8 per cent at soil surface after six months of burial. As the soil depths and duration of burial increased, the viability of sclerotia declined gradually. Only 8.8 per cent of the sclerotia germinated, when placed at 12.5 cm depth for six months as compared to 45.0 per cent germination at same depth after three months of burial (Fig. 4 and 5 and Table 1).

Fig. 1. Sclerotia collected from field

Fig. 2. Sclerotia placed at different depths in surface sterilized earthen pots filled with sterilized soil

Fig. 3. Sclerotia placed at different depths under field conditions

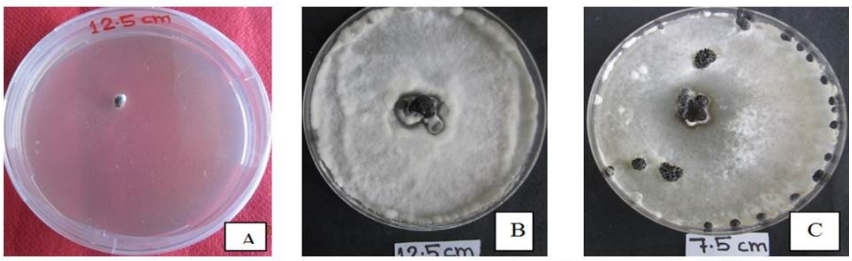

Fig. 4. Germinated sclerotia at 12.5 cm depth from screen house experiment (A. After 6 months, B. After 3 months); C. Germinated sclerotia at 7.5 cm depth (after 3 months) from field experiment

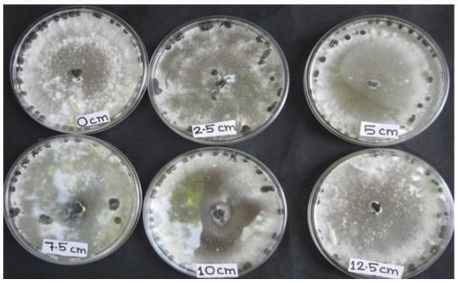

Fig. 5. Germinated sclerotia from screen house condition (After 3 months at all depths)

Table 1 Effect of soil depth and duration of burial of sclerotia of *S. sclerotiorum* for their viability in pots under screen house conditions

Depth (cm)	Germination of sclerotia (%)*			
	July	August	September	October
0.0	91.3 (72.9)	81.3 (64.3)	48.8 (44.2)	38.8 (38.4)
2.5	85.0 (67.3)	68.8 (56.0)	40.0 (39.2)	32.5 (34.6)
5.0	77.5 (61.8)	47.5 (43.5)	32.5 (34.6)	25.0 (29.9)
7.5	71.3 (57.6)	30.0 (33.1)	25.0 (29.9)	21.3 (27.1)
10.0	65.0 (53.7)	22.5 (28.2)	18.8 (25.5)	15.0 (22.6)
12.5	45.0 (42.1)	18.8 (25.5)	12.5 (20.6)	8.8 (17.0)
CD (P=0.05)	4.70	3.97	4.52	5.37
CV (%)	5.30	6.34	9.33	12.66

Note: Sclerotia were buried in pots in the 1st week of April, 2013; Figures in parentheses are angular transformed values
*Per cent germination of sclerotia was tested in the 1st week of each month

Table 2 Effect of soil depth and duration of burial of sclerotia of *S. sclerotiorum* for their viability under field conditions

Depth (cm)	Germination of sclerotia (%)*			
	July	August	September	October
0.0	83.8 (66.2)	51.3 (45.7)	36.3 (36.8)	28.8 (32.5)
2.5	77.5 (61.6)	45.0 (42.0)	28.8 (32.3)	25.0 (30.2)
5.0	75.0 (59.9)	35.0 (36.2)	26.3 (30.5)	23.8 (29.4)
7.5	71.3 (57.6)	27.5 (31.4)	17.5 (24.6)	0.0 (4.0)
10.0	66.3 (54.5)	17.5 (24.4)	15.0 (22.6)	0.0 (4.0)
12.5	42.5 (40.6)	13.8 (21.5)	11.3 (19.5)	0.0 (4.0)
CD (P=0.05)	4.95	7.33	6.04	3.69
CV (%)	5.74	14.58	14.53	13.94

Note: Sclerotia were buried in field in the 1st week of April, 2013; Figures in parentheses are angular transformed values
*Per cent germination of sclerotia was tested in the 1st week of each month

Viability of the sclerotia sharply declined with the increase in soil depths and duration of burial when tested in soil under field conditions also (Table 2). A maximum of 83.8 per cent sclerotial germination was recorded when sclerotia were placed at soil surface (0 cm) for three months in comparison to a minimum per cent germination of 28.8 per cent at soil surface after six months of burial. The per cent viability of sclerotia also reduced as the soil depth and duration of burial increased. None of the sclerotia germinated, when placed below 5 cm for six months in comparison to maximum of 71.3 per cent germination at 7.5 cm depth after three months of burial (Fig. 4 and Table 2).

Results are in agreement with Duncan *et al.* (2006), where they reported that sclerotia of *S. sclertiorum* on the soil surface had the highest viability (57.5%) followed by those at 5 cm depth (12.5%), and only few (2.5%) of those placed at the 10 cm depth after twelve months. Gradual reduction in viability of sclerotia with the increase in soil depths and durations of burial both under screen house and field conditions was also reported by Pande *et al.* (2008). Contrarily, Maiti and Sen (1988) opined that viability of sclerotia was found to be declined rapidly on the surface due to the alternate wetting and drying of soil. Significant reductions in the mean number of sclerotia and lettuce drop incidence occurred on the crop immediately after deep plowing (Subbarao *et al.,* 1996). Gurjar *et al.* (2004) stated that viability of sclerotia of *Sclerotium rolfsii* in chilli plant was reduced when buried in soil beyond 4 cm depth and lost their viability completely beyond 14 cm depth after 19 months. The survival of sclerotia in soil depends on many inter-related factors including initial population of sclerotia, previous crops, soil type, soil microorganisms and environmental conditions of particular geographical area, but how and to what degree they affect survival is not well understood. There is evidence that leaving the sclerotia on the soil surface enhances degradation, whereas burying the sclerotia enhances survival. It is thought that the more dramatic changes in temperature and moisture on the soil surface are whether deleterious or not to sclerotia vary primarily on particular location. Decline in sclerotia viability at deeper depths may be due to continuous wetting of sclerotia because of high water table at Hisar conditions.

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Efficacy of newer insecticides against *Spodoptera litura* in groundnut (*Arachis hypogaea* L.)

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ABSTRACT

Field experiments were conducted during *rabi*/summer season of 2010-11 and 2011-12 to evaluate the efficacy of five newer insecticides (chlorantraniliprole, flubendiamide, spinosad, thiodicarb, novaluron) with two conventional insecticides (dichlorvos and chlorpyriphos) against tobacco caterpillar, *Spodoptera litura* in groundnut. The experiments were conducted in a randomized block design with eight treatments and three replications. The results revealed that the maximum percentage of larval reduction and defoliation was in flubendiamide 480SC @ 150 ml/ha followed by chlorantraniliprole 20SC @ 125 ml/ha and novaluron 10EC @ 500 ml/ha. Highest dry pod yield of groundnut was recorded in flubendiamide (2650 and 2100 kg/ha) followed by chlorantraniliprole (2500 and 1983 kg/ha) and novaluron (2267 and 1958 kg/ha) as against 1750 and 1375 kg/ha in untreated control during 2010-11 and 2011-12, respectively. The maximum cost-benefit ratio of 1: 2.5 and 1: 2.13 was obtained with flubendiamide during 2010-11 and 2011-12, respectively.

Keywords: Efficacy, Groundnut, Newer insecticides, *Spodoptera litura*

Groundnut is the most important oilseed crop in India and grown in an area of 5.52 million ha with a production of 9.67 million tonnes and productivity of 1750 kg/ha. Six states namely Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Rajasthan and Tamil Nadu account for about 90 per cent of the total groundnut area of the country. Andhra Pradesh and Gujarat contribute more than 55 per cent of the total area and production of groundnut (DAC, 2014). The productivity of groundnut is low in India as compared to other countries. The crop is attacked by insect pests *viz*., tobacco caterpillar (*Spodoptera litura*), Bihar hairy caterpillar (*Spilarctia obliqua*) and gram pod borer (*Helicoverpa armigera*) which impose a great limitation in realizing the potential productivity. Conventional methods of pest control include extensive use of broad spectrum insecticides belonging to chlorinated hydrocarbons, organophosphates, carbamates and synthetic pyrethroides. Chitin synthesis inhibitors and newer insecticides of novel mode of action have recently been found to be highly effective in management of many lepidopteran pests (Khambete *et al*., 1999; Vadodaria *et al*., 2000; Tohnishi *et al.,* 2005). Moreover, they are selective, safe, environmental friendly and can fit ideally in Integrated Pest Management (IPM) programme. In light of the above, an attempt has been made in the present study to evaluate the field efficacy of certain newer insecticides along with conventional insecticides against *S. litura* in groundnut.

MATERIALS AND METHODS

The field experiments were conducted at Regional Agricultural Research Station, Polasa, Jagtial, Karimnagar district, Telangana State during the *rabi*/summer season of 2010-11 and 2011-12 to assess the efficacy of newer insecticides along with conventional insecticides on *Spodoptera litura viz.,* chlorantraniliprole 20SC @ 125 ml/ha, flubendiamide 480SC @ 150 ml/ha, spinosad 48SC @ 100 ml/ha, thiodicarb 80DF @ 500 g/ha, novaluron 10EC @ 500 ml/ha, dichlorvos 76WSC @ 625 ml/ha and chlorpyriphos 20EC @ 1250 ml/ha along with untreated control. The experiments were conducted in randomized block design with eight treatments and three replications. The popular groundnut variety, Kadiri 6 was sown in plots each measuring 5.0 m x 4.0 m at a spacing of 30 x 10 cm. Treatments were applied twice when the larval population crossed the economic threshold level (one larva/plant) by initiating the first spray at pre-flowering stage with a high volume knapsack sprayer with spray fluid @ 500 l/ha. The observation on larval population and per cent defoliation was recorded on 10 plants selected randomly one day before spray (pre count) and 7 and 15 days after the spray. The dry pod yield was recorded on the net plot area basis which was converted to kg/ha for statistical interpretations. The data were subjected to appropriate transformation and data were analyzed statistically as suggested by Panse and Sukhatme (1988).

RESULTS AND DISCUSSION

The results of the first year experiment conducted during *rabi*/summer season of 2010-11 revealed that spraying of flubendiamide 480SC @ 150 ml/ha recorded the lowest mean number of larvae and per cent defoliation (1.33 larvae

and 9.67% defoliation per 10 plants, respectively). It was followed by chlorantraniliprole 20SC @ 125 ml/ha (2.50 larvae and 13.50 per cent defoliation) and was on par with novaluron 10 EC @ 500 ml/ha treatment (3.33 larvae and 16.50% defoliation). The next best treatments were spinosad 48SC @ 100 ml/ha, thiodicarb 80 DF @ 500 g/ha, chlorpyriphos 20EC @ 1250 ml/ha, dichlorvos 76WSC @ 625 ml/ha with 4.17, 4.33, 4.67 and 5.00 larvae/10 plants and 23.83, 28.67, 27.50 and 32.33 per cent defoliation compared to untreated control (10.17 larvae and 53.50% defoliation). Higher dry pod yield was recorded in flubendiamide @ 150 ml/ha (2650 kg/ha) followed by chlorantraniliprole @ 125 ml/ha (2500 kg/ha), novaluron @ 500 ml/ha (2267 kg/ha) and spinosad @ 100 ml/ha (2200 kg/ha) treatments as against the minimum dry pod yield of 1750 kg/ha in untreated control (Table 1).

The results of the second year experiment conducted during *rabi*/summer season of 2011-12 revealed that low mean larval population and mean per cent defoliation was recorded in flubendiamide 480SC @ 150 ml/ha treatment (1.33 larvae and 11.92% defoliation) followed by chlorantraniliprole 20SC @ 125 ml/ha (2.33 larvae and 14.72% defoliation), novaluron 10EC @ 500 ml/ha (3.67 larvae and 17.08% defoliation) compared to untreated control (8.50 larvae and 38.08% defoliation/10 plants). Higher dry pod yield was recorded in flubendiamide @ 150 ml/ha (2100 kg/ha), chlorantraniliprole @ 125 ml/ha (1983 kg/ha) and novaluron @ 500 ml/ha (1958 kg/ha) as against the minimum dry pod yield of 1375 kg/ha in untreated control (Table 1).

The present findings are in conformity with Tohinishi *et al*. (2005) and Ameta and Ajay Kumar (2008) who reported that application of flubendiamide was significantly superior and highly effective in reduction of population of *H. armigera* and *S. litura.* Chowdary *et al*. (2010) also reported that chlorantraniliprole 20SC @ 30 and 20 g a.i./ha were superior in recording less larval population, lowest fruit damage and higher fruit yield against okra fruit and shoot borer. Raghuvani and Poshiya (2006) studied the efficacy of novaluron 10 EC @ 50, 75 and 100 g a.i./ha against pod borer of chickpea, *H. armigera* and reported that 100 g a.i./ha recorded lower pod damage and maximum grain yield in chickpea. Based on the efficacy and economics, the study suggests that flubendiamide 480SC @ 150 ml/ha or chlorantraniliprole 20 SC @ 125 ml/ha can be opted for inclusion in IPM programme against *S. litura* in groundnut.

Table 1 Efficacy of newer insecticides against tobacco caterpillar, *Spodoptera litura* in groundnut (*Rabi*/summer 2010-11 and 2011-12)

Treatment	Mean incidence of larvae/ 10 plants				Mean per cent defoliation/ 10 plants				Dry pod yield (kg/ha)		C:B ratio	
	2010-11		2011-12		2010-11		2011-12					
	Before Spray	After Spray#	Before Spray	After Spray	Before Spray	After Spray	Before Spray	After Spray	2010-11	2011-12	2010-11	2011-12
Chlorantraniliprole 20SC@125 ml/ha	10.33	2.50 (1.87)*	9.33	2.33 (1.82)	44.30	13.50 (21.55)**	37.66	14.72 (22.56)	2500	1983	1:2.4	1:2.06
Flubendiamide 480SC@150 ml/ha	9.66	1.33 (1.51)	8.33	1.33 (1.52)	46.00	9.67 (18.11)	36.66	11.92 (20.14)	2650	2100	1:2.5	1:2.13
Spinosad 48SC@100 ml/ha	10.66	4.17 (2.27)	10.00	4.17 (2.27)	44.00	23.83 (29.22)	37.66	22.67 (28.43)	2200	1625	1:2.0	1:1.52
Thiodicarb 80DF @ 500g/ha	9.33	4.33 (2.30)	9.66	5.0 (2.45)	45.30	28.67 (32.35)	37.33	26.67 (31.09)	2083	1917	1:1.9	1:2.00
Novaluron 10EC @ 500 ml/ha	10.66	3.33 (2.07)	9.00	3.67 (2.16)	45.00	16.50 (23.97)	37.66	17.08 (24.37)	2267	1958	1:20	1:2.02
Dichlorvos 76WSC @ 625 ml/ha	9.00	5.0 (2.37)	9.33	5.0 (2.44)	45.60	32.33 (34.64)	38.33	29.79 (33.06)	1883	1700	1:1.7	1:1.72
Chlorpyriphos 20EC @ 1250 ml/ha	9.66	4.67 (2.38)	9.00	3.83 (2.19)	43.60	27.50 (31.61)	38.33	27.08 (31.33)	2017	1858	1:1.9	1:1.99
Untreated Control	10.00	10.17 (3.34)	9.33	8.50 (3.08)	45.00	53.50 (47.01)	38.00	38.08 (38.09)	1750	1375	-	-
SEm±	-	0.11	-	0.06	-	0.75	-	0.61	85.16	75.40	-	-
CD (P=0.05)	NS	0.33	NS	0.19	NS	2.29	NS	1.86	182.24	230.93	-	-

* Figures in parentheses are square root transformed values; ** Figures in parentheses are angular transformed values; # Mean of two observations

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Field efficacy of some newer chemical insecticides against stem borer, *Nupserha* sp. near *vexator* (Pascoe) in sunflower (*Helianthus annuus* L.)

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ABSTRACT

A field experiment was conducted to evaluate the efficacy of some newer chemical insecticides *viz.,* thiodicarb 75WSP, indoxacarb 14.5SC, spinosad 45SC, profenophos 50EC, dichlorovos 76EC and chlorpyrifos 20EC against stem borer *Nupserha* sp. near *vexator* in sunflower at Oilseeds Research Station, Latur, Maharashtra. Results revealed that all the treatments were significantly superior in reducing the population of stem borer over untreated control. Among the insecticides, indoxacarb @ 1ml/l was most effective and was found on par with spinosad @ 0.3ml/l, profenophos @ 2ml/l and thiodicarb @ 2gm/l. Highest seed yield was recorded with spinosad (1416 kg/ha) and found on par with indoxacarb (1401 kg/ha) whereas the lowest yield was observed in untreated control (1010 kg/ha). The maximum incremental benefit cost ratio was obtained with application of chlorpyrifos (4.96) followed by indoxacarb (4.27), profenofos (3.43), and spinosad (3.09).

Keywords: Field efficacy, Newer insecticides, Sunflower, Stem borer

Sunflower (*Helianthus annuus* L.) is the fourth most important oilseed crop cultivated in India after groundnut, mustard and soybean. It is introduced in India for the first time during 1969 and the commercial cultivation of sunflower has become popular in many states of India since 1980's. The crop now widely grown in Karnataka, Maharashtra, Andhra Pradesh and Gujarat as monsoon, late monsoon and *rabi* crops and recently in northern states of Punjab, Haryana, Uttar Pradesh and Rajasthan as spring crop. As many as 251 insect species are known to attack sunflower crop worldwide (Rajmohan, 1976). But during 1993 sunflower cultivation in Marathwada region of Maharashtra was threatened by a new pest, identified as stem borer *Nupserha* sp. near *vexator* (Pascoe). It is a coleopterous grub belonging to family Cerambycidae: Lamiinae (Patil *et al*., 2009). A continuous and severe infestation in the range of 30-70% was observed during survey of the pest in Marathwada region of Maharashtra. The present study was undertaken to find out the effective insecticide molecules for the management of stem borer in sunflower.

MATERIALS AND METHODS

A field experiment was conducted to evaluate the efficacy of newer chemical insecticides against natural incidence of sunflower stem borer [*Nupserha* sp. near *vexator* (Pascoe)] at experimental farm of Oilseeds Research Station, Latur during *kharif* 2004, 2005, 2006, 2007 and 2012. For this purpose, sunflower cv. Morden was raised in plots of size of 4.2 x 4.5 m with a spacing of 60 x 30 cm. The experiment was laid out in a randomized block design with seven treatments including untreated control (Table 1) and replicated thrice. The application of insecticides was made at 25 and 45 days after sowing. Spraying operations were undertaken in the morning with the help of manually operated Gator sprayer and total quantity of spray solution of 500 l/ha was used. Five plants were selected randomly from the net plot of each treatment in each replication and observation on per cent infestation was taken at harvest. The data collected was converted into mean values using angular transformation. The observations on total number of predatory coccinellids were also recorded at grub stage before, 3 and 7 days after spray. Seed yield was recorded from each net plot, then the treatment wise total yield was calculated and converted into kg/ha.

RESULTS AND DISCUSSION

Efficacy of newer insecticides against stem borer: Five years pooled data revealed that all the treatments were significantly superior in reducing the infestation of stem borer over untreated control. However, treatment of indoxacarb @ 1ml/l was most effective (19.0%) and was on par with treatments of spinosad @ 0.3ml/l (21.1%), profenophos @ 2ml/l (24.5%) and thiodicarb @ 2gm/l (25.7%). The next best treatment in order of effectiveness was chlorpyrifos @ 2ml/l and dichlorovos @ 2ml/l which were also on par with each other. Untreated control recorded highest stem borer infestation of 44.3 per cent (Table 1).

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Safety of newer insecticides to natural enemies: Pooled data indicates that predatory coccinellids population before spray was uniformly distributed in all treatments. After spray untreated control recorded highest population of the coccinellids whereas the treatment of spinosad was the safest followed by profenophos, chlorpyrifos and indoxacarb are next having natural enemies presence. Treatments dichlorovos and thiodicarb were found most detrimental to the predators (Table 2).

Table 1 Effect of insecticides on stem borer damage in sunflower

Treatments	Stem borer (%)					
	2004	2005	2006	2007	2012	Pooled Mean
Thiodicarb 75 WP @ 2 g/l	17.6	31.7	14.5	21.3	43.3	25.7
	(24.8)	(34.2)	(22.3)	(27.4)	(41.2)	(30.2)
Indoxacarb 14.5 SC @ 1ml/l	15.5	26.7	12.3	20.2	20.3	19.0
	(23.2)	(31.1)	(20.5)	(26.6)	(26.8)	(25.6)
Spinosad 45 SC @ 0.35ml/l	16.8	28.3	14.0	18.5	28.3	21.1
	(23.9)	(32.1)	(22.0)	(25.5)	(32.1)	(27.1)
Profenophos 50 EC @ 1.5ml/l	18.1	30.7	16.8	13.8	43.2	24.5
	(24.9)	(33.6)	(24.20	(21.7)	(41.1)	(29.1)
Dichlorvos76 EC @ 2ml/l	19.4	49.0	23.5	19.6	52.9	32.8
	(26.1)	(44.4)	(29.3)	(26.2)	(46.7)	(34.4)
Chlorpyrifos 20 EC @ 2ml/l	18.5	39.3	20.2	19.8	47.9	29.1
	(25.5)	(38.8)	(26.6)	(26.3)	(43.8)	(32.4)
Untreated Control	22.2	51.7	30.6	28.0	89.1	44.3
	(28.1)	(46.0)	(33.6)	(31.9)	(71.6)	(42.0)
SEm±	0.7	1.7	1.1	1.4	2.0	2.3
CD (P=0.05)	2.1	5.5	3.4	4.2	6.2	6.2
CV (%)	5.0	8.3	8.0	9.0	8.4	16.8

Figures in parenthesis are angular transformed values

Table 2 Effect of insecticides on predators in sunflower

Treatments	Population of Predators											
	Before Spray				3 DAS				7 DAS			
	2006	2007	2012	Pooled Mean	2006	2007	2012	Pooled Mean	2006	2007	2012	Pooled Mean
Thiodicarb 75WP @ 2g/l	1.3	1.1	1.5	1.2	0.3	0.7	0.6	0.8	0.5	0.8	0.7	0.7
	(1.3)	(1.2)	(1.4)	(1.3)	(0.9)	(1.1)	(1.0)	(1.1)	(1.0)	(1.1)	(1.1)	(1.1)
Indoxacarb 14.5SC @ 1ml/l	1.2	1.3	1.5	1.5	0.6	1.0	0.8	1.1	1.1	1.1	0.9	1.0
	(1.3)	(1.3)	(1.4)	(1.4)	(1.0)	(1.2)	(1.1)	(1.2)	(1.2)	(1.2)	(1.2)	(1.2)
Spinosad 45SC @ 0.35ml/l	1.2	1.5	1.6	1.8	1.0	1.1	1.0	1.3	1.4	1.2	1.1	1.2
	(1.3)	(1.4)	(1.4)	(1.5)	(1.2)	(1.2)	(1.2)	(1.3)	(1.3)	(1.3)	(1.2)	(1.3)
Profenophos 50EC @ 1.5ml/l	1.0	1.1	1.6	1.9	0.8	1.2	0.6	1.2	1.2	1.4	1.0	1.1
	(1.2)	(1.2)	(1.4)	(1.5)	(1.1)	(1.3)	(1.0)	(1.3)	(1.3)	(1.3)	(1.2)	(1.2)
Dichlorvos 76EC @ 2ml/l	1.1	1.5	1.4	2.2	0.2	0.8	0.4	1.0	0.8	0.6	0.5	0.7
	(1.2)	(1.4)	(1.3)	(1.6)	(0.8)	(1.1)	(0.9)	(1.2)	(1.1)	(1.0)	(1.0)	(1.1)
Chlorpyrifos 20EC @ 2ml/l	1.0	1.4	1.6	2.5	0.4	1.1	0.8	1.3	1.0	1.2	0.8	1.0
	(1.2)	(1.3)	(1.4)	(1.7)	(0.9)	(1.2)	(1.1)	(1.3)	(1.2)	(1.3)	(1.1)	(1.2)
Untreated Control	1.2	1.4	1.6	2.8	1.8	1.3	1.8	1.8	1.6	1.8	1.8	1.8
	(1.3)	(1.3)	(1.4)	(1.8)	(1.5)	(1.3)	(1.5)	(1.5)	(1.4)	(1.5)	(1.5)	(1.5)
SEm±	NS	NS	NS	NS	0.7	0.1	0.1	0.1	0.7	0.1	0.1	0.0
CD (P=0.05)	NS	NS	NS	NS	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
CV (%)	NS	NS	NS	NS	11.0	12.0	9.2	7.9	8.8	8.7	9.6	4.2

Figures in parenthesis are square root transformed values

Effect on yield and economics: Data on yield over years revealed that there was significant impact of insecticidal treatments on seed yield of sunflower (Table 3). Pooled data revealed that highest seed yield (1416 kg/ha) was recorded in spinosad, followed by indoxacarb (1401 kg/ha) as against the lowest seed yield of 1010 kg/ha in untreated control. Net return was higher in indoxacarb followed by spinosad. The highest incremental benefit cost ratio (IBCR) was noticed in chlorpyrifos (4.96) followed by indoxacarb (4.27), profenofos (3.43), spinosad (3.09) and thiodicarb (1.82) (Table 4). Patil *et al*. (2009) reported that quinalphos found highly effective against stem borer and found on par with endosulfan and chlorpyrifos in sunflower. Patil and Basappa (2009) evaluated newer and conventional insecticides against stem borer in sunflower and reported that endosulfan followed by indoxacarb found most effective in reducing stem borer infestation. Thus, from the above findings it can be concluded that newer insecticides *viz.,* indoxacarb, spinosad and the conventional insecticides *viz.,* chlorpyrifos and profenofos can be effectively utilized for the management of stem borer in sunflower.

Table 3 Effect of insecticides on yield in sunflower

Treatments	Yield (kg/ha)				
	2005	2006	2007	2012	Pooled Mean
Thiodicarb 75WP @ 2g/l	1164	1319	1302	1350	1284
Indoxacarb 14.5SC @ 1ml/l	1311	1393	1328	1573	1401
Spinosad 45SC@ 0.35ml/l	1265	1378	1305	1715	1416
Profenophos 50EC @ 1.5ml/l	1230	1170	1293	1425	1280
Dichlorvos 76EC @ 2ml/l	1010	993	1028	1066	1024
Chlorpyrifos 20EC @ 2ml/l	1231	1170	1282	1191	1219
Untreated Control	1030	996	1000	1012	1010
SEm±	49	71	35	81	43.54
CD (P=0.05)	150	215	107	244	129.2
CV (%)	7.2	10.0	5.0	10.3	7.0

Table 4 Economics of insecticidal treatment on sunflower (Based on pooled data)

Treatments	Cost of cultivation excluding Plant Protection	Total cost of imposing the treatment	Total cost of cultivation (₹/ha)	Seed yield (kg/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C Ratio	Incremental cost (₹/ha)	Incremental Benefit (₹/ha)	IBCR
Thiodicarb 75 WP @ 2 g/l	10261	2060	12321	1284	26322	14001	2.14	2060	3740	1.82
Indoxacarb 14.5SC @ 1ml/l	10261	1555	11816	1401	28721	16905	2.43	1555	6644	4.27
Spinosad 45 SC @ 0.35ml/l	10261	2078	12339	1416	29028	16689	2.35	2078	6428	3.09
Profenofos 50EC @ 1.5ml/l	10261	1290	11551	1280	26240	14689	2.27	1290	4428	3.43
Dichlorvos 76EC @ 2ml/l	10261	730	10991	1024	20992	10001	1.91	730	-260	-0.36
Chlorpyrifos 20EC @ 2ml/l	10261	750	11011	1219	24990	13979	2.27	750	3718	4.96
Untreated Control	10261	-	10261	1010	20705	10444	2.02	-	-	-

Price of seed of sunflower = ₹2050/q

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Integration of mustard markets in Rajasthan State of India

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ABSTRACT

The study assessed the integration between mustard market pairs in Rajasthan state of India using monthly mustard price series of six markets from 2006-2014. The co-integration tests results indicate, Tonk and Alwar; Tonk and Dausa; Bharatpur and Alwar and Sriganganagar and Dausa are integrated in the long run at lag one. Tonk and Bharatpur and Bharatpur and Dausa are also integrated in the long run at lag two. Error correction model showed that the lowest speed of adjustment towards long run equilibrium was from Tonk to Bharatpur at rate of 43.2%. The highest speed of adjustment was 103.8%, running Bharatpur to Alwar market towards long run equilibrium. Impulse response function results shows when an unexpected positive shock is given to market price in Tonk, Sriganganagar and Bharatpur, the response thereof from other trading markets will be permanent over a period of twelve months.

Keywords: ECM, Market integration, Mustard, Rajasthan, VAR

Oilseeds are one of the important crops in the diet of most people in India. It is therefore not surprising that, India is the world's largest edible oil importer, followed by China and the European Union-27. The amount of edible oil needed by the country is projected to be about 189.38 lakh tonnes but the net domestic availability of edible oils is 89.57 lakh tonnes giving a deficit of 99.81 lakh tonnes which is imported into the country. The total value of oilseeds import was ₹405.79 crore in 2012-2013 (Anonymous, 2013). Rising domestic consumption in India will continue to drive demand for imported edible oil, which should reach 12.4 million metric tonnes in 2014-15, a 10 per cent increase over the current marketing year to close the gap of net domestic availability of edible oils (Anonymous, 2014). The total oilseeds produced in all India in 2012-2013 was 31.01 million metric tonnes. Among the states, Madhya Pradesh, Rajasthan and Maharashtra contribute 9.26, 6.20 and 5.01 million metric tonnes, respectively (Anonymous, 2013). Rajasthan state contributes 19.99 per cent of the total oilseeds produced in the country whereas Madhya Pradesh contributes highest percentage of oilseeds in the country representing about 29.93 per cent of the total oilseeds produced in 2012-13 production year.

Among the important oilseeds produced in the country are groundnut, rapeseed-mustard, castor, sesame, sunflower, safflower, linseed, and soybean. Rapeseed-mustard, which is cultivated all over India in different ecosystems and cropping sequences. The economic benefits of mustard includes; the seed and oil are used as a condiment in the preparation of pickles and for flavouring curries and vegetables; the oilcake is mostly used as cattle feed; the leaves of young plants are used as a green vegetable and the use of mustard oil for industrial purposes. Rajasthan is the highest producer of rapeseed-mustard seed in the country with production of 3.65 million metric tonnes in the 2012-13 production year which is represented by 46.64 per cent of the total production in the country (Anonymous, 2013). Realising the importance of mustard in India and the state, both central and state government have endeavoured to increase production of mustard in the state through several incentives. However, no farmer will put in extra effort to produce mustard if the mustard markets are not integrated or efficient. This is because production incentives and policies commonly become ineffective without strong market price transmission between markets. Thus without spatial integration of markets, price signals will not be transmitted from consumption mustard deficit markets to production mustard surplus markets and areas, prices will be more volatile, mustard producers will fail to specialise according to long term comparative advantage and the gains from trade will not be realised hence shifting from production of mustard to other competitive crop of high integration will be done by farmers. In light of this some studies have been done in the past to ascertain whether mustard markets are integrated or not in Rajasthan. However, most of these studies known, example Meena *et al*. (2011) used correlation analysis as the analytical tool for measuring market integration.

Correlation coefficient is considered to be a convenient measure of market integration because of its simplicity. However, correlation coefficient technique has been critique on the grounds that a statistically significant coefficient may be due to common trends in the price pairs from factors such as population growth, inflation or climate patterns, rather than price integration (Blyn, 1973; Abdulai, 2007). They argued further that, the trend may be due to the rising demand occasioned by population increase that may affect all parts of the region or due to common climatic condition. Here, all price series in a region would be affected by such

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influences even if each market within the region was independent of others. Hence cautions that time series correlation need to be restricted to residuals remaining after the trend and seasonal components have been removed. Price series correlation method has also been criticised by Bannor (2015) on the grounds that a high correlation between the markets does not necessarily mean that these two markets are well integrated in the sense that a competitive network of traders exists which ensures that agricultural goods move between market places in swift response to price difference that exceeds transport cost. Furthermore, price correlation assumes instantaneous price adjustment and can't capture the dynamic nature of marketing. Also, it is possible that price correlation might suggest spurious market integration because the prices may tend to move together for reasons other than market integration; like common trends, common seasonality, monopoly price fixing, etc. Price correlation tests may also overestimate lack of market integration if a lag in market information produces a lag in the price response between markets. Lastly, price correlation treats only a pair of markets at a time and can't be used for evaluating the marketing system as a whole. In order to overcome the weaknesses of price correlation tests used in other researches and also ascertain the current efficiency or integration of mustard markets in Rajasthan, this research was done.

MATERIALS AND METHODS

Sources of data: The secondary data used for this study was sourced from AGMARKNET database (from http://agmarkweb.dacnet.nic.in/sa_reports_menu.aspx). This database is under the Directorate of Marketing and Inspection of the Ministry of Agriculture of Government of India. Data set of 6 markets namely Alwar, Bharatpur, Sriganganagar, Dausa, Kota and Tonk of Rajasthan were sourced, covering monthly mustard prices from January 2006 to December 2014. In all, they were cumulative 108 observations. The markets represent highest arrivals and highest trading markets in Rajasthan.

Method of data analysis: The data analytical techniques that were used in this study comprised of descriptive statistics such as means and coefficient of variation. Tests such as trend analysis, seasonality indices, growth rate models or log linear model, unit root test, co-integration technique (Johansen co-integration test), error correction and vector autoregressive models were also used. Coefficient of variation was used to determine volatility of prices in the various markets, Augmented Dickey Fuller Tests (ADF) test, and DF-GLS test were used for the stationarity tests. Johansen co-integration test was used to test for long run integration between variables that are stationary of the same order and Error correction model, Vector Autoregressive model were used for short run causality analysis and speed of adjustment analysis. STATA 12 was used for all the analysis. The market integration approach adopted by the researchers was shaped by Mafimisebi *et al*. (2014); Kwasi and Kobina, 2014; Kwasi, 2015.

Unit root test: A stationary series or series with no unit root is one with a mean value which will not vary with the sampling period. In contrast, a non-stationary series will exhibit a time varying mean (Juselius, 2006). Before examining integration relationships between or among markets, it is essential to test for unit root and identify the order of stationarity, denoted as I(0) or I(1). This is necessary to avoid spurious and misleading regression estimates. The framework of ADF methods is based on analysis of the following model:

$$\Delta p_t = \alpha + \beta\, p_{t-1} + \gamma T + \sum_{k=1}^{n} \delta_k \Delta p_{t-k} + U_t \qquad (1)$$

Here, p_t is the mustard price series being investigated for stationarity, Δ is first difference operator, T is time trend variable, μ_t represents zero-mean, serially uncorrelated, random disturbances, k is the lag length; α, β, γ and δ_k are the coefficient vectors. Unit root tests were conducted on the β parameters to determine whether or not each of the mustard market series is more closely identified as being I(1) or I(0) process. DF-GLS test for a unit root in a time series was used in addition to Augmented Dickey Fuller (ADF). It performs the modified Dickey-Fuller t test (known as the DF-GLS test) proposed by Elliott *et al.* (1996). Essentially, the test is an Augmented Dickey-Fuller test, except that the time series is transformed *via* a generalized least squares (GLS) regression before performing the test. Elliott *et al.* (1996) and later studies have shown that this test has significantly greater power than the previous versions of the augmented Dickey-Fuller test.

Testing for Johansen co-integration (trace and eigen value tests): If two mustard market price series are individually stationary at same order, the Johansen co-integration model can be used to estimate the long run co-integrating vector using a Vector Auto regression (VAR) model of the form:

$$\Delta_{Pt=\alpha} \sum_{i=1}^{K-1} \Gamma i \Delta P_{t-1} + \Pi p_{t-1} + \mu_t \qquad (2)$$

Where p_t is a nx1vector containing the series of interest (the three variable series) at time (t), Δ is the first difference operator T_i and $\prod$ are nxn matrix of parameters on the i^{th} and k^{th} lag of

$$p_t, \Gamma i = \left[\sum_{i=1}^{k} A_i\right] - I_g, \Pi = \left[\sum_{i=1}^{k} A_i\right] - \mathrm{I_g}, \quad (3)$$

Ig is the identity matrix of dimension g, α is constant term, μ_t is nx1 white noise error vector. Throughout, p is restricted to be (at most) integrated of order one, denoted I(1), where I(j) variable requires j^{th} differencing to make it stationary. Equation (2) tests the co-integrating relationship between stationary series. Johansen and Juselius (1990) and Juselius (2007) derived two maximum likelihood statistics for testing the rank of $\prod$, and for identifying possible co-integration as the following equations show:

$$\lambda_{trace}[r] = -T \sum_{\mathrm{i=r+1}}^{\mathrm{m}} In(1 - \lambda_i) \quad (4)$$

$$\lambda_{max}[r, r + 1] = -TIn(1 - \lambda_{r+1}) \quad (5)$$

Where r is the co-integration number of pair-wise vector, λ_t is i^{th} eigen value of matrix $\prod$. T is the number of observations. The λ_{trace} is not a dependent test, but a series of tests corresponding to different r -value. The λ_{max} tests each eigen value separately. This model was used to test for; (1) integration between various mustard market price series of Rajasthan.

Test for Granger-Causality: After undertaking co-integration analysis of the long run linkages of the various variables, and having identified they are linked, an analysis of statistical causation was conducted. The causality test uses an error correction model (ECM) of the following form;

$$p_j^i = \beta_0 + \beta_i p^i(t-1) + \beta_2 p^j(t-1) + \sum_{k=1}^{m} \delta_k \Delta p^i(t-k) + \sum_{\mathrm{h=1}}^{\mathrm{n}} \Delta\sigma\Delta_{\mathrm{h}} \mathrm{h} \Delta p^j(t-h) + \mu_t \quad (6)$$

Where m and n are number *h* of lags determined by Akaike Information Criterion (AIC). If the null hypothesis that say Tonk mustard market prices in Rajasthan j do not Granger cause Bharatpur mustard market prices in Rajasthan i is rejected (by a suitable F-test) that $\sigma_h = 0$ for h = 1, 2….n and β=0, this indicates Tonk mustard market price j Granger-cause Bharatpur mustard market prices in Rajasthan i (Mafimisebi *et al*., 2014).

Impulse response function: Impulse response function is a shock to both VAR and ECM models used in the analysis. Impulse responses identify the responsiveness of the dependent variable which is (endogenous variables) in the models when a shock is put to the error term.

A simplified model of impulse response function for Tonk against Bharatpur market prices can be written as:

$$Tonk_t = \mathrm{B_0} + \mathrm{B_1} Bharatpur_{t-1} + \cdots + B_h Tonk_{t-h} + U_t \quad (7)$$

Where U_t is error term or shock or impulse. Hence the model will give us the effect on the VAR system when a unit shock is applied to variables.

RESULTS AND DISCUSSION

The results from Table 1, shows that, the mean price of mustard in Indian Rupees (₹) per quintal from the period of 2006 to 2014 for the six markets across Rajasthan was lowest at ₹ 2525.64 in Sriganganagar market. The highest average was recorded at price of ₹ 2690.50 in Bharatpur market. The minimum price was recorded in Dausa market at price of ₹ 1292.80 per quintal with maximum price recorded in Alwar market at price of ₹ 4358.54. Coefficient of variation indicates Sriganganagar market has low volatility of 25.50% compared to 26.92% in Dausa market, which has the highest. Volatility in the mustard markets is generally low. Such low fluctuations in prices can influence market integration of the mustard markets in Rajasthan positively. Generally, the wholesale price of rapeseed/mustard oil in Rajasthan is determined by the domestic production of rapeseed/mustard seed. Fluctuations in price can, therefore, be largely attributed to ups and downs in seed production and its market availability. Due to a glut in production and a inadequate storage facilities, producers flood the markets with rapeseed/mustard seeds just after harvesting. In addition, farmers are frequently pressured into rushing their product to market by the need to repay moneylenders for old debts. Other factors like the nature of existing supply and of the value chain, the availability and prices of substitute oils (mostly soya and palm oil), the MSP of production substitutes likes wheat and changes in consumer preferences have had an impact on wholesale price of rapeseed/mustard oil in the country. In addition, delayed crop arrivals in mandi, the heavy presence of speculators and stock pilers contribute to volatility (Pahariya and Mukherjee, 2007).

Table 2 shows growth rate of prices in selected markets in Rajasthan. The table shows that the growth rate of price from 2006-2014 was 0.768, 0.779, 0.778, 0.790, 0.7355 and 0.773 per cent for Alwar, Bharatpur, Sriganganagar, Dausa, Kota and Tonk markets, respectively. Generally the growth rate of prices has been almost similar for all the markets during the study period which could be a positive influence on market integration.

Table 3 shows the relationship between markets prices and arrivals. The results show that, there exists inverse relationship between prices and arrivals in markets of Alwar, Dausa and Kota. The results further reveal that, a one (1) tonne increase in arrivals of mustard in Alwar markets will

result in ₹ 0.04 decrease in price. Also a one (1) tonne increase in the arrivals of mustard will result in ₹ 0.0419 and ₹ 0.034 decrease in price in Dausa and Kota markets, respectively.

The study first examined each market time series for evidence of non-stationarity in order to proceed with co-integration approach. At level 0, all the selected mustard market price series in Rajasthan were not stationary. DF-GLS test and Augmented Dickey-Fuller showed similar results as indicated in Table 4.

The study went further to test the unit root in the selected market price series at first difference. DF-GLS test and Augmented Dickey Fuller showed similar results as indicated in table 5 that all the market price series prices are stationary at first difference.

Table 1 Descriptive statistics of mustard price series, 2006-2014 (N=108)

Markets	Mean(₹/qt)	Std. Dev.	Min(₹/qt)	Max(₹/qt)	CV (%)
Alwar	2634.95	688.83	1483.04	4192.82	26.14
Bharatpur	2690.50	714.77	1417.61	4358.54	26.57
Sriganganagar	2525.64	644.15	1437.26	3876.19	25.50
Dausa	2541.76	684.33	1292.80	4097.78	26.92
Kota	2606.49	676.81	1451.57	4177.21	25.97
Tonk	2621.38	692.75	1425.29	4181.04	26.43

Source: Authors own computation. CV= coefficient of variation

Table 2 Growth rate of prices in selected mustard markets in Rajasthan, 2006-2014

Markets	Coefficient	Std. Error	T value	P>(t)	R square
Alwar	0.00768	0.0003972	19.34	0.000	0.78
Bharatpur	0.00779	0.0004131	18.87	0.000	0.77
Sriganganagar	0.00778	0.0003461	22.48	0.000	0.83
Dausa	0.00790	0.0004127	19.13	0.000	0.76
Kota	0.00735	0.0004282	17.17	0.000	0.74
Tonk	0.00773	0.0003931	19.66	0.000	0.78

Table 3 Relationship between prices and arrivals of mustard markets in major wholesale markets in Rajasthan

Markets	Coefficient	Standard Error	T value	P value	R^2
Alwar	-0.040 (1.040)	0.020 (0.026)	-2.01 (40.69)	0.072* (0.000)	28.9
Bharatpur	-0.076 (1.076)	0.036 (0.039)	2.12 (27.51)	0.060* (0.000)	30.1
Sriganganagar	-0.020 (1.020)	0.012 (0.019)	1.64 (52.08)	0.133 (0.000)	21.1
Dausa	-0.0419 (1.049)	0.022 (0.028)	1.88 (36.94)	0.090* (0.000)	26.1
Kota	-0.034 (1.034)	0.012 (0.017)	2.87 (60.62)	0.017** (0.000)	45.6
Tonk	-0.016 (1.016)	0.015 (0.022)	1.05 (46.95)	0.319 (0.000)	9.9

Source: Authors own computation. Figures in parenthesis represent constant term statistics; **, * = Significant at 5 and 10 per cent, respectively

Table 4 Unit root testing

Variables	Price Level 1(0) Intercept with Trend	
Markets	ADF Statistics CV=-3.449	DF-GLS Test Statistics CV=-3.022
	Test Statistics	Test Statistics
Alwar	-2.210	-2.679
Bharatpur	-2.212	-2.221
Sriganganagar	-2.469	-2.336
Dausa	-2.383	-2.368
Kota	-1.882	-2.148
Tonk	-1.980	-2.109

H_o: variables are not stationary or has unit root; H_1: Variables are stationary or does not have unit root
NB: If the absolute value of ADF and DF-GLS Test Statistics is less than their 5% critical value we accept null hypothesis. It is also when the MacKinnon approximate p-value for Z(t) is insignificant.

Table 5 Unit root testing at first difference

Variables	First Difference 1(1) Intercept with trend	
Market prices	ADF Statistics CV=-3.449	DF-GLS Test Statistics CV=-3.023
	Test Statistics	Test Statistics
Alwar	-6.810	-5.752
Bharatpur	-6.659	-5.821
Sriganganagar	-7.737	-5.084
Dausa	-7.418	-5.041
Kota	-6.673	-4.300
Tonk	-8.140	-4.437

Source: Author's computation from time series data analysis
H_o: variables are not stationary or has unit root; H_1: Variables are stationary or does not have unit root
NB: If the absolute value of ADF and DF-GLS Test Statistics is greater than their 5% critical value we reject null hypothesis. It is also when the MacKinnon approximate p-value for Z(t) significant.

Before the co-integration analysis, suitable number of lags should be selected. The number of lags is selected by applying five different multivariate lag selection criteria: the Akaike information criterion (AIC), the Hannan-Quin information criterion (HQIC), and the Schwarz's Bayesian information criterion (SBIC), FPE and LR. Vector Autoregression (VAR) and ECM lag order pre-estimation was done on the differenced series and lag length of the model with the least AIC, HQIC, LR and FPE values chosen as the appropriate lag length to be included in the co-integration test. The test indicated the right maximum lag length for the analysis was between one to four lags for various market pairs analysis. This indicates the maximum time for price to be transmitted from one mustard market to the other in the long run or to move into long run equilibrium is about four months at most.

The co-integration tests results as showed in the Table 6, indicate, Tonk and Alwar; Tonk and Dausa; Bharatpur and Alwar and Sriganganagar and Dausa are integrated in the long run at lag 1 i.e., there is long run relationship between these two markets hence the prices of the market pairs move together in a period of at most one month. Tonk and Bharatpur and Bharatpur and Dausa are also integrated in the long at lag 2. The rest of the market pairs are not integrated in the long run.

Government initiative of ensuring the entry of private sector in the storage and extraction of oil from oilseeds such as mustard and also relaxation of restrictions on stock limits and inter-state movement of mustard and other essential commodities has contributed to the high spatial price transmission between markets. The large number of private players in the processing of mustard in the state also contributes to the high market integration of mustard markets. Commenting on this, Burman *et al.* (2012) reported, there were seventy oil processing units in operation in the Bharatpur district of Rajasthan alone which process mustard seeds.

Contract farming, co-operatives and establishment of direct sale or purchase centres has also contributed significantly in increasing the spatial price transmission

between mustard markets in the state. On increase marketing efficiency in markets in India, Bethla (2008) argues that, market integration for farm commodities has improved in the post-reform period compared to the pre-reform period.

The error correction model was used to analyse the markets pairs that were co-integrated in the long run. The results from the error correction model showed that, the lowest speed of adjustment towards long run equilibrium was from Ton to Bharatpur at rate of 43.2 per cent. The highest speed of adjustment was 103.8%, running Bharatpur to Alwar market towards long run equilibrium. This is followed by a speed of adjustment of 101.6% running from Tonk to Dausa market towards along run equilibrium in a period of at most one month. High speed of adjustment towards long run equilibrium within a period of two months can be attributed to MSP and procurement policy of the government, which helps absorb price shocks and bring stability, particularly in the states where procurement operations are effectively undertaken.

Agricultural futures exchanges and commodity exchange has also be attributed to the increase of the efficiency of markets with an added advantage of advance price discovery and effective forward linkages like warehousing and financing to decrease distress sales of mustard. Futures trading provide arbitrage opportunity to the traders. Arbitrage is the practice of taking advantage of a price difference between two or more exchanges or between two futures contracts with different expiry dates or between the cash and derivatives market.

The analysis for co-integrated markets shows, there is short run causality between the markets used in the study with most having unidirectional causality except Tonk to Bharatpur. Alwar Granger causes Tonk; Tonk Granger causes Dausa; Bharatpur Granger causes Alwar; Bharatpur Granger causes Dausa in the short run when there is a prices change. The short run causality means that a change in one of the prices of the market pairs results in an instantaneous less than two months reflection in the other market pair resulting in high efficiencies of the mustard markets. The results agree with Acharya and Agarwal (2014) quoting Wilson (2001) reported there is increasing degree of market integration in post liberalization period. They further argued that rapeseed-mustard markets started from a very low degree of integration during the eighties and became more integrated during the nineties.

The gains in efficiency in both production, processing and marketing of oilseeds will ultimately reduce domestic prices of edible oils for consumers (Brennan and Bantilan, 2003) and also increase competitiveness and reduce surge in large scale import of edible oils, which will justify the removal of non-market distorted seed subsidy (controversial case between India and WTO threatening the Bali Agreement) to seed production and capital subsidy to processing units; which will go long run to reduce India's huge dependence on oil import (Bannor and Madhu, 2015).

Table 6 Co-integration results for market pairs

Markets Pairs	Trace Statistics	5% Critical Value	No. lags	Rank	Remarks
Tonk - Alwar	1.06*	3.76	1	Rank 1	Co-integration
Tonk - Bharatpur	1.43*	3.76	2	Rank 1	Co-integration
Tonk - Sriganganagar	6.57	15.41	4	Rank 0	No Co-integration
Tonk - Dausa	2.00 *	3.76	1	Rank 1	Co-integration
Tonk - Kota	14.53	15.41	2	Rank 0	No Co-integration
Bharatpur - Alwar	1.05*	3.76	1	Rank 1	Co-integration
Bharatpur - Sriganganagar	12.78	15.41	4	Rank 0	No Co-integration
Bharatpur - Dausa	2.39*	3.76	2	Rank 1	Co-integration
Bharatpur - Kota	14.42	15.41	2	Rank 0	No co-integration
Ganganagar - Alwar	10.09	15.41	3	Rank 0	No co-integration
Ganganagar - Dausa	0.96*	3.76	1	Rank 1	Co-integration
Ganganagar - Kota	12.65*	15.41	1	Rank 0	No co-integration

Source: Author's computation

At rank 0: H_o: There is no co-integration between the variables
H1: There is co-integration between the variables

NB: We accept null hypothesis when trace statistics or max statistics is less than the 5% critical value at rank 0.

At rank 1: H_o: There is (1) co-integration of the variables at rank 1
H_1: There is no (1) co-integration of the variables at rank 1.

NB: We accept null hypothesis when trace statistics or max statistics is less than the 5% critical value at rank 1.

Table 7 Vector Error Correction (VECM) Model results for the co-integrated variables

Market Pairs	P Value	Error Correction Term	Short run model/Causality		Short run causality remarks
			Prob>Chi	Direction	
Tonk-Alwar	0.000	-1.006	0.456,0.0134*	Unidirectional	Short run
Tonk-Bharatpur	0.049	-0.432	0.000*, 0.054*	Bidirectional	Short run
Tonk-Dausa	0.000	-1.016	0.007*,0.651	Unidirectional	Short run
Bharatpur-Alwar	0.000	-1.038	0.000*, 0.771	Unidirectional	Short run
Bharatpur-Dausa	0.001	-0.524	0.000*,0.393	Unidirectional	Short run
Ganganagar-Dausa	0.000	-0.954	0.146,0.117	None	No short run

Source: Author's computation, A<->B=Bidirectional, A->B=A causes B, A<-B=B causes A,*=5% Sign.
Ho: No short run causality running from variable A to B
H1: Short run causality running from A to B or variable A causes changes in variable B in the short run
NB: Reject null hypothesis when the Prob> chi value is <5%

Table 8 Vector Autoregressive (VAR) model for the non co-integrated markets Granger Causality Wald Tests

Markets Pairs	Prob>chi 2	Direction	Short run causality
Tonk-Sriganganagar	0.001*, 0.016*	Bidirectional	Short run
Tonk-Kota	0.056*, 0.025*	Bidirectional	Short run
Bharatpur-Sriganganagar	0.000*, 0.019*	Bidirectional	Short run
Bharatpur-Kota	0.000*, 0.412	Unidirectional	Short run
Ganganagar-Alwar	0.354, 0.002*	Unidirectional	Short run
Ganganagar-Kota	0.734, 0.026*	Unidirectional	Short run

Source: Author's computation, A<->B=Bidirectional, A->B=A causes B, A<-B=B causes A, *=5% Sign.
H_o: No short run causality running from variable A to B
H_1: Short run causality running from A to B or variable A causes changes in variable B in the short run
NB: Reject null hypothesis when the p value is <5%

The unrestricted vector autoregressive (VAR) model was run for the non-co-integrated market pairs. The results of the Wald tests show that mustard price series between Tonk and Sriganganagar; Tonk and Kota; Bharatpur and Sriganganagar causes each other in the short run whereas Bharatpur Granger causes Kota; Sriganganagar Granger causes Alwar and Sriganganagar Granger causes Kota in less than one month though in the long run they drift apart. This shows that mustard markets in Rajasthan are highly integrated both in the long and short run.

Impulse responses: Impulse response function is a shock to both VAR and ECM models used in the analysis. Positive shocks are shocks that affect the market prices of the markets in the consumption markets positively (i.e., a decrease in the price of mustard in the production area market i.e., Sriganganagar, Tonk and Bharatpur market price) while negative shocks are shocks that affect the market prices of the markets in the consumption markets negatively (i.e., an increase in the price of mustard in the production area market i.e., Sriganganagar, Tonk and Bharatpur market price) (Bannor, 2015).

The results from Fig.1 and Table 9 show impulse response function when an unexpected positive shock is given to market price in Tonk, Sriganganagar, and Bharatpur or when one positive standard deviation is given to Tonk, Sriganganagar and Bharatpur the response thereof from Alwar, Dausa, Kota mustard wholesale market prices. The results shows within a period of one year or twelve months, the response influence of shocks from Tonk, Sriganganagar, and Bharatpur on Alwar, Dausa, Kota mustard wholesale market prices will be permanent. However an orthogonalized shock or unexpected shocks that is local to the Bharatpur mustard wholesale market prices will also have a temporary effect on wholesaler mustard prices in Bharatpur and the same can also be said of Kota mustard wholesaler prices.

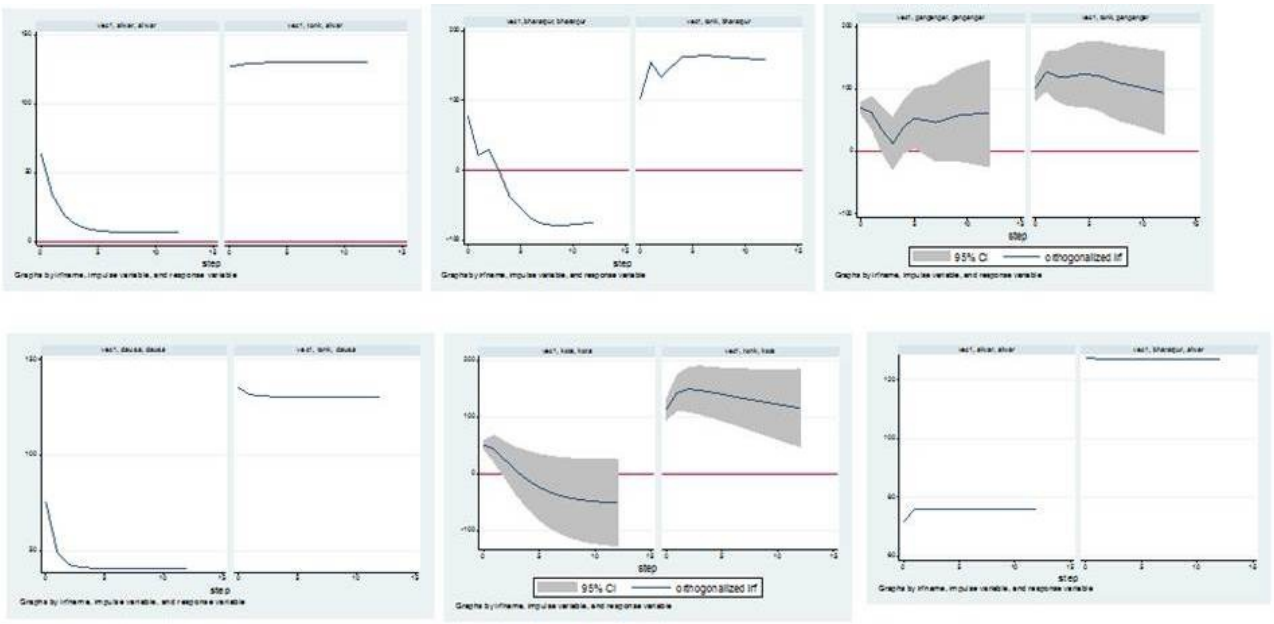

Fig. 1. Impulse Responses

Table 9 Impulse response of markets from unexpected shocks to average mustard wholesaler prices in different selected markets

Unexpected shock to Markets	Response from Markets	Remarks on Type of Response
Tonk	Alwar	Permanent
	Bharatpur	Permanent
	Sriganganagar	Permanent
	Dausa	Permanent
	Kota	Permanent
	Tonk	Permanent
Bharatpur	Alwar	Permanent
	Sriganganagar	Permanent
	Dausa	Permanent
	Kota	Permanent
	Tonk	Permanent
	Bharatpur	Transitory
Sriganganagar	Alwar	Permanent
	Dausa	Permanent
	Kota	Permanent
	Sir Ganganagar	Permanent
Dausa	Dausa	Permanent
Kota	Kota	Transitory
Alwar	Alwar	Permanent

Source: Authors own computation

Generally, most of the mustard markets in Rajasthan are integrated with both bidirectional and unidirectional causality. In the context of policy implications, Government should continue to invest in domestic mustard production, warehousing, processing factories and other infrastructure to be able to maintain and sustain the efficiency of the mustard markets in Rajasthan and its marketing channels. Government should also in addition to policies undertaken,

create the development of oilseed clusters with best transport and infrastructure facilities (which will encourage mustard along with other oilseed crops like sunflower) to reduce transaction costs for both farmers and processors. Government of India cross cutting programmes and policies on oilseeds especially for mustard marketing is paying of positively, which should be acknowledged and encouraged to make India more competitive not only in Rajasthan but across the states and in the world.

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Scaling up of sunflower (*Helianthus annuus* L.) productivity through improved component technology in Kurnool District of Andhra Pradesh

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ABSTRACT

Frontline demonstrations (FLDs)were conducted in Kurnool district of Andhra Pradesh to know the yield gaps between improved technology (IT) and farmers practice (FP) in sunflower crop. In the FLDs, the hybrid NDSH1 performed better in terms of seed yield both under rainfed (604 kg/ha) and irrigated conditions (1968 kg/ha) as compared to cultivation of local private hybrids in FP (500 and 1845 kg/ha, respectively). Spraying of Boron (B) at ray floret opening stage also resulted in improved seed yields over its non application across the years of demonstration. In addition, in all the years of study, by adopting proper spacing and thinning practice, marked improvement in seed yield and additional net returns were observed in farmer's fields. The study recommends that as the sunflower yields are less in farmers field in the study area, they can be improved by adopting improved component technologies *viz.,* hybrid (NDSH1), spraying of micro-nutrient Boron at ray floret opening stage and adopting proper spacing and thinning.

Keywords: Boron, Frontline demonstration, NDSH-1, Plant spacing, Sunflower

Sunflower (*Helianthus annuus* L.) is one of the most important edible oilseed crops in the world including India. The crop is well known for its broad range of adaptability (Koutroubas *et al*., 2008) and high oil content of about 43% (Nasim *et al*., 2011). In India, sunflower is cultivated in an area of 0.73 million ha with a total production of 0.50 million tonnes and with an average productivity of 692 kg/ha, where as in Andhra Pradesh, it is grown in an area of 0.16 million ha with a production of 0.124 million tonnes and productivity of 785 kg/ha (Anonymous, 2013). In Andhra Pradesh, Kurnool district is one of the prominent sunflower growing areas, where the crop is largely cultivated under rainfed conditions during late *kharif* and as irrigated crop during *rabi* and summer seasons. It is observed that the productivity level of sunflower in farmer's fields is low due to several biotic and abiotic stresses besides unavailability of quality seeds of improved hybrids in time and non adoption of recommended production technologies. Selection of the right sunflower hybrid is critical as the final income is dependent on both seed and oil yields. As not all hybrids available in the market maximise both seed and oil yields, farmers need to be cautious while choosing the hybrids. Further, non adoption of recommended row spacing leads to low or over plant population which reduces seed setting etc. as lower plant density delays canopy closure and increases light interception leading to high seed production per plant, but low seed production per unit area (Basha, 2000). More so, excess plant population leads to more inter plant competition for soil moisture and nutrients resulting in smaller head size and poor seed set. Hence, optimum plant density plays a greater role in increasing sunflower productivity. Also, sunflower is one of the most sensitive crops to Boron (B), and its deficiency at flowering stage affects pollen viability and abortion of stamens and pistils resulting in poor seed set due to malformed capitulums and consequently low seed yield (Dell and Longbin, 1997; Chatterjee and Nautiyal, 2000). The poor seed yields in the farmer's fields reflect a wide gap between the available improved techniques and its actual application by the farmers. Hence, there is a tremendous opportunity for increasing the production and productivity of sunflower grown in the area by adopting improved technologies which in turn helps in improving the economic and social status of the farmers.

MATERIALS AND METHODS

Frontline demonstrations (FLDs) on sunflower were conducted at farmers' fields in different villages of Kurnool district in scarce rainfall zone of Andhra Pradesh to assess its performance during *kharif* 2009 under rainfed and *rabi* seasons of the 2010-11 and 2011-12 under irrigated conditions. The soils of the district where FLDs were taken up are sandy loam in texture, low in nitrogen, medium in phosphorus and medium to high in potash. Improved component technology like cultivation of hybrid NDSH-1 [early maturing hybrid with a potential yield of 1400 kg/ha, oil content (40%) released from Regional Agricultural Research Station, Nandyal, ANGRAU], adoption of recommended spacing (60cm × 30 cm), thinning of seedlings

at 15 days after emergence keeping one healthy seedling per hill where two seeds/hill were sown and spraying of micro-nutrient Boron (concentration @ 2g/litre of water) @ 500 l/ha at ray-floret opening stage were demonstrated in farmers field. Each FLD is conducted in an area of one acre and compared with existing farmers practice adjacently taken up in one acre. Well before conducting FLDs, a list of farmers was prepared from group meeting and specific skill training was imparted to the selected farmers regarding different aspects of cultivation as suggested by Chaudhary (1999). The inputs like seeds, fertilizers and need based plant protection chemicals were distributed to 72 number of farmers from four villages. A team of scientists including Agronomist, Plant Breeder and Plant Pathologist have visited and monitored the demonstration sites at an interval of 15-20 days during the crop growing period. Finally, data on seed yield, cost of cultivation and returns was collected after harvesting. Different parameters as suggested by Yadav *et al.* (2004) were used for calculating gap analysis, costs and returns.

Yield gap = Demonstration yield - Farmer's practice yield
Additional return = Demonstration return - Farmer's practice return

RESULTS AND DISCUSSION

The study suggests that the production level of sunflower can be improved by cultivating suitable hybrids. The mean productivity of sunflower was 604 kg/ha in rainfed with 6 farmers while it was almost three times under irrigated situation (1968 kg/ha) with 10 farmers. Based on field demonstration data, it is apparent that the hybrid NDSH 1 performed well over local popular private hybrids both under rainfed and irrigated situations (Kumar *et al*., 2013). However, the relative advantage was more in rain fed situation (23.6%). In rainfed situation, terminal drought is a common phenomenon that drastically affects the seed yield. Being the short duration (85 days) hybrid, NDSH1 can effectively escape the terminal drought over local hybrids which are of 110 days crop duration. Therefore, NDSH 1 would be a potential hybrid for both rainfed as well as irrigated conditions with an additional income of ₹ 3104 and 4480/ha, respectively (Table 1).

Besides suitable hybrid, seed setting is also one of the major constraints in maximizing the sunflower productivity. Unavailability of optimum boron (B) in soil leads to boron deficiency in crop plants that affects flowering, pollen germination, pollen tube growth and seed development (Cakmak *et al.,* 1997). However, in the study it was observed that, generally farmers do not apply B fertilizer to sunflower crop grown in the region and hence, foliar application of B was done in rainfed and irrigated conditions of Nandyal region. The results from 20 farmers indicated that, application of B @ 2 gm/l of water at ray floret opening stage could markedly increase the seed yield in both rainfed and irrigated situations (Table 2). However, the relative increase was observed more under rainfed situation. The data across the years of demonstration indicated that the economic advantage in terms of B:C ratio was 1.6 in rainfed and 2.9 and 3.4 in irrigated conditions. Under rainfed condition, the yield advantage may be associated with B as well as supplemental moisture application in the form of foliar spray.

Table 1 Comparative seed yield and economic assessment of hybrid NDSH-1 over local variety at farmer's field

Season	Improved Technology	No. of demons.	Mean seed yield (kg/ha)		% Increase in yield	Yield gap (kg/ha)	Cost of cultivation (₹/ha)		Gross returns (₹./ha)		Net returns (₹./ha)		Additional net returns (₹./ha)	B:C Ratio	
			IT	FP			IT	FP	IT	FP	IT	FP		IT	FP
Kharif (2009)	NDSH-1	6 (R)	604 (38.4)	500 (26.3)	23.6 (9.7)	104	7794	8398	14167	11667	6373	3269	3104	1.8	1.4
Rabi (2010-11)	NDSH-1	10 (I)	1968 (63.0)	1845 (74.0)	6.7 (1.7)	123	18870	19670	57990	54410	39120	34740	4480	3.1	2.8

IT: Improved Technology; FP: Farmers practice; R: Rainfed; I: Irrigated; Standard Error Mean values are depicted in parentheses

Table 2 Effect of foliar spray of Boron on seed yield and economics of sunflower under rainfed and irrigated field situation

Season	Improved Technology	No. of demons.	Mean seed yield (kg/ha)		% Increase in yield	Yield gap (kg/ha)	Cost of cultivation (₹/ha)		Gross returns (₹/ha)		Net returns (₹./ha)		Additional net returns (₹/ha)	B:C Ratio	
			IT	FP			IT	FP	IT	FP	IT	FP		IT	FP
Kharif (2009)	Boron	1 (R)	625	500	25.0	125	9650	9375	15000	12000	2350	5625	2725	1.6	1.3
Rabi (2010-11)	Boron	10 (I)	2170 (12.8)	1865 (24.2)	16 .0 (1.2)	305	19288	18788	66395	57045	47107	38257	8850	3.4	3.0
Rabi (2011-12)	Boron	10 (I)	1960 (18.4)	1787 (29.9)	10.0 (1.5)	173	19288	18788	56826	51809	37538	33021	4517	2.9	2.8

IT: Improved Technology; FP: Farmers practice; R: Rainfed; I: Irrigated; Standard Error Mean values are depicted in parentheses

SCALING UP OF SUNFLOWER PRODUCTIVITY THROUGH IMPROVED COMPONENT TECHNOLOGY

Maintaining optimum plant population is essential for higher seed yield of sunflower in farmer's field. In general, farmers adopt row spacing according to seed drill used by them in closely spaced crops like groundnut, jowar and wide row spacing crops like cotton and sunflower. Over and under population was observed in farmers sunflower fields and often resulted in poor yield. Hence, optimum plant population should be maintained by proper inter row and intra row spacing. Based on farmer field demonstration (5 farmers) under rainfed situation, sowing of sunflower at 60 cm x 30 cm spacing yielded 20.3 per cent higher compared to farmer's practice. Similarly, under irrigated condition, thinning alone (10 farmers) resulted in 7 per cent increase in sunflower yield where as adopting optimum row spacing, the yield improvement was 11 per cent. However, combination of both row spacing and thinning have almost additive effect and resulted in 16 per cent yield improvement over conventional farmers' practice (Table 3).

The study depicted that there is significant yield gap between improved technology and farmers practice and can be combated by adoption of appropriate hybrid, boron spray and maintaining optimum plant population through proper row spacing/thinning. The yield improvement with adoption of improved technology under rainfed situation was found in the order of boron spray> hybrid>spacing/thinning. The study also suggests that the impact of these technologies at farmers fields are more prominent in rainfed condition over irrigated. Under irrigated condition, the relative performance of different technologies are boron spray >spacing/thinning > hybrid. As the yield level of sunflower in rainfed condition is very low, there is a dire need of adoption of these technologies to improve the productivity. Meanwhile, it is expected that the combination of all these technologies would have interactive impact on sunflower productivity in farmer's field.

Table 3 Performance of sunflower crop with proper row spacing and thinning on seed yield and monetary returns

Season	Improved Technology	No. of demons.	Mean seed yield (kg/ha)		% Increase in yield	Yield gap (kg/ha)	Cost of cultivation (₹/ha)		Gross returns (₹/ha)		Net returns (₹/ha)		Additional net returns (₹/ha)	B:C Ratio	
			IT	FP			IT	FP	IT	FP	IT	FP		IT	FP
Kharif (2009)	Row spacing and Thinning	5 (R)	750 (88.4)	625 (88.4)	20.3 (3.0)	125	9038	8938	17563	14125	8525	5187	3338	1.9	1.6
Rabi (2010-11)	Row spacing and Thinning	20 (I)	2141 (16.7)	1839 (21.9)	16 .0 (1.8)	302	20214	19045	65295	56015	45081	36970	8111	3.2	2.9
Rabi (2011-12)	Row spacing	5 (I)	2040 (24.5)	1840 (33.1)	11.0 (1.9)	200	18780	18780	59160	53360	40380	34580	5800	3.2	2.8
Rabi (2011-12)	Thinning	5 (I)	1890 (50.9)	1760 (74.8)	7.0 (2.3)	130	18895	19795	54810	51040	35915	31245	4670	2.9	2.6

IT: Improved Technology; FP: Farmers practice; R: Rainfed; I: Irrigated; Standard Error Mean values are depicted in parentheses

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Metroglyph analysis on genetic diversity in germplasm accessions of sunflower (*Helianthus annuus* L.)

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ABSTRACT

A study on genetic diversity in sunflower germplasm accessions was carried out at the Oilseeds farm, Department of Oilseeds, TNAU, Coimbatore, Tamil Nadu. The materials consisted of 46 germplasm accessions collected from the Indian Institute of Oilseeds Research, Hyderabad. Observations on six characters *viz.,* days to 50% flowering, plant height (cm), head diameter (cm), 100-seed weight (g), volume weight (g/100ml) and seed yield/plant (g) were recorded. Metroglyph and index score method was used to assess the genetic variability. All the accessions were grouped into nine groups. Maximum number of genotypes (11) were grouped in group IV followed by group V with nine genotypes. The cluster VIII possessed two accessions with moderate head diameter, 100-seed weight, volume weight and seed yield/plant. The genotypes belonging to the groups II, V and VIII recorded moderate seed yield/plant. The genotypes in the clusters III, VI and IX recorded high seed yield/plant. Highest index score of 16 was observed by GMU 539 in the cluster IX and the accessions GMU 520 in the cluster V and GMU 558 in the cluster IX recorded next highest index score of 15. Findings of the present study suggested that the genotypes having high index scores and belonging to different groups could be utilized in breeding programme to create high variability for various characters.

Keywords: Genetic diversity, Germplasm accessions, Metroglyph analysis, Sunflower

Sunflower is one of the important edible oilseed crops of the world. The crop is spreading to diverse agroclimatic conditions and shows adaptability to all types of soils, which necessitates the development of more productive hybrids of diverse duration. Success of plant breeding depends upon the nature and magnitude of variability present in the germplasm. Improvement in sunflower emphasizes the generation of heterotic hybrid that is achieved by heterotic vigour available in the genetically diverse parental lines. Involvement of genetically divergent parents in hybridization will result in enhanced vigour or heterosis in the resultant hybrid. Several works have been reported on the evaluation of divergence in sunflower crop using morphoagronomic characters (Arshad *et al*., 2007). Metroglyph and index score method advocated by Anderson (1957) was used for analysis of morphological characters in different crop species. This analysis is used to classify the available germplasm into distinct clusters on the basis of their genetic diversity. Metroglyph analysis has been used to access the genetic variability in several crop species across the genus by many authors (Bhargava *et al*., 2009; Datta *et al*., 2013; Ghafoor and Ahmad, 2005; Khan *et al*., 2007; Laiju *et al*., 2002; Punitha *et al*., 2010; Rashid *et al*., 2007). With this background, 46 accessions of sunflower germplasm were analyzed using metroglyph analysis.

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The material for the present study consisted of 46 germplasm accessions of sunflower were evaluated at the Oilseeds farm, TNAU, Coimbatore during *rabi* 2013-14. These accessions were received from the Indian Institute of Oilseeds Research, Hyderabad. Each genotype was raised in 4.5m length with spacing of 60x30cm. All the recommended agronomic practices were followed to raise a good healthy crop. Five randomly selected plants from each line were taken for recording observations on six characters *viz.,* days to 50% flowering, plant height (cm), head diameter (cm), 100- seed weight (g), volume weight (g/100ml) and seed yield/plant (g). The mean for each line was worked out for each of these characters and range was calculated. The mean values were used to carry out metroglyph analysis. As per the model, the glyphs were first plotted on the basis of two extremely variable traits namely, seed yield/plant (g) and plant height (cm) in X and Y axes, respectively. Each germplasm accession has a special number and was represented as a glyph which was the intersection point of mean values of X and Y co-ordinates. All the other characters having medium and high scores were represented by rays on the glyph (Fig.1). Each ray represents a particular character obtained by dividing the range of variation into three equal classes giving the grades low, medium and high for each character. The length of the ray assigned to the character depends upon the index score of accession for that character. The index values and the position of rays for

different characters are represented in the Table 1. The glyph positions and rays were used to assess the variability pattern for assessment of different divergent groups among the germplasm accessions. The total score of the individual entry was indicated within the corresponding glyph. The total score of individual genotype is given in Table 2.

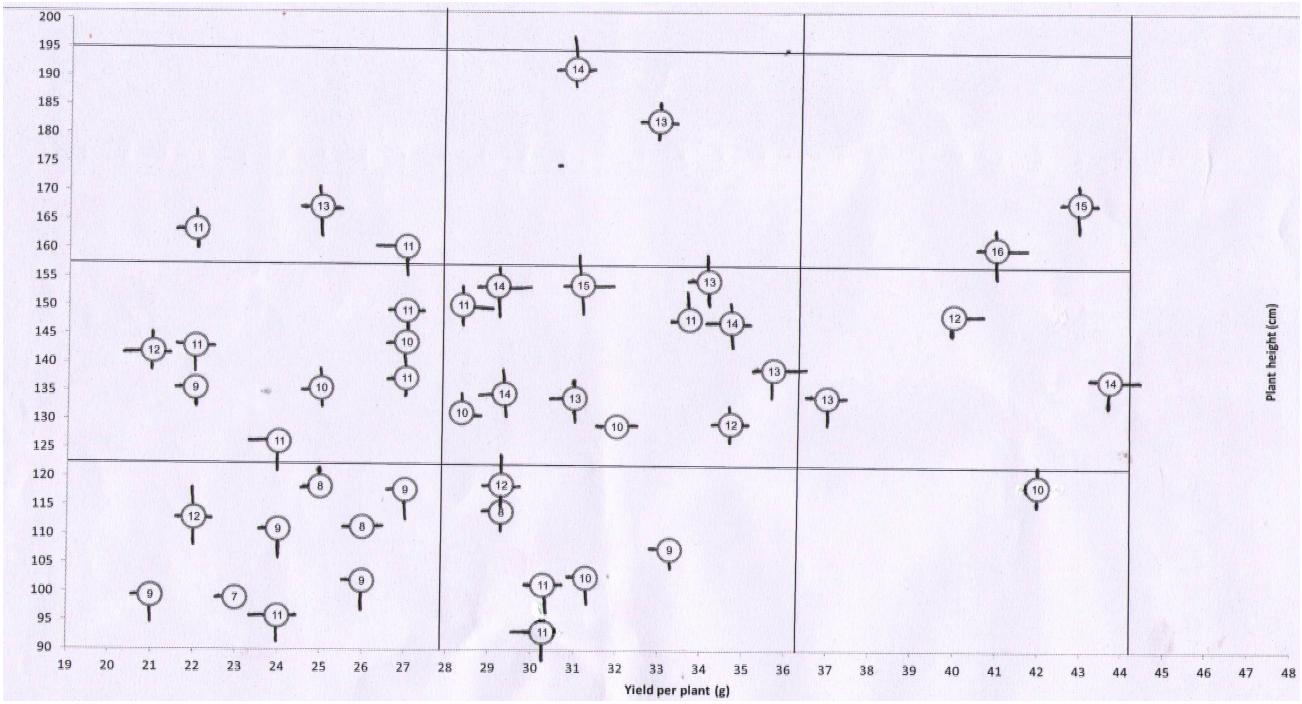

Fig. 1. Scatter diagram of metroglyphs representing 46 germplasm accessions on seed yield and its contributing characters of sunflower

Table 1 Index scores and signs used for characters for metroglyph analysis of 46 germplasm accessions of sunflower

Characters	Score 1	Score 2	Score 3
	Values less than	Values between	Values more than
Days to 50% flowering	55 days	55 - 60 days	60 days
Plant height (cm)	125.17 cm	125.17 - 158.82 cm	158.82 cm
Head diameter (cm)	14.07 cm	14.07 - 16.42 cm	16.42 cm
100-seed weight (g)	5.0 g	5.0 - 5.9 g	5.9 g
Volume weight (g/100ml)	20.4 g	20.4 - 25.7 g	25.7g
Seed yield/plant (g)	28.67 g/plant	28.67 - 36.32 g/plant	36.32 g/plant

All the 46 glyphs drawn in the scatter diagram were divided into three groups for seed yield/plant as low (21.00 - 28.66 g/plant), medium (28.67 - 36.32 g/plant) and high (36.33 - 44.00 g/plant). In the same way, three divisions of plant height such as short (91.50 - 125.16 cm), medium (125.17 - 158.82 cm) and high (158.83 - 192.50 cm) were obtained. By obtaining these classifications, all the individuals were brought into nine groups. Variations for other characters were represented by the variations in the lengths of the corresponding rays on all the glyphs. The length of each ray for other characters was classified as low (with low value), medium (with medium value) and high (with high value). The accessions based on days to 50% flowering were grouped as short duration (50-54 days), medium duration (55-60 days) and long duration (61-66 days). Based on head diameter, grouping of accessions was made as low (11.70-14.06 cm), medium (14.07-16.42 cm) and high (16.43-18.80 cm) and low (4.0-4.9 g), medium (5.0- 5.9 g) and high (6.0-7.0 g) based on 100-seed weight and low (15.0-20.3 g), medium (20.4-25.7 g) and high (25.8-31.0 g) based on volume weight. The signs used to calculate scores for different characters of all accessions are depicted in Table 1.

Table 2 Score value of individual genotypes of sunflower

S. No.	Genotype	Score value	S. No.	Genotype	Score value
1	GMU-301	11	24	GMU-470	11
2	GMU-317	14	25	GMU-475	12
3	GMU-321	13	26	GMU-477	9
4	GMU-322	8	27	GMU-479	11
5	GMU-342	11	28	GMU-484	10
6	GMU-363	13	29	GMU-487	8
7	GMU-377	11	30	GMU-488	11
8	GMU-386	14	31	GMU-498	11
9	GMU-392	13	32	GMU-517	14
10	GMU-400	9	33	GMU-520	15
11	GMU-401	10	34	GMU-539	16
12	GMU-408	9	35	GMU-558	15
13	GMU-409	14	36	GMU-568	9
14	GMU429	12	37	GMU-583	14
15	GMU-430	13	38	GMU-598	10
16	GMU-432	12	39	GMU-1019	10
17	GMU-433	12	40	GMU-1025	13
18	GMU-438	11	41	GMU-1002	9
19	GMU-451	12	42	GMU-1074	7
20	GMU-442	8	43	GMU-1094	11
21	GMU-452	13	44	GMU-1129	11
22	GMU-463	10	45	GMU-1120	11
23	GMU-465	9	46	GMU-1177	10

The sunflower accessions could be categorized into nine groups which differed among themselves. Scatter diagram revealed that maximum number of genotypes (12) was found in group V. The group IV was the second having nine genotypes with medium plant height and medium seed yield per plant. The cluster IX comprised of two genotypes having high 100-seed weight, medium volume weight and high seed yield/plant. The cluster VIII possessed two accessions with moderate head diameter, 100-seed weight, volume weight and seed yield/plant. The cluster VI consisted of three accessions with high 100-seed weight, moderate volume weight and high seed yield/plant. The genotypes belonging to the groups II, V and VIII recorded moderate seed yield/plant. The genotypes in the clusters III, VI and IX recorded high seed yield/plant. The constellation of different groups based on values for different characters is presented in the Table 3. Considerable reliance can be laid on the index score assigned to the various inbred lines to judge their potential. In this study, it could be seen that the index score ranged from 7 to 16. Highest index score of 16 was observed by GMU 539 in the cluster IX and the lines GMU 520 in the cluster V and GMU 558 in the cluster IX recorded next highest index score of 15. Among 46 genotypes,, GMU-317, GMU-321, GMU-386, GMU-1094, GMU-1129, GMU-438 and GMU-488 recorded high values for 100-seed weight and volume weight and the genotypes *viz*., GMU-430, GMU-517, GMU-520, GMU-409 and GMU-539 recorded more head diameter and 100-seed weight. The genotype, GMU-539 showed high values for head diameter, 100-seed weight and volume weight. These genotypes could be utilized in breeding programme to create maximum variability of good combinations of characters in sunflower.

Table 3 Germplasm accessions in different groups of sunflower

Grouping	No. of accessions	Genotypes
I	9	GMU-322, GMU-408, GMU-429, GMU-465, GMU-477, GMU-487 GMU-1002, GMU-1074, GMU-1094
II	6	GMU-401, GMU-432, GMU-442, GMU-479, GMU-568, GMU-1129
III	1	GMU-598
IV	9	GMU-301, GMU-377, GMU-400, GMU-438, GMU-451, GMU-488, GMU-1019, GMU-1120 GMU-1177
V	12	GMU-317, GMU-321, GMU-342, GMU-386, GMU-392, GMU-430 GMU-433, GMU-463, GMU-484, GMU-498, GMU-517, GMU-520
VI	3	GMU-409, GMU-452, GMU-475
VII	2	GMU-470, GMU-1025
VIII	2	GMU-363, GMU-583
IX	2	GMU-539, GMU-558

Table 4 Total index score of 46 germplasm accessions based on yield components of sunflower

Total index score	No. of accessions	Genotypes
7	1	GMU-1074
8	3	GMU-322, GMU-442, GMU-487
9	6	GMU-400, GMU-408, GMU-465, GMU-477, GMU-568, GMU-1002
10	6	GMU-401, GMU-463, GMU-484, GMU-598, GMU-1019, GMU-1177
11	11	GMU-301, GMU-342, GMU-377, GMU-438, GMU-470, GMU-479, GMU-488, GMU-498, GMU-1094, GMU-1129, GMU-1120
12	5	GMU-429, GMU-432, GMU-433, GMU-451, GMU-475
13	6	GMU-321, GMU-363, GMU-392, GMU-430, GMU-452, GMU-1025
14	5	GMU-317, GMU-386, GMU-409, GMU-517, GMU-583
15	1	GMU-520, GMU-558
16	1	GMU-539

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Exploitation of heterosis in linseed (*Linum usitatissimum* L.)

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ABSTRACT

Heterosis was estimated for 55 hybrids for eight different characters and was expressed as increase or decrease over superior parent. Hybrids in which R-17, Gaurav and Shubhra were involved as female parents and 1/76 and Shubhra as male parents exhibited highest positive heterosis for most of the characters. This indicated the presence of higher frequency of additive alleles in these parents. Hybrids *viz*., Gaurav x 1/76 and Shubhra x 1/76 were found superior in respect of seed yield/plant, primary branches/plant, number of capsules/plant and 100-seed weight.

Keywords: Additive allele, Heterosis, Hybrid, Linseed, Parent

Linseed (*Linum usitatissimum* L.) is an important *rabi* oilseed crop next in importance to rapeseed-mustard, mostly grown under rainfed and input starved condition. India ranks first in area in the World, but stands at 5th place in terms of production after Canada, China, USA and Ethiopia. In terms of productivity, India is far below (408 kg/ha) to UK (1636 kg/ha), USA (1484 kg/ha), Canada (1197 kg/ha), Ethiopia (1065kg/ha) and China (1029 kg/ha). Although, the area is decreasing in the World but the silver lining is the improvement in the productivity all over the World (2.12%) and in India (5.97%) as well (Anonymous, 2012). Linseed is predominantly a self pollinated crop and the scope of hybrid vigour depends upon the direction and magnitude of heterosis. The success of developing commercial hybrids depends upon the choice of superior parents for higher expression of heterosis by spotting the potentiality of good hybrid combinations. Hybrid technology has been widely acclaimed as a modern approach for the genetic improvement of yield in various crop species. Therefore, the present investigation was carried out to exploit the heterosis in linseed.

A set of 11 parents namely N-3, Jawahar-23, R-17, Sweta, T-397, Gaurav, Shubhra, LC185, EC41498, 1/76, NP-22 and 55 F1s were sown in randomized block design with three replications at Oilseed Research Farm, C. S. Azad University of Agriculture and Technology, Kanpur during 2010-11. Each genotype was sown in 2 rows of 3 m length with row to row and plant to plant spacing of 40 and 10 cm, respectively. All recommended package and practices were followed to raise a healthy crop. Observations on different yield contributing traits namely days to 50% flowering, days to maturity, plant height (cm.), primary branches/plant, number of capsules/plant, number of seeds/capsule, 100-seed weight (g) and seed yield/plant (g) were recorded on 10 randomly selected plants in parents and F_1s in each replication. The data were subjected to genetic analysis.

Heterosis was estimated for 55 hybrids for eight different characters and was expressed as increase or decrease over better parent (Table 1). For days to 50 per cent flowering and days to maturity, heterosis in negative direction is considered desirable since earliness is preferred over late flowering and maturity, the hybrid R 17 x Shubhra recorded highest significant negative heterosis (-7.04%) for days to 50 per cent flowering and -2.89 per cent for days to maturity. Thirty one hybrids exhibited significant negative heterosis for plant height while fourteen positive. The cross Shubhra x LC41498 (-20.63%) recorded highest negative heterosis. For primary branches/plant, 38 hybrids out of 55 hybrids have shown significant positive heterosis where as only four crosses showed significant negative heterosis. Highest heterosis was observed in cross Sweta x Gaurav (192.57%) followed by T-397 x Gaurav (129.03%) and Gaurav x 1/76 (98.84%). Reddy *et al.* (2013) also reported positive desirable heterosis for primary branches/plant. For number of capsules/plant, most of the crosses showed significant positive heterosis ranged from -28.25 to 240.69 per cent. Highest heterosis was observed in Gaurav x 1/76 (240.69%). Only 10 crosses showed significant positive heterosis for number of seeds/capsule and 45 crosses exhibited significant negative heterosis. It ranged from -35.77% (EC41498 x 1/76) to 21.86% (R-17 x Gaurav). For 100-seed weight, 27 hybrids have recorded significant positive heterosis while 28 hybrids have recorded significant negative heterosis. For seed yield/plant, all the hybrids have shown significant positive heterosis except two cross N-3 x R-17 and R-17 x LC185. The cross combinations which recorded higher heterosis over better parent were Gaurav x1/76 (295.62%), EC41498 x 1/76 (229.22%), N-3 x T-397 (176.08%) and Shubhra x1/76 (119.37%).

From the above results it is clear that different hybrids exhibited different magnitude of heterosis for different characters. No single cross exhibited significant heterosis for

all the characters. A perusal of data reveals that most hybrids in which R-17, Gaurav and Shubhra were involved as female parents have exhibited highest positive heterosis for most of the characters. Further parents 1/76 and Shubhra were involved as male parents in most of the top hybrids with respect to heterosis. This indicated the presence of higher frequency of additive alleles in these parents. Hybrid Gaurav x 1/76 and Shubhra x 1/76 were found superior in respect of seed yield/plant, primary branches/plant, number of capsules/plant and 100-seed weight. These hybrids are useful for exploitation of heterosis. Therefore mentioned hybrids have wide scope and needs to be tested in large scale trials in order to confirm their superiority.

Table 1 Per cent heterosis for yield and its component characters in linseed in best selected hybrids

Characters	Hybrid	Heterosis (%)
Days to 50% flowering	R-17 x Shubhra	-7.04**
	Sweta x EC 41498	-5.72**
	Sweta x Shubhra	-5.02**
	N-3 x R-17	-4.69*
Days to maturity	R-17 x Shubhra	-2.89*
	Gaurav x 1/76	-2.15*
	T-397 x 1/76	-2.12*
Plant height	Shubhra x LC 41498	-20.63**
	R-17 x Shubhra	-19.03**
	R-17 x EC 41498	-18.03**
	Sweta x Shubhra	-16.72**
Primary branches/plant	Sweta x Gaurav	192.57**
	T-397 x Gaurav	129.03**
	Gaurav x 1/76	98.84**
	Shubhra x 1/76	49.35**
No. of capsules/plant	Gaurav x 1/76	240.69**
	Shubhra x 1/76	228.10**
	N-3 x 1/76	188.04**
	T-397 x Gaurav	183.78*
No. of seeds/capsule	R-17 x Gaurav	21.86**
	Gaurav x 1/76	20.48**
	Shubhra x 1/76	14.40**
	N-3 x EC 41498	10.36**
100-seed weight	R-7 x Shubhra	25.98**
	N-3 x R-17	20.71**
	R-17 x EC 41498	20.63**
	Jawahar 23 x R-17	19.31**
Seed yield/plant	Gaurav x 1/76	295.62**
	EC 41498 x 1/76	229.22**
	N-3 x T-397	176.08**
	Shubhra x 1/76	119.37**

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

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Effect of zinc sources and levels on sunflower (*Helianthus annuus* L.) hybrid in Alfisol

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ABSTRACT

A field experiment was conducted at Indian Institute of Oilseeds Research during the rainy season of 2014 with sunflower (*Helianthus annuus* L.) hybrid DRSH-1 as a test crop on Alfisol. Three different zinc sources ($ZnSO_4.7H_2O$, $ZnSO_4.H_2O$ and Zn-EDTA) and levels (10, 15 and 20 kg/ha) with recommended dose of N, P_2O_5 and K_2O @ 90, 60 and 30 kg/ha were applied to soil to study the plant parameters i.e., plant height, stem girth, head diameter at 90 days after sowing. Seed yield was recorded at harvest. Plant height, stem girth and head diameter increased up to 20 kg Zn/ha application. Highest plant height (170.3 cm) and greater head diameter (17.6 cm) and highest stem girth (8.1 cm) and seed yield (1680 kg/ha) were achieved with the application of 20 kg $ZnSO_4.H_2O$/ha.

Keywords: Alfisol, Head diameter, Seed yield, Sunflower, Zinc levels, Zinc sources

Sunflower (*Helianthus annuus* L.) is an important nontraditional oilseed crop. The present acreage under sunflower cultivation in India is about 6.91 lakh ha area with production and productivity of 5.47 lakh t. and 791 kg/ha, respectively during 2013-14 (Padmaiah *et al.,* 2015). Sunflower can play a major role in meeting the shortage of edible oils in the country. Among oilseed crops, sunflower has gained much popularity because of its short duration, photo-insensitivity, wider adaptability to different agro-climatic regions and soil types. In semi-arid soils, especially Alfisol, among the several reasons attributed for its low production, deficiency of zinc an important micronutrient for crop growth has attained macro importance. Further, use of the micronutrient mixture for foliar sprays and chelates have led to very little residual fertility so hidden hunger of Zn is emerging wide spread. Zinc deficiency was reported in these soils (Srinivasa Rao and Sudha Rani, 2013; Murthy *et al.,* 2009). Hence, an attempt was made in the present investigation to find out an optimum dose and source of zinc for the sunflower hybrid DRSH-1 by studying yield attributes and seed yield.

A field experiment was conducted at Indian Institute of Oilseed Research, Rajendranagar, Hyderabad during the rainy season of 2014. The soil of the experimental site was sandy loam in texture, moderately alkaline with pH 8.3, EC 0.082 dS/m, very low in organic carbon (0.26%), low in available nitrogen (150.68 kg/ha), available phosphorus (9.56 kg/ha), medium in available potassium (193.9 kg/ha), medium in sulphur (25.2 kg/ha) and deficient in DTPA extractable zinc (0.48 mg/kg). Recommended dose of nitrogen, phosphorus (P_2O_5) and potassium (K_2O) were applied at 90:60:30 kg/ha through urea, diammonium phosphate and muriate of potash, respectively.

The treatment details are presented in table 1. Randomised block design with three replications was adopted. The nitrogen was equally split and applied with 2nd and 3rd irrigation while, all phosphorus, potassium and zinc were applied as basal dose. The sunflower hybrid DRSH-1 was sown in 60 cm x 30 cm spacing. The crop was kept free of weeds by manual weeding. Yield attributes like plant height, stem girth and head diameter were recorded at 90 days after sowing (DAS) and seed yield at harvest. All the parameters were analysed by following standard statistical procedure (Gomez and Gomez, 2012).

The data on plant height indicated that lowest and highest values being recorded in T_1 and T_7 at 90 DAS, respectively. Increase in plant height from 151.9 cm to 185.5 cm in treatments received 0 and 20 kg $ZnSO_4.H_2O$ kg/ha, respectively was observed. Among the different zinc levels and sources though there was an increase in plant height from 0 to 20 kg Zn/ha zinc application had not shown any significant effect on plant height. Similar results were found by Ahmadi (2010) and Khan *et al.* (2009).

Among different sources and levels of zinc, higher stem girth was (8.1 cm) recorded in T_7 (RDF+$ZnSO_4.H_2O$ @ 20 kg/ha) at 90 DAS might be ascribed to the adequate supply of nutrients that resulted in greater plant height, higher production of photosynthates and higher dry matter production in stem. Stem girth is an inherent character of plant which does not effect due to external factors. Such as environmental as well as agronomic factors.

At 90 DAS, among the three sources of zinc, application of zinc through zinc sulphate monohydrate @ 20 kg/ha gave significantly maximum head diameter (17.6 cm) over other

[1]ICAR-Indian Institute of Oilseeds Research, Hyderabad-500 030

sources, which was on par with 10, 15 and 20 kg $ZnSO_4.7H_2O$/ha. The lowest head diameter (13.2 cm) was observed in control. Among zinc levels, application of zinc at 20 kg/ha resulted in significantly maximum head diameter (17.6 cm) than at low levels (10, 15 kg/ha) but were on par with each other.

Zinc application was effective on head diameter and increased capitulum growth because it is important for proper functioning of many enzyme systems, synthesis of nucleic acids and normal crop development and growth (Ebrahimian *et al.,* 2010). These results are in agreement with the observations of Khan *et al.* (2009). Highest head diameter (17.8 cm) was recorded in treatment that received 10 kg zinc and further suggested that greater head diameter increase can be achieved with high dose of zinc alone or in combinations with other micronutrients.

The results revealed that there was significant increase in seed yield of sunflower with increasing levels of zinc. Among various sources, RDF+$ZnSO_4.H_2O$ @ 20 kg/ha recorded significantly highest seed yield as compared to control. Seed yield was lowest at T1:control (1122 kg/ha) and highest at T_7: $ZnSO_4.H_2O$ @ 20 kg/ha (1680 kg/ha) with recommended dose of N, P, K for sunflower. On an average, the per cent increase in seed yield was 49% in the treatment T_7 over the control T_1.

Seed yield is the function of several growth parameters (plant height, leaf area index and dry matter accumulation), yield attributing characters *viz.,* head diameter, number of filled seeds, test weight and yield/plant. Among different levels and sources (namely $ZnSO_4.H_2O$, $ZnSO_4.7H_2O$ and Zn-EDTA), the $ZnSO_4.H_2O$ @ 20 kg/ha has shown (Table 1) better influence on seed yield. Greater head diameter, higher number of filled seeds/head and test weight due to adequate supply of recommended dose of fertilizers with zinc application had positively reflected in higher seed yield. Head diameter is the most important attributing character, which improves the seed yield by providing maximum number of florets for higher seed set. The cumulative effect of all these growth and yield components were reflected on seed yield.

Other studies have also revealed that the application of Zn significantly increased seed yield (Riley *et al.,* 2000). The highest seed yield was obtained with zinc application of 60 kg Zn/ha. In increasing Zn levels provides better conditions for the pod formation and increases number of seeds per pod in rapeseed (Ahmadi, 2010).

Increase in seed yield may be attributed to the fact that soil under investigation was deficient in zinc and application of zinc and its role of zinc in biosynthesis of indole acetic acid (IAA) further its role in initiation of primordial for reproductive parts and partitioning of photosynthates towards them etc. which resulted in better flowering and fruiting. The finding of present investigations are also supported by Jat and Mehra (2007) and Deo and Khandelwal (2009).

Table 1 Effect of different sources and levels of zinc on plant height, stem girth, head diameter and seed yield of sunflower hybrid DRSH-1

	Treatment	Plant height (cm)	Stem girth (cm)	Head diameter (cm)	Seed yield (kg/ha)
T_1	Control (RDF-90:60:-30)	151.9	7.2	13.1	1122
T_2	RDF + $ZnSO_4.7H_2O$ @ 10 kg/ha	171.1	7.6	16.0	1319
T_3	RDF + $ZnSO_4.7H_2O$ @ 15 kg/ha	172.7	7.6	16.2	1365
T_4	RDF + $ZnSO_4.7H_2O$ @ 20 kg/ha	176.3	7.9	16.6	1377
T_5	RDF + $ZnSO_4.H_2O$ @ 10 kg/ha	179.0	7.3	15.5	1395
T_6	RDF + $ZnSO_4.H_2O$ @ 15 kg/ha	181.6	7.9	16.7	1453
T_7	RDF + $ZnSO_4.H_2O$ @ 20 kg/ha	185.5	8.1	17.6	1680
T_8	RDF + Zn-EDTA @ 10 kg/ha	160.5	7.3	13.3	1168
T_9	RDF + Zn-EDTA @ 15 kg/ha	163.8	7.4	13.4	1236
T_{10}	RDF + Zn-EDTA @ 20 kg/ha	168.7	7.6	13.5	1283
	SEm ±	7.5	7.5	0.68	71.9
	CD (P =0.05)	NS	NS	2.04	215.2

RDF- $N:P_2O_5:K_2O$ (90:60:30)

Siddiqui *et al.* (2009) reported that the application of zinc @ 15 kg/ha gave superior seed yield (2251 kg/ha) beyond this dose, there was no further significant increase in sunflower seed yield. The result of the experiment are supported by Patil *et al.* (2006) also reported that soil application of $ZnSO_4$ (10 and 20 kg/ha) was the best treatment in increasing seed yield and quality of sunflower under black soil conditions. However, in the present study 20 kg/ha $ZnSO_4.H_2O$ gave higher seed yield in Alfisols. One probable reason could be the increase in solubility of zinc in soil with the application of sulphur. In the present study, higher seed yield recorded in $ZnSO_4.H_2O$ could be due to the

better utilization of bioavailable Zn from this source compared to the other source.

Riley *et al.* (2000) revealed that Zn-treated plants exhibited a significant increase in yield components compared to control. It is evident that this element plays important role in plants. The increase in yield induced by Zn treatments will markedly affect plant growth and development. The increased in yield attributes and yield of sunflower due to zinc may be attributed basically to the reason that Zn shows beneficial effect on chlorophyll content and so it indirectly affect the photosynthesis and reproduction.

Thus, from the above field studies, it can be inferred that soil application of 20 kg $ZnSO_4.H_2O$/ha in zinc deficient Alfisol is adequate to obtain higher seed yield (1680 kg/ha) of sunflower hybrid (DRSH-1).

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Response of sesame (*Sesamum indicum* L.) to micronutrients and NPK levels on the growth, yield and nutrients uptake in coastal sandy soil

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ABSTRACT

A pot experiment was conducted to find out the effect of NPK levels and micronutrients *viz.,* Zn and Mn on the yield and nutrients uptake by sesame in coastal sandy soil. The experimental soil was sandy texture with pH 8.41, low in organic carbon, available N and P, medium in available K and deficient in Zn and Mn. The treatments consisted of different levels of NPK and micronutrients. The experiment was laid out in a factorial completely randomized design with three replications, using sesame variety TMV 7. The results of the study indicated that application of 150% NPK + $ZnSO_4$ @ 25 kg/ha + $MnSO_4$ @ 5 kg/ha recorded the highest seed and stalk yield of 52.4 and 184.7 g/pot, respectively. However, it was found to be on par with the treatment which received 125% NPK + $ZnSO_4$ @ 25 kg/ha + $MnSO_4$ @ 5 kg/ha and recorded the seed and stalk yield of 50.9 and 179.5 g/pot, respectively. Application of Zn and Mn along with NPK improved the uptake of micronutrients by sesame in addition to the yield and oil content.

Keywords: Coastal Sandy Soil, Manganese, NPK, Sesame, Uptake, Yield, Zinc

Sesame (*Sesamum indicum* L.) is one of the important crops grown in coastal sandy soil. The low productivity of sesame in coastal sandy soil has been attributed to the imbalanced nutritional status of plant, particularly, the inadequate availability of nutrients especially micronutrients. The poor retention and leaching of nutrients in sandy soil necessitates the increased rate of nutrients application especially NPK in such soil as compared to normal soils. Among the micronutrients, Zn and Mn are more common by deficient in coastal sandy soil. The micronutrients play a vital role in sesame production and improving the quality (Jain *et al.,* 2000; Elayaraja, 2008). Micronutrients are recognized as a key element for protein synthesis and it plays an important role in various enzymatic activities and in the development of plant growth and synthesis of oil in sesame crop (Singaravel *et al.,* 2001). Hence, the present study was undertaken to establish the influence of micronutrients and NPK levels on the sesame yield and nutrient uptake.

A pot experiment was carried out in the Department of Soil Science and Agricultural Chemistry, Annamalai University, Annamalai Nagar during April - June 2013, to find out the influence of NPK and micronutrients on the growth, yield and nutrients uptake by sesame in coastal sandy soil. The treatments consisted of Control (A_1); 75% NPK (A_2); 100% NPK (A_3); 125% NPK (A_4) and 150% NPK (A_5) and different micronutrients *viz.,* Control (B_1); $ZnSO_4$ @ 25 kg/ha (B_2); $MnSO_4$ @ 5 kg/ha (B_3) and $ZnSO_4$ @ 25 kg/ha + $MnSO_4$ @ 5 kg/ha (B_4). The experiment was studied in a factorial completely randomized design with three replications, using sesame variety TMV 7. Farm yard manure @ 12.5 t/ha was applied to all the treatments. The experimental soil analysed sandy texture with pH 8.41; EC 1.65 d S/m; organic carbon 2.3 g/kg; zinc 0.70 mg/kg and manganese status of 0.96 mg/kg. The alkaline $KMnO_4$-N; Olsen-P and NH_4OAc-K, were low (134.1 kg/ha), low (9.3 kg/ha) and medium (153.5 kg/ha) status, respectively. Calculated quantity of nitrogen (35 kg N/ha), phosphorus (23 kg P_2O_5/ha) and potassium (23 kg K_2O/ha) were applied through urea, super phosphate and muriate of potash, respectively as per the treatment. Required quantities of $ZnSO_4$ and $MnSO_4$ as per the treatment were incorporated just before sowing. Seed and stalk yield at maturity stage were recorded in all the treatments. The seed and stalk samples were collected at harvest, dried at 70°C, powdered and diacid extract was prepared. The concentrations of nutrients *viz*., N, P, K, Zn and Mn were estimated using the standard procedure as outlined by Jackson (1973) and uptake were calculated.

The results clearly indicated that, application of different levels of NPK and micronutrients either Zn or Mn and or both favourably increased the growth, yield characters and yield of sesame (Table 1). Among the various levels of NPK, application of 150% NPK recorded the highest mean values in respect of plant height, number of branches/plant and dry matter production, yield characters like number of capsules/plant, number of seeds/capsule and 1000-seed weight of sesame. However, it was found to be on par with 125% NPK application.

Table 1 Influence of micronutrients and levels of NPK on the growth, yield characters and yield of sesame

Treatments	Growth characters			Yield characters			Yield (g /pot)	
	Plant height (cm)	Number of branches/ plant	Dry matter production (g/pot)	Number of capsules/plant	Number of seeds/capsule	1000-seed weight (g)	Seed	Stalk
A_1B_1	53.6	3.36	126.1	26.8	37.1	2.11	33.1	112.5
A_1B_2	69.4	4.70	145.6	30.3	39.3	2.31	36.9	134.5
A_1B_3	74.0	5.47	154.3	32.1	41.2	2.41	39.4	142.7
A_1B_4	75.1	5.94	167.4	34.9	43.1	2.58	42.2	148.2
A_2B_1	63.4	4.23	141.9	29.3	39.1	2.28	36.7	126.9
A_2B_2	78.3	5.31	159.8	32.4	41.3	2.42	39.4	144.5
A_2B_3	82.5	6.12	167.8	34.6	43.4	2.55	42.4	152.6
A_2B_4	85.7	6.72	180.8	37.2	45.2	2.72	44.9	159.7
A_3B_1	72.0	4.76	154.7	31.7	42.0	2.43	40.3	139.1
A_3B_2	82.7	5.79	169.6	34.5	44.3	2.56	42.2	153.1
A_3B_3	90.3	6.65	179.6	36.9	46.4	2.66	44.9	162.1
A_3B_4	95.0	7.15	192.0	39.3	47.3	2.85	47.4	170.3
A_4B_1	82.5	5.51	164.5	33.9	44.0	2.60	43.9	149.0
A_4B_2	91.6	6.58	179.6	37.7	46.3	2.71	45.7	161.7
A_4B_3	97.6	7.46	190.8	40.1	48.4	2.86	47.9	170.6
A_4B_4	106.7	8.41	202.5	42.7	50.4	3.00	50.9	179.5
A_5B_1	84.3	5.70	167.6	35.9	45.0	2.66	44.4	150.1
A_5B_2	92.4	6.79	181.2	38.8	47.3	2.77	47.3	163.6
A_5B_3	99.8	7.64	194.1	41.3	49.3	2.90	49.8	173.5
A_5B_4	108.3	8.56	204.6	43.8	51.3	3.05	52.4	184.7

	S.Ed	CD*	S.Ed	CD*	S.Ed	CD*	S.Ed	CD*	S.Ed	CD*	S.Ed	CD*	S.Ed	CD*	S.Ed	CD*
A	1.88	3.78	0.13	0.28	4.20	8.45	0.87	1.75	0.97	1.95	0.03	0.07	1.07	2.17	3.42	6.89
B	2.09	4.22	0.15	0.31	4.52	9.10	0.94	1.89	1.00	2.01	0.03	0.08	1.14	2.31	3.53	7.10
A×B	2.14	4.31	0.17	0.36	4.90	9.85	1.00	2.01	1.06	2.15	0.04	0.10	1.21	2.45	4.15	8.35

A_1 - Control; A_2 - 75% NPK; A_3 - 100% NPK; A_4 - 125% NPK and A_5 - 150%

B_1 - Control; B_2 - $ZnSO_4$ @ 25 kg/ha; B_3 - $MnSO_4$ @ 5 kg/ha and B_4 - $ZnSO_4$ @ 25 kg/ha + $MnSO_4$ @ 5 kg/ha

The sesame responded well for the micronutrients application. Irrespective of the level of NPK, addition of either Zn or Mn and or both significantly increased growth and yield characters of sesame. The treatment (B_4) which received combined application of both Zn and Mn recorded the highest mean values of growth characters *viz.,* plant height, number of branches/plant and dry matter production, yield characters like number of capsules/plant, number of seeds/capsule and 1000-seed weight, respectively.

The interaction effect between NPK and micronutrients in improving growth and yield characters of sesame was significant. The combined application of $ZnSO_4$ @ 25 kg/ha + $MnSO_4$ @ 5 kg/ha along with 150% NPK (A_5B_4) recorded the highest growth characters like plant height (108.3 cm), number of branches/plant (8.56) and dry mater production (204.6 g/pot); yield characters like number of capsule/plant (43.8), number of seeds/capsule (51.3) and 1000-seed weight (3.05 g), respectively. However, it was found to be on par with treatment (A_4B_4) which received 125% NPK and $ZnSO_4$ @ 25 kg/ha + $MnSO_4$ @ 5 kg/ha, which recorded a value of 106.7 cm plant height, 8.41 number of branches/plant, 202.5 g/pot of dry matter production, 42.7 number of capsule/plant, 50.4 number of seeds/capsule and 3.0 g of 1000-seed weight, respectively.

The increased growth of sesame in the combined application of $ZnSO_4$ + $MnSO_4$ applied treatment might be due to significant improvement in N fixation. Zinc enhanced the plant growth through auxin production and activation of several enzyme systems as evidenced by Shanker *et al.* (1999) and Javia *et al.* (2010). Manganese influenced the nitrogen and carbohydrate metabolism of plants which might have contributed for the better plant growth (Singaravel *et al.,* 2001). The beneficial influence of micronutrients on the growth and yield characters of sesame might be due to activation of various enzymes and efficient utilization of applied nutrients, especially nitrogen and phosphorus resulting in increased growth and yield characters of sesame as reported by Chaurasia Neetha Jain and Namrata Jain (2009).

Though the increasing levels of NPK increased yield of sesame, application of 150% NPK registered the highest yield. Application of Zn and Mn either alone or in combination with NPK favourably improved the yield of sesame. However, the combined application of NPK along with micronutrients registered higher yield as compared to the treatments which received either NPK or micronutrients alone.

The interaction effect due to NPK and micronutrients with the yield of sesame was significant. The highest seed and stalk yield of 52.4 and 184.7 g/pot was recorded with the treatment supplied with 150% NPK along with $ZnSO_4$ @ 25 kg/ha + $MnSO_4$ @ 5 kg/ha (A_5B_4). This was comparable

with treatment which received 125% NPK + $ZnSO_4$ and $MnSO_4$ (A_4B_4) application which recorded 50.9 g/pot of seed and stalk yield of 179.5 g/pot, respectively.

The increased sesame yield with the application of Zn and Mn along with NPK might be attributed to the rapid mineralization of N, P and K from inorganic fertilizers and steady supply of these nutrients to the crop at the critical stages as opined by (Subramaniyan *et al.,* 2001). In addition, Zn and Mn through activation of various enzymes and increased basic metabolic rate in plants facilitated the synthesis of nucleic acids and hormones, which in turn enhanced the seed yield due to greater availability of nutrients and photosynthates. These results are in agreement with those of Narkhede *et al.* (2001) and Chaurasia Neetha Jain and Namrata Jain (2009).

Sandy soil exhibits very low nutrient status because of low organic carbon and poor physical properties. In the present study, the influence of micronutrients and increasing NPK levels in enhancing better nutrition of sesame with respect to major and micronutrients uptake was well evidenced (Table 2). Both the micronutrients *viz.,* $ZnSO_4$ and $MnSO_4$ either alone or in combination with NPK proved their usefulness in increasing the uptake of major nutrients. However, the effect of combined application of $ZnSO_4$ @ 25 kg/ha + $MnSO_4$ @ 5 kg/ha was much pronounced. The highest uptake of NPK by seed and stalk were recorded by the treatment which received 150 per cent NPK along with $ZnSO_4$ + $MnSO_4$ application (A_5B_4). However, this was found to be on par with treatment supplied with 125 per cent NPK along with $ZnSO_4$ and $MnSO_4$ (A_4B_4).

Table 2 Influence of micronutrients and levels of NPK on the major and micronutrients uptake by sesame

Treatments	Major nutrients (mg/pot)						Micronutrients (mg/pot)			
	N uptake		P uptake		K uptake		Zn uptake		Mn uptake	
	Seed	Stalk	Seed	Stalk	Seed	Stalk	Seed	Stalk	Seed	Stalk
A_1B_1	759	614	141	189	324	653	3.13	2.16	3.64	2.05
A_1B_2	855	678	159	208	371	740	4.05	2.76	4.11	2.40
A_1B_3	923	730	163	221	402	785	3.72	2.44	4.37	2.77
A_1B_4	971	772	175	238	423	828	4.37	2.89	4.72	3.08
A_2B_1	814	661	154	206	350	714	3.58	2.45	3.99	2.36
A_2B_2	902	714	173	212	397	788	4.37	2.98	4.41	2.73
A_2B_3	966	773	160	236	425	827	4.01	2.69	4.70	3.07
A_2B_4	1022	821	188	249	448	883	4.68	3.14	5.03	3.39
A_3B_1	915	744	167	219	379	776	3.92	2.67	4.32	2.69
A_3B_2	961	793	182	234	416	842	4.64	3.18	4.69	3.03
A_3B_3	1085	854	193	248	444	889	4.34	2.92	4.99	3.35
A_3B_4	1087	913	198	263	467	939	4.96	3.35	5.29	3.64
A_4B_1	1001	819	174	230	401	831	4.24	2.88	4.63	2.97
A_4B_2	1066	866	190	244	432	890	4.94	3.39	4.96	3.32
A_4B_3	1133	929	202	259	461	940	4.64	3.11	5.29	3.64
A_4B_4	1184	978	210	272	483	892	5.46	3.69	5.67	4.01
A_5B_1	1015	830	177	232	409	836	4.55	3.07	4.92	3.23
A_5B_2	1084	888	192	247	439	893	5.22	3.58	5.25	3.58
A_5B_3	1149	940	204	262	465	944	4.90	3.33	5.56	3.89
A_5B_4	1207	989	213	274	487	898	5.53	3.78	5.84	4.18

	S.Ed	CD*	S.Ed	CD*	S.Ed	CD*	S.Ed	CD*	S.Ed	CD*	S.Ed	CD*	S.Ed	CD*	S.Ed	CD*	S.Ed	CD*	S.Ed	CD*
A	24.7	49.8	19.5	39.3	3.44	6.92	4.01	8.07	6.8	13.7	16.8	33.8	0.09	0.19	0.06	0.13	0.20	0.09	0.19	0.20
B	25.9	52.1	20.9	42.2	3.73	7.50	4.57	9.20	8.0	16.2	18.0	36.2	0.11	0.24	0.07	0.16	0.24	1.00	0.21	0.24
A×B	28.6	57.5	23.2	46.7	4.42	8.89	4.85	9.75	9.2	18.5	19.5	38.5	0.12	0.26	0.08	0.18	0.25	0.11	0.24	0.25

A_1 - Control; A_2 - 75% NPK; A_3 - 100% NPK; A_4 - 125% NPK and A_5 - 150%

B_1 - Control; B_2 - $ZnSO_4$ @ 25 kg/ha; B_3 - $MnSO_4$ @ 5 kg/ha and B_4 - $ZnSO_4$ @ 25 kg/ha + $MnSO_4$ @ 5 kg/ha

The increased uptake of major nutrients was mainly due to the fact that the micronutrients like zinc and manganese are involved in nitrogen fixation and translocation into plant parts, which might have lead to higher dry matter production. The higher nitrogen absorption may also be due to stimulatory effect of zinc and manganese on nitrogen uptake (Shehu *et al.,* 2010). The higher P uptake may be due to the increased dose of applied P fertilizers which ultimately resulted in better root growth and increased physiological activity of roots to absorb more phosphorus (Salwa *et al.,* 2010). The stimulatory effect of Mn and Zn in absorption of potassium might be reason for increased K uptake. These results are in accordance with the findings of Elayaraja and Singaravel (2012).

Micronutrients play a significant role in sustaining the sesame yield. In the present study, both the micronutrients evaluated along with different levels of NPK fertilizers was significantly increased the micronutrients uptake by sesame. The uptake of Zn and Mn by sesame increased with increased level of NPK. The highest mean NPK uptake was noticed with treatment applied with 150% NPK (A5). However, it was found to be equally efficacious with

application of 125% NPK (A_4). Among the micronutrients, combined application of Zn and Mn registered a higher Zn and Mn uptake as compared to the treatment which received either Zn or Mn alone.

The interaction effect due to the application of NPK and micronutrients on Zn and Mn uptake by sesame was significant. The combined application of 150 per cent NPK and $ZnSO_4$ @ 25 kg/ha + $MnSO_4$ @ 5 kg/ha (A_5B_4) recorded the highest Zn uptake of 5.53 and 3.78 mg/pot and Mn uptake of 5.84 and 4.18 mg/pot by seed and stalk, respectively. This was equally efficient with treatment (A_4B_4) which received 125 per cent NPK and $ZnSO_4$ @ 25 kg/ha + $MnSO_4$ @ 5 kg/ha and recorded the Zn uptake of 5.46 and 3.69 mg/pot and Mn uptake of 5.67 and 4.01 mg/pot by seed and stalk, respectively.

The application of $ZnSO_4$ @ 25 kg/ha + $MnSO_4$ @ 5 kg/ha along with 125 per cent NPK significantly promoted the nutrition of Zn and Mn by sesame. The increased nutrient uptake might be due to supply of these nutrients through micronutrient fertilizers. The earlier reports of Singaravel *et al*. (2001) and Purushottam (2005) support the present findings.

The results of the present investigation clearly indicated that application of 125 per cent NPK + $ZnSO_4$ @ 25 kg/ha + $MnSO_4$ @ 5 kg/ha would be beneficial for increasing the growth, yield and nutrients uptake by sesame.

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Identification of *Podosphaera xanthii* causing powdery mildew on sesame (*Sesamum indicum* L.)

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ABSTRACT

Powdery mildew is one of the severe diseases on sesame (*Sesamum indicum* L.) causing high yield loss. It occurs on epidemic scale during flowering and post flowering stages under favourable weather conditions of high humidity and low night temperature. In contrary, one accession of sesame (Tripura local) from Meghalaya was heavily infected with powdery mildew during peak summer of 2015. Microscopic analysis of the anamorph and molecular characterization using ITS primers specific to the powdery mildew confirmed the causal organism. Use of species specific ITS primers resulted in a 454 bp amplicon specific to *Podosphaera.* Blast analysis of the sequence showed highest similarity with *Podosphaera xanthii* confirming the pathogen.

Keywords: *Podosphaera xanthii,* Powdery mildew, *Sesamum indicum*

Sesame (*Sesamum indicum* L.) is an important and ancient oilseed crop having its origin in Africa. It is a diploid species (2n = 26) grown in tropical and subtropical areas throughout the world (Kun *et al.,* 2014). Currently, Myanmar, India, China, Nigeria are the world's largest producers of sesame, followed by Mozambique, Niger, Ethiopia, Chad, Thiland, Mexico, Bangaladesh and Paraguay (FAOSTAT, 2013). India is the second largest producer of sesame with an area of 1.86 m ha with total production of 636000 metric tons and productivity of 341.9 kg/ha contributing around 19 per cent in the world's total production (FAOSTAT, 2013). In India, it is predominantly grown in West Bengal, Rajasthan, Madhya Pradesh, Gujarat and Uttar Pradesh during different seasons.

Although sesame is widely used for different purposes, the crop suffers from low yield due to its low harvest index, disease susceptibility, seed shattering, and indeterminate growth habit (Ashri, 1998). Among the biotic stresses, powdery mildew is one of the economically important diseases decreasing sesame yields significantly from 25 to 50 per cent depending upon the level of severity (Venkata *et al.,* 2013). In the experimental plots of the Indian Institute of Oilseeds Research, Hyderabad, severe infection of powdery mildew on one accession (Tripura local) of sesame from Meghalaya was observed under extreme hot condition (day temperature 42°C; night temperature 35°C) among 350 genotypes raised. So far, different fungal species have been reported *viz., Erysiphe cichoracearum* (Reddy and Haripriya, 1990), *E. orontii* (Rajpurohit, 1993), *Oidium* sp. (Venkatakrishnaiya, 1958), *O. erysiphoides* (Mehta, 1951; Roy, 1965), *O. sesami* (Puzari *et al.,* 2006), *O. mirabilifolii* (Srinivasulu *et al.,* 2003), *Sphaerotheca fuliginea* (Gemawat and Verma, 1972; Lawrence, 1951), and *Leveillula taurica* (Patel *et al.,* 1949) to cause powdery mildew on sesame. All these fungal species are morphologically similar. Hence, an attempt was made to characterize the pathogen using ITS sequences developed by Chen *et al.* (2008). Also, an experiment was carried out to check the cross infectivity of powdery mildew of sesame on sunflower and *vice versa* for development of appropriate management techniques.

Leaves of sesame cv. Tripura local infected with powdery mildew were collected from the experimental plot of Indian Institute of Oilseeds Research, Hyderabad. For microscopic observation of the pathogen, the conidia were dislodged along with the hyphae. The conidia were stained with lactophenol cotton blue and observed under light microscope (Leitz, Diaplan). Both pathogenicity tests and cross-infectivity studies were carried out using the dusting method as described earlier (Prathap Reddy *et al.,* 2013). In this method, conidia were dusted on test leaves moistened with water and covered with zip-loc bags for 72 hours after which the covers were removed. Observations on the pathogen growth and spread were observed at 3 days interval up to 21 days following infection. For these tests, the sesame variety GT-10 and sunflower cultivar PS 2023B (highly susceptible) were used.

Powdery mildew infected leaves of sunflower cv. Morden served as reference for molecular analysis. For molecular characterization, total DNA was extracted from infected sesame and sunflower leaves using cetyl trimethyl ammonium bromide (CTAB) method described by Namba *et al.* (1993) with minor modification. The DNA concentration was determined using the NanoVue Plus spectrophotometer. Powdery mildew-specific ITS universal primer pair PN23 (5'-CAC CGC CCG TCG CTA CTA CCG-3')/PN34 (5'-TTG CCG CTT CAC TCG CCG TT-3') primers, and primer sets

S1 (5'-GGA TCA TTA CTG AGC GCG AGG CCC CG-3')/S2 (5'-CGC CGC CCT GGC GCG AGA TAC A-3'), G1 (5'-TCC GTA GGT GAA CCT GCG GAA GGA T-3')/G2 (5'-CAA CAC CAA ACC ACA CAC ACG GCG-3'), and L1 (5'-CCC TCC CAC CCG TGT CGA CTC GTC TC-3')/L2 (5'-CTG CGT TTA AGA GCC GCC GCG CCG AA-3'), specific to the ITS regions of *Podosphaera xanthii* (PX), *Golovinomyces cichoracearum* (GC), and *Leveillula taurica* (LT), respectively developed by Chen *et al.* (2008) were used. The PCR amplification was carried out in 15 µl of reaction containing 0.4 µM of each primer, 0.15 mM dNTPs, 1 U Taq DNA polymerase, 1X PCR buffer with 1.5 mM $MgCl_2$ (Bangalore Genei, India), and 8 ng of template DNA. Amplification was performed in thermal cycler (Applied Biosystems GeneAmp 9700) using the following amplification conditions: 5 min at 94°C for the initial denaturation, followed by 35 cycles reaction profile involving 40 sec of denaturation at 94°C, 1 min of annealing at 62°C, and 1.5 min of extension at 72°C with a final extension at 72°C for 5 min. The PCR amplified products were observed on 2% agarose gel stained with ethidium bromide and documented using the syngen gel documentation system. The amplified products of sesame and sunflower were purified and sequenced with a pair of primers S1/S2 and G1/G2, respectively at Bioserve Biotechnologies, India. Nucleotide sequences read with Chromas software (http://www.technelysium.com.au/chromas lite.html) were subjected to BLAST search (www.ncbi.nlm.gov) and the sequence of sesame was deposited with NCBI Genbank.

Unusually very severe infection of powdery mildew was observed in one accession of sesame (Tripura local) among 350 genotypes raised in the farm (Fig. 1a). Powdery mildew generally infects at flowering and post flowering stages but in this genotype, the whole plant was vulnerable to the pathogen attack from the vegetative stage itself. The genotype is highly distinct with white coloured small poppy type seeds. It is a late maturing type with initiation of flowering at 65 DAS unlike other genotypes where flowering starts at 30 DAS. The plant had vigorous growth with bushy growth with 4 to 5 branches; stem and leaves were highly pubescent, leaves succulent, dark green, smooth, very large, lower leaves highly serrated, medium-sized capsules (2-3 cm) with poor capsule setting.

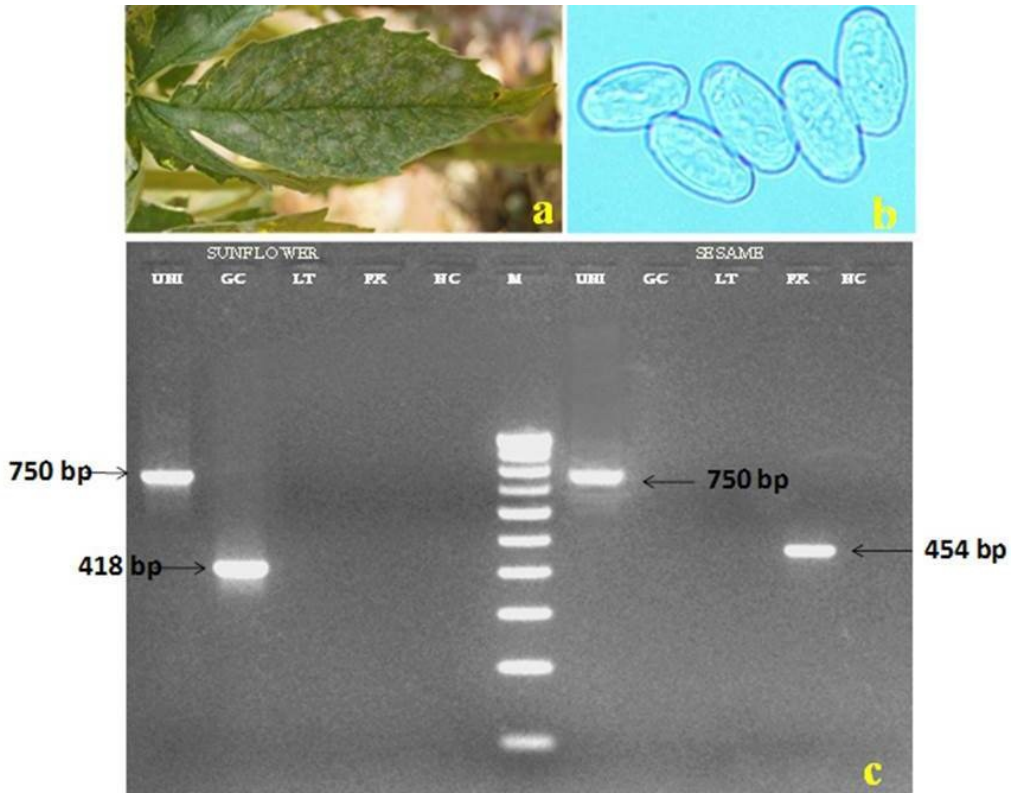

Fig. 1a. Powdery mildew infected leaf of sesame (Tripura local), b. Conidia of *P. xanthii,* c. PCR confirmation of powdery mildew genera in sunflower and sesame using ITS specific primer (M 100 bp marker, NC negative control, UNI amplification with universal primer pair for powdery mildew, GC amplification with ITS primers specific to *G. cichoracearum,* LT amplification with ITS primers specific to *L. taurica,* PX amplification with ITS primers specific to *P. xanthii*).

The microscopic examination of the powdery mildew fungus showed oidium type conidiospore with cylindrical fibrosin bodies of conidia (Fig. 1b) which were identical to *Podosphaera xanthii* Castagne Braun & Shishkoff. Conidiophores were erect, septate, conidia hyaline, dolliform shaped, short chains, 23 x 11 µm. Molecular analysis with universal primer pair produced an amplicon of 750 bp in both sesame and sunflower (Fig. 1c). PCR amplified products with the universal primer pairs produced an amplicon of 750 bp which confirms the organism as powdery mildew (Chen *et al.,* 2008). PCR amplification with ITS primers specific to the three genera *viz., Golovinomyces, Leveillula* and *Podosphaera* resulted in a 454 bp amplicon with S1/S2 primers in sesame while there was no amplification with G1/G2 and L1/L2 primers which indicated that the organism causing powdery mildew in sesame is *Podosphaera xanthii.* The powdery mildew causal organism in sunflower is predominantly *Golovinomyces cichoracearum* and the present analysis confirmed the results wherein a 418 bp amplicon was obtained with G1/G2primers (Fig. 1c). The sequence of *P. xanthii* isolate (Hyderabad) on sesame has been assigned the NCBI Accession No. as KT229645. Sequence analysis of the PCR amplified products of sesame showed 98% similarity with *P. xanthii* (Accession No. LC012888.1). For screening of germplasm and development of disease management techniques, it is essential to detect the causal organism accurately. In most of the earlier studies, the pathogen was identified based on disease symptoms or conidial characters which are labour intensive and require considerable experience in differentiating the morphologies of the powdery mildews. In this study, we have used molecular analysis and the pathogen causing powdery mildew in sesame was confirmed to be *Podosphaera xanthii* Castagne Braun & Shishkoff (=*Sphaerotheca fuliginea* auct p.p.).

Pathogenicity test showed growth of *P. xanthii* isolated from Tripura local on GT-10 in sesame and *G. cichoracearum* on PS2023B. However, in cross-infectivity studies, there was no infection of *P. xanthii* of sesame on sunflower and *G. cichoracearum* of sunflower on sesame. Reports of infection in sesame by *Erysiphe cichoracearum* (syn *Golovinomyces cichoracearum*) has been reported earlier (Reddy and Haripriya, 1990) and likewise reports on infection of *Podosphaera xanthii* (syn *Sphaerotheca fuliginea*) on sunflower are also available (Saliman *et al*., 1982; Chen *et al*., 2008). But lack of cross infectivity could be due to different biotypes of the pathogens as reported by Saliman *et al*. (1982).

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