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CONTENTS

Review Article

Hyperspectral imaging applications in rapeseed and mustard farming — Abhinav Kumar, Vandana Bharti, Vinod Kumar, P D Meena and G Suresh — 1

Research Papers

Quantitative trait loci analysis for seed quality traits in sunflower (*Helianthus annuus* L.) recombinant inbred lines — J Vanitha, N Manivannan, R Chandirakala and S Abirami — 9

Inheritance of pod shattering in soybean [*Glycine max* (L.) Merrill.] — Dilip S Thakare, Vivek P Chimote, M P Deshmukh, R C Rokade and A T Adsul — 15

Crop diversification with castor (*Ricinus communis* L.) for enhancing the productivity, profitability and resource conservation under rice based cropping system — P Kathirvelan, S Manickam, S R Venkatachalam, P Arutchenthil and M Deivamani — 20

Evaluation of seed dressing chemicals for the management of sucking pests in summer groundnut (*Arachis hypogaea* L.) — D V Khanpara, G M Parmar, R M Vikani and K L Dobariya — 23

Performance of oilseeds in India - a temporal analysis — I Krishna Teja, S V Ramana Rao, D Vishnu Sankar Rao and B Ravindra Reddy — 26

Short Communications

Physio-biochemical evaluation of soybean (*Glycine max* L.) genotypes exhibiting variable seed coat colour — M T Thombre, S V Damame, P K Lokhande and R M Naik — 32

Study on genetic divergence analysis of indigenous and exotic lines of linseed (*Linum usitatissimum* L.) based on morphological and quality traits — Devender Sharma, Satish Paul and Ranjana Patial — 38

Physiological and biochemical basis of cold storage in groundnut (*Arachis hypogaea* L.) seeds — N Nithya and J Renugadevi — 44

Agronomic evaluation of groundnut varieties under rainfed conditions of Dharmapuri District, Tamil Nadu — M Sangeetha, P S Shanmugam and N Tamil Selvan — 49

Review Article

Hyperspectral imaging applications in rapeseed and mustard farming

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ABSTRACT

Hyperspectral Imaging (HSI) technology provides incomparable capabilities for detection of physical, chemical, and biological properties of the samples, which is not possible with either spectroscopy or imaging alone. In agriculture, this technique is quite useful for monitoring the agricultural situation, retrieval of biophysical parameters and management/decision support for agricultural development. The applications of the technique are of considerable importance for macronutrient analysis of plants including mapping of foliar nitrogen, detection of nitrogen deficiency, visualization of chemical distribution in leaves etc. For rapeseed and mustard farming, the technology has been found to be fairly useful for the detection of different pathogens and disease prognosticating, detection of pests and monitoring damages due to infestation, macronutrient analysis for monitoring fertilizer application, mapping of weeds population, prediction of seed yield, and determination of oilseed planting area.

Keywords: Agriculture, Hyperspectral imaging, Mustard, Oilseed rape, Rapeseed

Rapeseed (*Brassica napus* L.) - Mustard [*Brassica juncea* (L.) Czern. and Coss] is one of the major annual edible oilseed crops cultivated in India. The crop contributed 25 per cent of the total oilseed production and accounts for nearly one-third of the oil produced in the country. It ranks second in area next only to soybean in India as well as in the world. It is a major *rabi* oilseed crop of northern part of the country cultivated in an area of 5.74 m ha with 6.82 m t production and 1183 kg/ha productivity. Rapeseed-Mustard constitutes an important source of edible oil for human consumption. The refined by-product in the form of cake contributes as protein and energy rich feed for livestock. Use of rapeseed oil as a renewable resource has been recently increased in many applications (Högya *et al.,* 2010). Acquiring of temporal and spatial variability of crop growth is one of the goals in precision agriculture (PA) (Zhang *et al.,* 2002). The physiological indices such as content of soluble sugar, leaf chlorophyll, soluble protein, enzyme activity contents etc. could be applied to interpret the crop growth status. For enhancing crop production, improved tools for detection of stress are the need of the hour. Remote sensing has potential to offer key inputs for the implementation of precision farming (Moran *et al*., 1997; Ray *et al*., 2001).

Hyperspectral imaging also called as imaging-spectroscopy or 3D spectroscopy, combines digital imaging and spectroscopy in to a single system. Relying on this capability, the technology has grown tremendously and has widespread applications in all fields including agriculture (Kumar *et al.,* 2016a, b). This technology provides an alternative to traditional methods for facilitating sustainable agriculture by mapping and monitoring the agricultural situation, retrieval of biophysical parameters and management/decision support for agricultural development. This reviews focusses on different applications of the technique in rapeseed-mustard farming including detection of major oilseed pathogens and forecasting of various diseases, determination of pests and monitoring infestation induced damages, macronutrient analysis for monitoring fertilizer application, mapping of weeds, seed yield prediction, and determination of planting area etc.

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Spectral features of rapeseed leaves and petals

The spectral and spatial information of each pixel in the hyperspectral image of rape seed leaves can be utilized to predict the quality parameters. The spectral characteristics of rapeseed leaves are best characterized between 500 to 900 nm wavelength range (Fig. 1). Like leaves of other green plants, the reflectance peak for rapeseed leaves has been observed around 550 nm and reflectance valley is observed in range of 650-700 nm (Zhang *et al.,* 2015).

The spectral characteristics of rapeseed leaves damaged by various pest and pathogens vary considerably and are different from healthy leaf spectra. Baranowski *et al.* (2015) have studied the spectral features of rapeseed leaves in response to infection with Alternaria. The reflectance response of the diseased leaf spectra after Alternaria infection differed from that of healthy uninfected areas. The reflectance of the Alternaria infected leaf area in the VNIR-SWIR range was more as compared to the uninfected area. Figure 2 presents typical false-colour images of

rapeseed leaves in visible and near infrared (VNIR) and short wavelength infrared (SWIR) region, 3 days after inoculation with *Alternaria alternate*. Researchers observed maximum differences in reflectance between diseased and uninfected areas in the visible range at 545 - 700 nm wavelengths, the region which includes chlorophyll absorption red-edge sub-region.

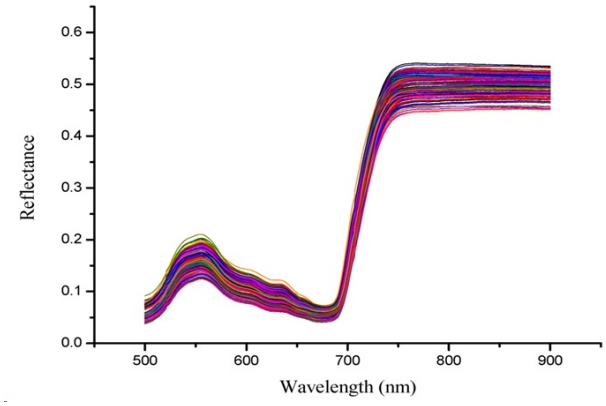

Fig. 1. Raw spectra (500-900 nm) of rapeseed leaves samples (Source: Zhang *et al*., 2015)

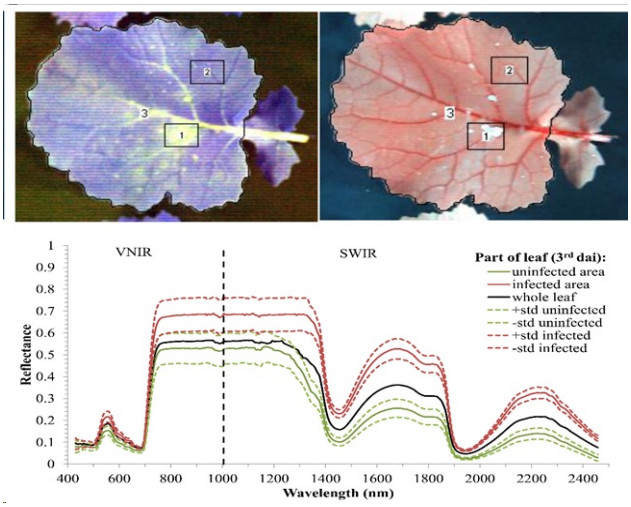

Fig. 2. False-colour images of VNIR and SWIR hyperspectral bands of an oilseed rape leaf infected with *Alternaria alternate* (Source: Baranowski *et al*., 2015)

Spectral characteristics of rapeseed petals in the entire spectral range of 900-1700 nm have been studied by (Zhao *et al.,* 2016) and are presented in Figure 3. The researchers observed valleys or broadband peaks in the NIR region, however no significant spectral differences were observed between petals infected with fungi *Sclerotinia sclerotiorum* and healthy petals in the NIR spectral region. However, the spectral pattern in 980 -1450 nm wavelength ranges showed significant and clear-cut differences between the healthy and infected petals. The high reflectance of infected petals in comparison to uninfected petals may be due to the decay process of infected petals. These spectral characteristics of the leaves and petals of rapeseed can be exploited for detection of damages caused by various pests and pathogens.

Hyperspectral imaging for determination of rapeseed and mustard planting area

Recently, Zhuokun *et al.* (2013) have demonstrated the utility of multi-range spectral feature fitting (MRSFF) for determining planting area of oilseed rape. The spectra of field canopy at various stages of growth were extracted from the images captured through Hyperion. The differences between field measured spectra and image spectra were determined. Further at each wavelength range image, spectral variance coefficient weights corresponding to the field-measured spectra were calculated. The range of wavelength for characterization of spectral properties of the target were determined using MRSFF, through this technology the researchers succeeded in extraction of planting area of oilseed rapecrop. Therefore the study proved that hyperspectral imaging technology using MRSFF holds in precision agriculture (Zhuokun *et al.,* 2013).

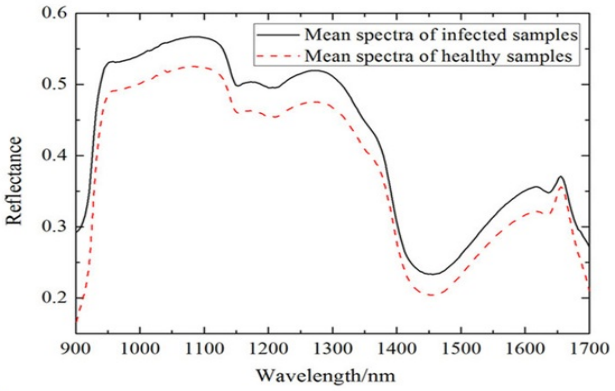

Fig. 3. Comparison of spectral reflectance curves of rapeseed petals infected with fungi *Sclerotinia sclerotiorum* and healthy petals (Source: Zhao *et al*., 2016)

Hyperspectral imaging for seed yield determination using hyperspectral images of oilseed rape leaves

Determination of seed yield is critical for planning of harvest schedule and generation of prescription maps. However, prediction of oilseed rape yield of individual plants at early stages is a challenging task. Accurate estimation of seed yield is beneficial for economy reasons and also benefits environment. Zhang and He (2013) developed a technique for rapid estimation of rapeseed yield utilizing hyperspectral images of oilseed rape leaves in the visible and near infrared (VIS-NIR) region (380-1030 nm). Amongst all stages, images captured during the flowering stage showed maximum association with seed yields. Thus the spectral characteristics of the leaves at flowering stage throws light

on pertinent information on the yield differences amongst individual plants. Therefore hyperspectral imagingcan be exploited for rapid estimation of seed yield for precision farming.

Hyperspectral imaging for prognosticating major diseases of oilseed rape and mustard

Disease prognosticating is an essential part of agriculture for enhancing crop productivity. The infestation and proliferate of crop diseases are governed by short-term weather aberrations throughout a crop growth cycle. Thus, prognosticating the disease in oilseed crops is important for adaptation of management strategies for improving productivity. Though, timely decision to apply pesticides is a key management strategy, indiscriminate use of pesticides not only increases costs but also toxic residue levels in agricultural produce. The pesticide use could be minimised if infected crops patches within the fields are identified and pesticides are applied only to the diseased areas. Recent developments in optical sensor technology have the potential to enable direct detection of foliar disease under field conditions (West *et al.,* 2003). Optical and thermal properties of leaves, canopies in different spectral regions are affected due to infestation by different plant pathogens through necrotic lesions, premature senescence or browning and canopy dryness (Malthus and Madeira, 1993; West *et al.,* 2003). The interaction of electromagnetic radiation with plants varies with the wavelength of the radiation. Depending on the vigour the same plant leaves will exhibit significant differences in the way they reflect light (Knippling 1970; Wooley 1971; West *et al.*, 2003). Such differences support hyperspectral observations over a number of bandsfor detection of crop diseases (Thenkabail *et al.*, 2002; Laudien *et al.*, 2004). Some important mustard diseases in India are blight (*Alternaria* sp.), white rust (*Albugo candida*) and Sclerotinia rot (*Sclerotinia sclerotiorum*). It has been demonstrated that the applicability of hyperspectral imaging techniques is quite pertinent for detection of Alternaria blight (Baranowski *et al.*, 2015; Zhao *et al.*, 2016), mustard rot (Bhattacharya and Chattopadhyay, 2013) and fungi, *Aspergillus glaucus* and *Penicillium* sp. in canola (Senthilkumar *et al.*, 2012).

Hyperspectral imaging for detection of blight: Among the biotic stresses, Alternaria blight disease caused by *Alternaria brassicae* (Berk.) Sacc. is one of the important diseases of mustard. Early detection of biotic stresses caused by host (*Alternaria alternate; Alternaria brassicae*; and *Alternaria brassicicola*) and non-host (*Alternaria dauci*) pathogens to oilseed rape (*B. napus*) belonging to the genus *Alternaria* have been demonstrated by Baranowski *et al.* (2015) using thermal and hyperspectral imaging in visible and near infrared (VNIR) and short wavelength infrared (SWIR) ranges. Distinct differences in leaf temperature during various stages of infection development were utilized and hyperspectral data obtained from the leaf surfaces was used to distinguish Alternaria species.

Hyperspectral imaging for detection of Sclerotinia rot: Sclerotinia rot is another important disease affecting the crop. The symptoms of the disease include discolouration, dryness, and shrinkage of canopies. Outbreak of the disease is accompanied by periods of continued minimal temperature and alternating clear and cloudy sky with intermittent drizzling (Chattopadhyay, 2008; Venette *et al.*, 1998). A 3 stage detection system was developed by (Bhattacharya and Chattopadhyay, 2013) using a combination of satellite-based remote sensing observations and minimum air temperature, for detecting Sclerotinia rot (*Sclerotinia sclerotiorum*) in mustard. A new technique for tracking Sclerotinia rot (*Sclerotinia sclerotiorum*) at successive stages in mustard fields based on analysis of surface reflectance's in red (R), shortwave infrared (SWIR) and near infrared (NIR) regions as well as land surface temperature (LST) from Moderate Resolution Imaging Spectroradiometer (MODIS) AQUA were utilized for characterization of outbreak of the disease (Bhattacharya and Chattopadhyay, 2013). Zhao *et al.* (2016) detected fungal infection of *S. sclerotiorum* of rapeseed petals by applying hyperspectral imaging in the spectral region of 874-1734 nm coupled with chemo-metrics. Since infected petals are often regarded as the source for the spread of fungi during growth, the detection of fungal pathogen in rapeseed petals is critical to restrict disease spread.

Hyperspectral imaging for detection of fungus *Aspergillus glaucus* and *Penicillium* spp.: Hyperspectral imaging in near-infrared (NIR) region has also been reported to detect different stages of fungal infections caused due to fungus *Aspergillus glaucus* and *Penicillium* spp. in stored canola (Senthilkumar *et al.*, 2012). In this study, canola seeds were infected artificially with the above fungus and subjected to hyperspectral imaging at 61 evenly distributed wave lengths between 1000 and 1600 nm. Healthy and fungal infected canola seeds were classified with a classification accuracy of more than 95 per cent for healthy canola seeds and more than 90 per cent for the initial stages of *A. glaucus* and *Penicillium* spp. infected canola seeds. With increase in levels of fungal infection, classification accuracy further increased.

Hyperspectral imaging for detection of major insect pests of rapeseed-mustard

With the advancement of plant growth, different pests and pathogens infect brassica crop and are unmanageable without chemical treatments (Alford *et al.*, 2003). Indiscriminate pesticide use have also led to the resistance amongst the insect populations to commonly used pesticides. Such resistance due to superfluous treatments is an emerging

issue for pest management programmes (Valantin-Morison *et al.*, 2007). To avoid unnecessary chemical use, early detection methodology for infestation in crops is very much needed. Detection of pests is visually easy, but it might be subjected to biasness and lack of precision (Richardson *et al.*, 2001; Steddom *et al.*, 2005). Alternative methods for monitoring damage of crops include, techniques relying on digital image analysis (Diaz-Lago *et al.*, 2003), spectral imaging (Guan and Nutter, 2002; Riedell and Blackmer, 1999), hyperspectral imaging (Zhao *et al.*, 2011; Reisig and Godfrey, 2010; Liu *et al.*, 2010) and multi-spectral imaging (Kim *et al.*, 2000).

Hyperspectral imaging for detection of aphid infestation: Mustard production in India suffers from aphid, *Lipaphis erysimi* (Kaltenbach), infestation considerably. Kumar *et al.* (2010) demonstrated assessment of aphid infestation in mustard using hyperspectral remote sensing. Kumar *et al.* (2013) found that remote sensing using hyperspectral data can be a very useful tool for monitoring the aphid infestation in mustard. Spectral reflectance from healthy and infested canopies of mustard using both field and laboratory spectroscopy were compared and it was observed that aphid infested plant has 67 to 94 per cent lower leaf area index (LAI) than healthy plant. The researchers observed most significant spectral bands for the aphid infestation in the visible range (550-560 nm), and near infrared regions (700-1250 nm and 1950-2450 nm). In 1950-2450 nm spectral regions, even the different levels of aphid infestation could be identified. The spectral indices RVI, NDVI, SIPI and AI were found significantly correlate with the aphid infestation and these indices could be applied for identification of aphid infestation in mustard.

Hyperspectral imaging for detection of cabbage caterpillar infestation: Cabbage caterpillar (*Pieris rapae* L.) is yet another pest damaging leaves of oilseed rape. A novel algorithm for recognition of damages induced by the pest on oilseed rape leaves has been developed by Zhao *et al.* (2012). Cabbage caterpillar infestation of oilseed rape cause wormholes on rapeseed leaves. The percentage of area covered by wormholes on leaves is an effective index to evaluate infestation variability. Hyperspectral imaging technology can be used to extract leaf from non-vegetation objects efficiently. Wormhole reconstruction can then be carried out for counting the wormholes area. The reconstruction of wormholes that are entirely within the leaf contour can be easily processed by holes filling function.

Hyperspectral imaging for mapping of weeds in oilseed fields

Remote sensing has also been widely used as a tool for mapping weed population in field crops (Lamb and Brown, 2001; Moran *et al.,* 1997; Zwiggelaar, 1998). This technique is an effective way of weed patch delineation, where weed infestations are detected based on variations in the plant canopy spectral response. The weeds grow in definite patches and successful delineation of patch boundaries creates a potential for applications of herbicide on a site-specific and need-base basis. Minimizing herbicide use by this practice reduces cultivation costs (Medlin *et al.,* 2000) and promote environmental friendliness (Timmermann *et al.,* 2001).

Aerial remote sensing platforms were first utilized for detection of weeds in agricultural fields in the early 1980s. Menges *et al.* (1985) used conventional colour (CC) and colour infrared (CIR) photography for distinguishing weeds from agricultural crops in fields. With the advancement in digital technology, Lamb and Weedon (1998) employed a four-camera, airborne, digital imaging system for recording green, blue, red and NIR wavebands over a fallow field of weeds (*Pancium effusum* R. Br.) in oilseed rape. Image analysis included an unsupervised classification of an NDVI and supervised classifications of multi-band images. Ground referencing was accomplished by visually mapping weedy areas with a GPS unit on an all-terrain vehicle (ATV). Overall classification accuracy assessments for this pre-emergence weed detection application ranged from 85 to 87 per cent. The studies indicated that hyperspectral image technology can also be used as potential tool for recognition of weed emergence.

Hyperspectral imaging for detection of N, P, K content and distribution in oilseed leaves

Nitrogen (N), phosphorus (P) and potassium (K) are critical for enhancingcrop growth and yield. The traditional way of application of fertilisers results in either over- or under-application because of variability in needs of individual plants. Indiscriminate use of fertilizers have led to degradation of soil quality, pollution of groundwater, increased costs, along with decrease in crop yields (Dong *et al.,* 2010; Farruggia *et al.,* 2004; Jørgensen *et al.,* 2007; Rathke *et al.,* 2006). Understanding the nutritional requirements of oilseed rape leaves is required for optimization of the fertilizer dose and process. The conventional technique for estimation of nutrient composition of leaves through chemical analysis consumes time and is destructive too. Detection of leaf nutrient content is important for real-time fertilizer application, precision diagnosis, and estimation of productivity which can be economic and environmental friendly. Determination of leaf and canopy spectral reflectance characteristics of leaf, as well as, canopy is a promising technique for estimation of bio-chemical composition of crops. Rapid and non-destructive determination of content and distribution of NPK in oilseed rape leaves using hyperspectral imaging

system have been demonstrated by Zhang *et al.* (2013). The spectral data extracted from the hyperspectral images captures at 380-1030 nm wavelength region were utilized for generating distribution map of NPK composition of leaves. The results proved that HSI is a potential technology for rapid non-destructive estimation of oilseed rape leaf macronutrients and could be applied for detection of NPK *in situ* (Zhang, *et al.,* 2013).

Detection of micronutrients and quality attributes of oilseeds

Spectral techniques to determine several quality factors, such as oil, protein and total glucosinolate contents of rapeseeds have been developed by several researchers (Petisco *et al.,* 2010), chlorophyll of rape leaves (Fang *et al.,* 2007), acetolactate synthase activity, protein content and total amino acids in herbicide-stressed oilseed rape leaves (Liu *et al.,* 2008, 2011). Prediction models of SPAD value (Soil and Plant Analyzer Development, often used as a parameter to indicate chlorophyll content) were successfully built using hyperspectral imaging technique in oilseed rape leaves by Ding *et al.* (2015). Best prediction performance was achieved using the PLS model at 500-900 nm wavelength. Furthermore, hyperspectral imaging in the visible and near-infrared regions covering spectral range of 380-1030 nm has also been utilized as a rapid and non-destructive method for estimation of the soluble protein content in oilseed rape leaves (Zhang *et al.,* 2015). Distribution of protein content within the rape leaves were noticed and mapped on the basis of the SPA-PLS model.

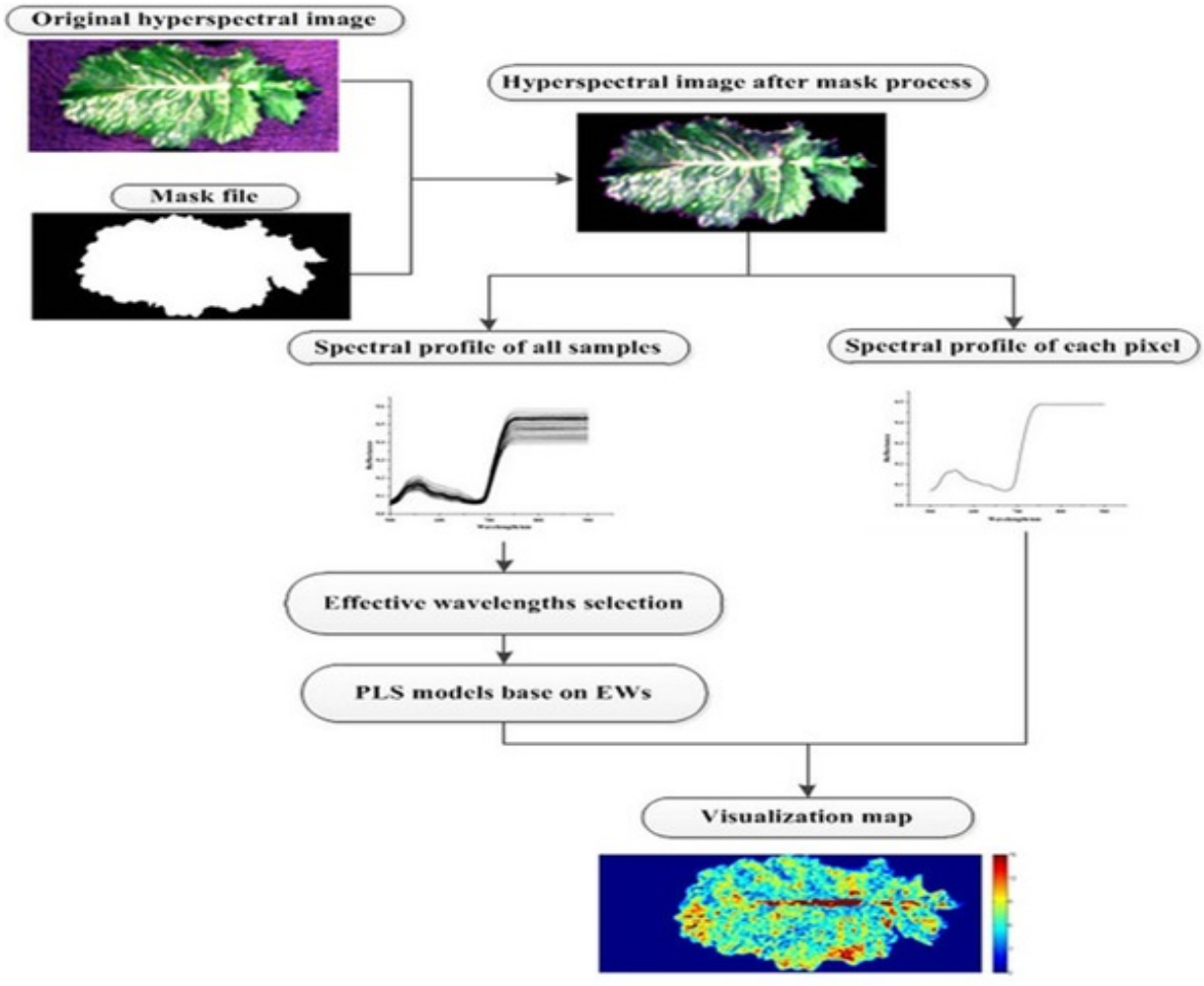

Fig. 4. Distribution map of MDA content in oilseed rape leaves built by PLS model
(Source: Kong *et al.,* 2016)

Malondialdehyde (MDA) is yet another quality attribute and a widely used marker of oxidative lipid injury caused due to environmental stress. The conventional methods are of no use for detection of changes in MDA composition within the same samples. Researchers have utilized hyperspectral imaging within 400-1000 nm range for detection of percentage of MDA in oilseed rape leaves under herbicide stress. Further the distribution map of MDA was also built using partial least squares (PLS) model through competitive adaptive reweighted sampling (CARS) (Kong *et al.,* 2016). Figure 4 shows the distribution map of MDA content in rapeseed leaves. The distribution map is very helpful for visualization of differences in MDA content which could be exploited for understanding the physiological status of oilseed rape leaves exposed to stress. The technique can be utilized for detection of stress to herbicides at earlier stages, well before irreversible damages and yield losses have occurred.

Remote sensing of crop plant vigour has generally focused on the link between plant pigments, especially chlorophylls, and biomass; the combination of which is collectively referred to as photosynthetically active biomass-PAB (Hall *et al.,* 2002). The technique has also been used for the determination of concentration of pigments of Oilseed Rape (He *et al.,* 2015). A hyperspectral imaging system covering the spectral range of 380-1030 nm was used to estimate leaf pigment concentration. The results indicated that hyperspectral imaging with ELM method was an efficient technique for leaf pigment content determination. The selected sensitive wavelengths would be helpful to develop portable instrument or on-field monitoring sensors in the precise agricultural management (He *et al.,* 2015).

Applications of hyperspectral imaging (HSI), discussed in this review undoubtedly prove the usefulness of HSI in successful brassica farming. However most of the systems are costly, therefore portable low-cost systems are needed for large-scale and on-field application of the technology in field crops. To conclude, the technology holds promise for increasing productivity of rapeseed and mustard, mainly through disease forecasting, timely application of control measures for getting rid of major pests and pathogens, guiding fertilizer application, monitoring weed patch delineation. Further the techniquealso have potential for extraction of planting area and rapid estimation of seed yields.

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Quantitative trait loci analysis for seed quality traits in sunflower (*Helianthus annuus* L.) recombinant inbred lines

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ABSTRACT

The present investigation was carried out in sunflower $F_{2:5}$ progenies of a cross TNHSF239-68-1-1-1 x 17B to identify the markers associated with seed quality traits. In this study, the QTL mapping work was based on the genotyping data obtained in the segregating population for the publicly available ORS markers previously mapped was used. In ICIM, the QTL analysis resulted into five QTLs *viz.,* volume weight, seed colour, strips on margin, pollen colour and oil content. The QTL for volume weight had a LOD of 2.93 and 24.86 per cent of phenotypic variation with the flanking markers ORS471 and ORS1265 on chromosome 7. The QTL for seed colour was formed on chromosome 11 had a LOD of 36.58 and 96.46 per cent of phenotypic variation with the flanking markers ORS707 and ORS503. The QTL for strips on margin was formed on chromosome 10 had a LOD of 3.23 and 63.88 per cent of phenotypic variation with the flanking markers ORS502 and ORS1037. The QTL for pollen colour had a LOD of 64.52 and 97.94 per cent of phenotypic variation with the flanking markers ORS707 and ORS503 on chromosome 11. The QTL for oil content was formed on chromosome 8 had a LOD of 2.51 and 28.99 per cent of phenotypic variation with the flanking markers ORS537 and ORS613. Hence the QTL identified for seed quality traits with closely linked markers may be exploited for the genetic improvement of sunflower genotypes through marker assisted selection.

Keywords: ICIM QTL analysis, Seed quality traits, SSR markers, Sunflower

Sunflower (*Helianthus annuus* L.) is a major oilseed crop gaining paramount importance in the world and ranks next only to soybean and groundnut in the total world production of oilseeds. The introduction of this crop to India has helped considerably to increase the country's oilseed production. The area under cultivation keeps increasing due to the crop's day neutrality, wide adaptability, short duration, high yielding potential, remunerative market price and good quality oil (Vairam and Gnanamalar, 2016; Suresh *et al.,* 2015). Despite these facts there is an acute shortage of oilseeds in India due to low productivity and ever increasing population growth. More emphasis is being given to the cultivation of oilseed crop in recent past especially in sunflower to increase the oilseed production and making the country self-reliance in edible oils. Oil concentration (OC) of sunflower seeds (44% in average) is higher than oilseed rape OC (40%) and far higher than soybean OC (18%). The other constituents of sunflower achene are proteins (18%), cellulose (15%), water (9%), carbohydrates and minerals (14%) (Roche *et al.,* 2006). Sunflower shows a good promise due to its desirable drought tolerance, wider adaptability and photo and thermo insensitivity. It can be conveniently fitted into the most of the crop rotations and crop sequences. Molecular markers in applied breeding programs facilitate the appropriate choice of parents for crosses to map or tag the gene blocks associated with economically important traits often termed as Quantitative Trait Loci (QTLs). The developed mapping population needs to be studied for the existence of phenotypic variability for various quantitative traits. The proper phenotyping of the mapping population is a prerequisite in any mapping study. In the present research programme, attempt has been made to identify QTLs for seed quality traits using mapping population of sunflower.

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MATERIALS AND METHODS

Plant materials: Two sunflower inbred lines namely, TNHSF239-68-1-1-1 and 17B with significant differences (Table 1 and Fig. 1) for various traits namely, stripe on seeds surface (both on margin and between margins), seed colour, hull weight and oil content were selected as female and male parent respectively to develop the $F_{2:5}$ population. These, parents were crossed during June to October, 2009. The F_1 plants were raised during January to April, 2010 and confirmed with polymorphic SSRs. The $F_{2:5}$ population was raised during June to October, 2011 and leaf samples were collected to extract DNA.

Phenotypic data: Recombinant inbred lines of 94 in $F_{2:5}$ generation was used in the present study. The experiment was laid out with two replications in randomized block design with a plot size of 2.4 m^2 with spacing of 60 × 30 cm during June to October, 2011 at Oilseeds Farm, Department of Oilseeds, Tamil Nadu Agricultural

University, Coimbatore. Data were recorded on five out of seven plants were selected randomly in each replications for recording morphological traits namely, days to 50% flowering, plant height (cm), head diameter (cm), pollen colour (score), stripes on seed margin (score), stripes between seed margin (score), seed colour (score), volume weight (g/100 ml), 100-seed weight (g), hull weight (g/100 seed), kernel weight (g/100 seed), hull (%), oil content (%) and oil yield (g/plant). The oil content of the seeds was estimated by using Pelicon Soxoplus apparatus and expressed in percentage. The mean data from each replication were subjected to statistical analysis as per the standard method. The mean data over replication were used as phenotypic data for QTL analysis.

Table 1 Description of morphological characters of parents

Characters	TNHSF239-68-1-1-1 (P1)	17B (P2)
Seed stripes	No stripes on the surface of seeds	Stripes present on surface, stripes strongly expressed in the margins
Pollen colour	Yellow	White
Seed colour	Black	Brown colour
100-seed weight (g)	3.7	5.2
Hull weight/100 seeds (g)	1.5	2.5
Hull (%)	25	35
Oil content	Very high (40-42%)	Very low < 33%
Seed yield/plant	Low	High
Oil yield	Low	High

Fig. 1. Seed morphological variation in parents

DNA isolation, SSRs and PCR condition: Genomic DNA of individual progenies and parents were extracted by CTAB method (Doyle and Doyle, 1987) and the quality was checked by using 0.8 % (w/v) agarose gel electrophoresis. The polymerase chain reaction (PCR) mixtures (5 µl) contained 10 ng template DNA, 1 X Taq Polymerase buffer with 1.5 mM $MgCl_2$, 0.2 mM dNTP, 0.5 µM of forward and reverse SSR primers and 0.03 IU of Taq polymerase. Amplification was performed in 0.2 ml well PCR plates (96 wells/plate) in a thermal cycler (Applied Biosystems). The samples were initially incubated at 94.0°C for 3 min and then subjected to 20 times of the following cycle: 94.0°C for 30 s, 63.0°C for 30 s (-0.5°C reduction per cycle) and 72.0°C for 1 min. This was followed by another 20 cycle of 94.0°C for 15 s, 55.0°C for 30 s and 72.0°C for 1 min. Final extension was 72.0°C for 10 min. Amplified products were analyzed using 6% non denaturing polyacrylamide gel at constant current of 350 V for about 4 h and silver stained (Benbouza *et al.,* 2006).

Linkage and QTL analysis: Genotyping and phenotyping data obtained from the mapping population was subjected to linkage analysis using QTL IciMapping software version 3.2 (Wang *et al*., 2012). Linkage groups were established using a minimum LOD score of 3.0, ordering by RECORD, rippled by SARF criterion with a window size of 5. The resultant linkage map was used to estimate the QTL using ICIM through the QTL ICI mapping software version 3.2. The QTL were estimated using ICIM-ADD mapping method, with mapping parameters of 1 cM step and 0.001 probabilities in stepwise regression. The LOD threshold used was 2.5 as manual input.

RESULTS AND DISCUSSION

Analysis of variance for various characters: Analysis of variance showed significant differences for all the characters except plant height and head diameter (Table 2). It indicates the presence of significant variability in the experimental materials. Burli *et al.* (2001) reported significant differences among the parents and crosses for days to 50% flowering. A significant difference for seed yield was reported by Mohan and Seetharam (2005) and Loganathan *et al.* (2006). Similarly significant differences for 100-seed weight and oil content were reported by Ashok *et al*. (2000).

Polymorphism survey and molecular analysis: In the present study, TNHSF239-68-1-1-1 and 17B have been chosen as parents. These parents have differential phenotypes for surface stripe (both on margin and between margins), oil content and hull weight. This population was made in an attempt to identify marker linked to these traits. The parents were surveyed with 156 SSR primers to assess the parental polymorphism. Among the 156 SSR primers studied, 43 (28.66%) were polymorphic between parents. These polymorphic primers (Table 3) were utilized for profiling the $F_{2:5}$ progenies. The reported map position for the publicly available ORS markers previously mapped by Hu *et al.* (2006) was used to estimate the QTLs following inclusive composite interval mapping of additive and dominant (ICIM-ADD) method. The position of these markers were in an already established linkage map reported by Hu (2006) was used (Table 4).

Inclusive composite interval mapping (ICIM): Genotyping and phenotyping data obtained were analyzed for mapping QTL by using the method inclusive composite interval mapping (ICIM) through QTL ICI mapping software version 3.2. In ICIM, the QTL analysis resulted into five QTLs *viz.,* volume weight, seed colour, strips on margin, pollen colour and oil content (Table 5 and Fig. 2). Negative skewness was observed for seed colour, oil content and volume weight. Hence directional selection could be made for these traits. The trait oil content, pollen colour, seed colour, stripes on margin and volume weight had platy kurtic nature. Due to wider variability, directional selection could be made to improve the per se performance of these traits. The QTL for volume weight had a LOD of 2.93 and 24.86 per cent of phenotypic variation with the flanking markers ORS471 and ORS1265 on chromosome 7. Similarly Abdi *et al.* (2012) detected the most important stable QTL in the interval 10.01 -11.01 near marker ORS169 for grain yield and hundred grain weight accounted for 0.23 per cent to 16.75 per cent of the variation. The QTL for seed colour was formed on chromosome 11 had a LOD of 36.58 and 96.46 per cent of phenotypic variation with the flanking markers ORS707 and ORS503. The QTL for strips on margin was formed on chromosome 10 had a LOD of 3.23 and 63.88 per cent of phenotypic variation with the flanking markers ORS502 and ORS1037. The QTL for pollen colour had a LOD of 64.52 and 97.94 per cent of phenotypic variation with the flanking markers ORS707 and ORS503 on chromosome 11. Stripe on margin and between margins and seed colour had no association with oil content. But, it had significant and negative association with hull content (Vanitha *et al.,* 2014). Hence light coloured seed and striped (both on margin and between margins) progenies may be avoided in oilseed sunflower breeding programme. This will help in the marker assisted breeding programme to incorporate these traits. The QTL for oil content was formed on chromosome 8 had a LOD of 2.51 and 28.99 per cent of phenotypic variation with the flanking markers ORS537 and ORS613. This chromosomic region is important for oil content as it is also reported by Tang *et al.* (2006), Ebrahimi *et al.* (2008) and Haddadi *et al.* (2010) for seed oil content. Hence the QTL identified for seed quality traits with closely linked markers may be exploited for the genetic improvement of sunflower genotypes through marker assisted selection.

Table 2 Analysis of variance of F_5 progenies for various characters

Source of variation	Degrees of freedom	Days to flowering	Plant height (cm)	Head diameter (cm)	Pollen colour	Stripes on margin	Stripes between margin	Seed colour
Treatment	142	9.12**	241.99	3.97	0.44**	1.05**	1.02**	5.04**
Error	142	3.93	234.13	3.52	0.04	0.24	0.27	1.68
Total	285							

Source of variation	Degrees of freedom	Volume weight (g/100ml)	100-seed weight (g)	Hull weight (g/100 seed)	Kernel weight (g/100seed)	Hulling percentage	Oil content (%)	Oil yield (g/plant)
Treatment	142	30.45**	1.69**	0.21**	1.08**	51.88**	54.97**	23.28**
Error	142	6.87	0.41	0.07	0.32	27.58	15.78	12.53
Total	285							

Table 3 Number of polymorphic markers per chromosomes used in the study

Chromosome Number	Number of polymorphic markers	Chromosome Number	Number of polymorphic markers
1	6	8	5
2	2	9	1
3	1	10	3
4	4	11	3
5	3	12	1
6	2	13	4
7	3	14	5

Table 4 Map position for seed quality traits in sunflower recombinant inbred lines

Markers	Chromosome Number	Position on linkage map (cM)
ORS605	1	17.1
ORS509	1	50.9
ORS606	1	54.6
ORS959	1	69.3
ORS371	1	77.7
ORS552	1	81.2
ORS1045	2	13.6
ORS1065	2	17.9
ORS1040	3	10.6
ORS785	4	65.6
ORS366	4	76.6
ORS523	4	79.3
ORS334	4	105.2
ORS315	5	4.9
ORS533	5	44
ORS852	5	66.7
ORS996	6	52.8
ORS328	6	73.1
ORS805	7	19.7
ORS471	7	31.6
ORS1265	7	50.2
ORS1143	8	1.1
ORS878	8	27.7
ORS595	8	64.9
ORS537	8	72
ORS613	8	91.9
ORS733	9	23.3
ORS502	10	10.9
ORS1037	10	61.1
ORS1085	10	91.8
ORS707	11	20.1
ORS503	11	76.5
ORS799	11	93.2
ORS307	12	55.6
ORS310	13	22.6
ORS1017	13	28.8
ORS378	13	103.8
ORS885	13	107.3
ORS1245	14	53.9
ORS513	14	54.9
ORS727	14	56
ORS847	14	57.6
ORS677	14	62.6

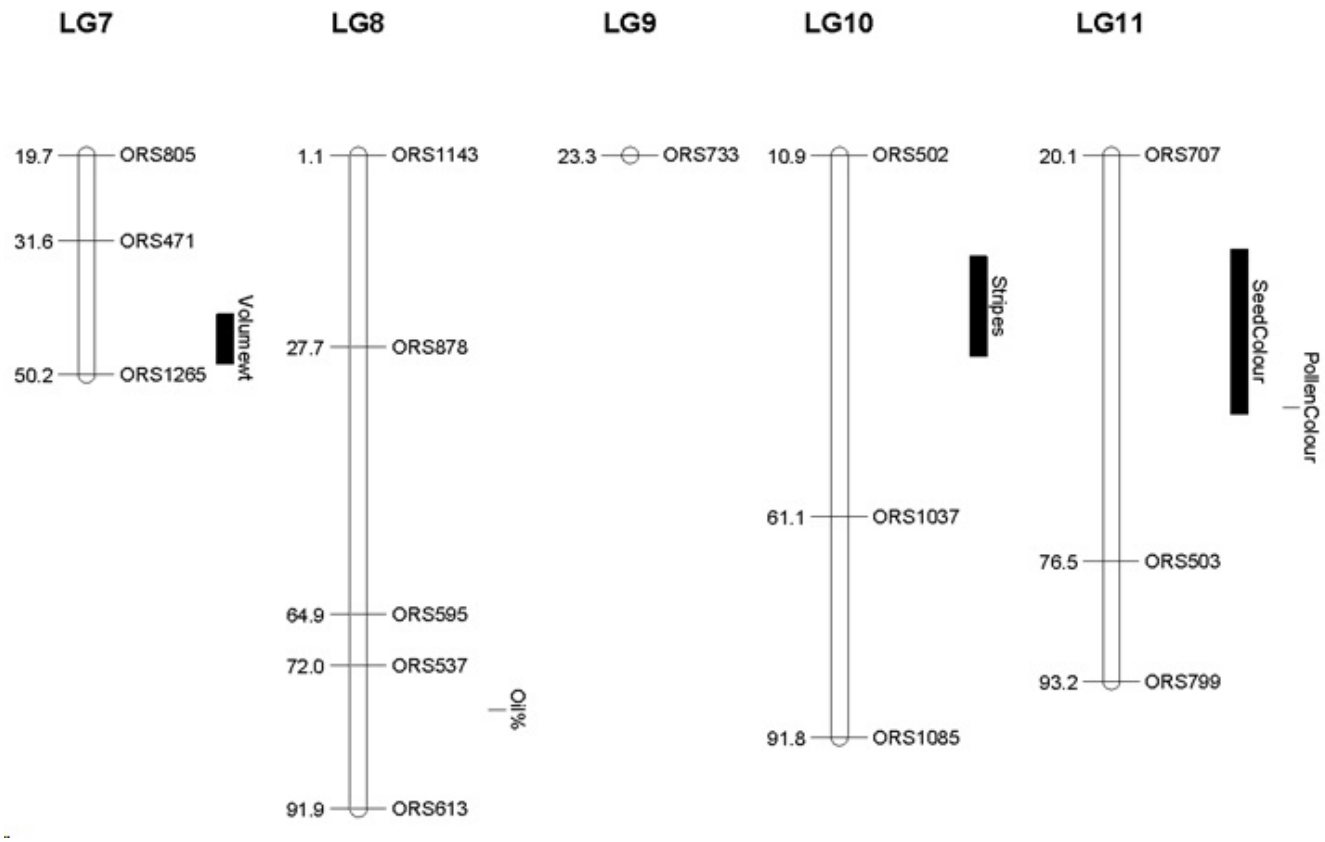

Fig. 2. Genetic linkage map of sunflower and QTL position in the cross TNHSF239-68-1-1-1× 17B

Table 5 QTL mapping of $F_{2:5}$ population of TNHSF239-68-1-1-1 x 17B cross for seed quality traits in sunflower

Character	Chromosome	Position	Left Marker	Right Marker	LOD	PVE (%)	Add
Volume weight	7.00	45.70	ORS471	ORS1265	2.93	24.86	-2.11
Seed colour	11.00	45.10	ORS707	ORS503	36.58	96.46	1.88
Strips on morgin	10.00	31.90	ORS502	ORS1037	3.23	63.88	-0.64
Pollen colour	11.00	55.10	ORS707	ORS503	64.52	97.94	-0.49
Oil content	8.00	78.10	ORS537	ORS613	2.51	28.99	3.43

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Inheritance of pod shattering in soybean [*Glycine max* (L.) Merrill.]

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ABSTRACT

In the present investigation, inheritance of pod shattering in soybean was studied in three crosses involving four parents, among them MACS-450 and DS-9712 were tolerant to pod shattering while Monetta and Kalitur were susceptible to pod shattering. The contrasting parents were used to develop three cross combinations *viz.,* Monetta × MACS-450, Kalitur × DS-9712 and Kalitur × MACS-450. Inheritance of pod shattering was found to be governed by partial dominance of susceptibility over the resistance. Two major genes with inhibitory epistasis were involved in inheritance of pod shattering in soybean. As regards to inheritance of pod shattering tolerance parents MACS-450 and DS-9712, F_1s of susceptible × resistant crosses and backcrosses with resistant parent showed tolerance. Two major genes with inhibitory epistasis were involved in inheritance of pod shattering in soybean as evidenced from F_2 ratio (13:3) and confirmed by test cross ratio (3:1) in tolerant × susceptible crosses. Two dominant genes with inhibitory epistasis were involved in the inheritance of pod shattering tolerance in soybean.

Keywords: Inheritance, Inhibitory epistasis, Pod shattering, Soybean

Soybean [*Glycine max* (L.) Merrill] cultivation is rapidly expanding partly due to its high nutritional value as food for both humans and livestock and as an important industrial crop. It is considered as a "Golden bean" due to its dual qualities *viz*., high protein (40%) and oil (18 to 20%) content. India is the fifth largest producer of soybean in the world. However, India's share in world production of soybean is only 5 per cent (Sharma, 2015). Pod shattering is the opening of pods along both the dorsal and ventral sutures of the soybean pod. Fully mature pods of soybean are extremely sensitive to opening, resulting in seed dehiscence. Though this trait is important for the adaptation of the wild species to natural environments as a mechanism for seed dispersal, it leads to a significant yield loss in soybean production, if found in cultivated forms. This can take place in susceptible varieties prior to harvest due to disturbance of the canopy by wind or during harvesting as the harvesting equipment moves through the crop during dry weather conditions, leading to seed losses of 50-100 per cent (IITA, 1986). This loss of seed not only has a drastic effect on yield but also results in the emergence of the soybean as a weed in the subsequent growing season.

Pod shattering trait in soybean can be controlled by several strategies. In Japan, timely planting is done so that, seeds are generally harvested in cool and humid seasons, which have masked the problem of pod dehiscence (Funatsuki *et al.,* 2008). It may be possible to increase the resistance to pod shattering by delaying or stopping the breakdown of the dehiscence layer by manipulating the enzymes responsible (Jenkins *et al.,* 1996). It may also be possible to achieve this by increasing the size or number of vascular strands within the dehiscence zone, increasing the area of the dehiscence zone or modifying pod wall thickness to reduce the mechanical effects of desiccation (Morgan *et al*., 1998). Among the available control options, genetic improvement, by introducing resistance genes from related species into susceptible cultivars is usually more effective, less costly, not subject to environmental conditions and easier for growers to implement. However, this is both time consuming and laborious. The hybridization strategy also has to cope with transferring two or more genes, which are recessive in action into each of the breeding lines. Indeed, different genetic backgrounds have revealed different number of genes to be important in shattering resistance/tolerance in soybean (Carpenter and Fehr, 1986; Tukamuhabwa *et al.,* 2000). This has necessitated breeders to perform test crosses at each generation during the attempt to produce elite material, since the shattering resistance behaves as a partially recessive trait (Tsuchiya, 1986; Tukamuhabwa *et al.,* 2002). These difficulties have been compounded by the fact that shattering is a difficult and time-consuming trait to assess in the field because field assessments, based on visual observation and handling, are subjective and depend greatly on the maturity and moisture status of the crop (Morgan *et al.,*1998). The knowledge of inheritance of pod shattering provides useful tool for selection of suitable parents and segregating populations for developing shattering tolerance progeny which is also challenging task to breeder due to complex nature of inheritance of the character.

MATERIALS AND METHODS

The present investigation was conducted at Post Graduate Institute, Department of Botany Research Farm, MPKV, Rahuri during the period from 2013-2014 and 2014-2015.

On the basis of susceptibility and tolerance to pod shattering of soybean, four genotypes were selected. Among the four promising parents, MACS-450 and DS-9712 were tolerant to pod shattering while, Monetta and Kalitur were susceptible to pod shattering. The contrasting parents were used to obtain three cross combinations. Three cross combinations for pod shattering traits *viz*., Monetta × MACS-450 (S×R); Kalitur × DS-9712 (S×R) and Kalitur × MACS-450 (S×R) were conducted in *kharif* 2013 to produce the F_1 seeds. In early summer 2014 F_1s sown and F_2s seeds were made. Backcrosses, BC_1 and BC_2 of three crosses were also made in early summer 2014. The experiment was laid out in randomized block design with three replications in *kharif* 2014. The experimental material consisted of 18 treatments consisting of 4 parents, $3F_1$s, $3F_2$s, $3BC_1$s and $3BC_2$s, of three crosses (Monetta × MACS-450, Kalitur × DS-9712 and Kalitur × MACS-450). The parents, F_1s, F_2s, and back crosses were randomized separately in each of the three replications. Sowing was done in rows of 3 m length and having 45 x 10 cm distance in a row to plant (productive soil). One row was assigned to each P_1s, P_2s, F_1s, while the two rows to each of the BC_1s and BC_2s and 10 rows to F_2s. This has permitted for raising of 30 plants in each of P_1s, P_2s, F_1s, 60 plants in BC_1s and BC_2s, and 300 plants in each of the F_2s, in each of the three replication for each cross. Fertilizer dose of 50 kg N and 75 Kg P_2O_5/ha for irrigated situation was applied at the time of sowing. The experiment was sown on 7th of July 2013. All inter-culturing operations were carried out regularly as per need and stage of crop growth.

Pod shattering screening was done under the laboratory condition as per oven dry method reported by Tiwari and Bhatnagar (1997) with little modification. The properly harvested 20 pods each of P_1s, P_2s, F_1s, F_2s, BC_1s and BC_2s generations were kept in brown paper bags at room temperature for 15 days to equalize the moisture content of all pods. Then the bags were kept in Hot air oven for 40°C (6 hrs in a day and ambient temperature at night) for 7 days. Percentage of shattering were recorded when more than 70 per cent pods of susceptible parents were shattered and number of shattered pods were counted and expressed in percentage as below:

$$\text{Pod shattering percentage (\%)} = \frac{\text{Number of pods shattered}}{\text{Total number of pods}} \times 100$$

Percentage of pod shattering induced was recorded and determined according to 1-5 scale. The scoring was used by Asian Vegetable Research Development Centre (AVRDC, 1979) indicating 1=0%, 2=1-10%, 3=11-25%, 4=26-50% and 5=>50% where, very resistant, resistant, moderately resistant/tolerant, moderately susceptible and very susceptible, respectively. Whereas, scored in 0-10 scales used by Bailey *et al.* (1997), where, 0 < 1% = 0, 1-10% =1, 11-20% = 2, 21-30%=3, 31-40% = 4, 41-50% = 5, 51-60%=6, 61-70%=7, 71-80 = 8, 81-90%=9, 91-100%=10. Based on the scale (1-3 scale) of Bailey *et al.* (1997), Mohammed (2010) and Bhor *et al.* (2014) phenotypic classes were assigned as follows: progenies with the score of 1 were considered as resistant, progenies with score of 2 as intermediate and 3 as susceptible.

RESULTS AND DISCUSSION

Results of various resistant and susceptible plants observed in F_2 and backcross generations for all three crosses studied for pod shattering resistance are presented in Table 1. The genetics of soybean pod shattering observed in the present findings are discussed crosswise:

Cross I (Monetta × MACS-450): The F_1 plants of the cross Monetta × MACS-450 (S × R) produced were used to record per cent pod shattering at 40°C oven dry and as determined by following AVRDC scale. It was observed number of plants ranged from 15 to 60 per cent as intermediate but it was very close to shattering susceptible parents. This indicated that the susceptibility was partially dominant over resistance for soybean pod shattering.

The segregating F_2 generation cross Monetta × MACS-450 (S × R) studied for 294 plants. Out of this, 241 (126 highly susceptible + 115 intermediate) pod shattering susceptible and 53 pod shattering resistant/tolerant plants were observed in F_2 ranged from (10-75%). Results in this study according to the chi-square test fitted the two phenotypic classes because the intermediates were behaving as susceptible phenotypes. The data showed non-significant chi-square value (0.1) for the expected ratio of 13 (7 S + 6 I) : 3 (Table 2). The observed ratio was 13.12 : 2.88 (observed plants was 241:53) as against expected ratio of 13:3 which was closely fitted with the fitment table 13:3 indicating the presence of inhibitory gene interaction for inheritance of pod shattering in soybean. Among BC_1 generation of the cross studied for 24 plants. Out of this, 15 susceptible and 9 intermediate plants were observed as it was cross between susceptible F_1 and susceptible parent. In BC_2 generation of the cross studied for 26 plants, the data showed non-significant chi-square value (0.05) for the expected ratio of 3:1. The observed ratio was 2.92:1.08 which was closely fitted with the fitment table 3:1. The test cross ratio confirmed the presence of inhibitory gene interaction for the inheritance of pod shattering in soybean.

Cross II Kalitur × DS-9712: The F_1s of the cross Kalitur × DS 9712 (S × R) produced intermediate shattering ranged from 25 to 65 per cent plants but it was very close to shattering susceptible parents (Table 1). This indicated that the susceptibility was partially dominant over resistance for soybean pod shattering.

The segregating F_2 generation cross Kalitur × DS 9712 (S × R) studied for 289 plants. Out of this, 246 (117 highly susceptible + 129 intermediate) pod shattering susceptible and 43 pod shattering resistant/tolerant plants were observed in F_2 ranged from 10-80 per cent (Table 1 and 2). Results in this study according to the chi-square test fitted the two phenotypic classes because the intermediates were behaving as susceptible phenotypes. The data showed non-significant chi-square value (0.09) for the expected ratio of 13:3. The observed ratio was 13.62:2.38 (observed plants was 246:43) as against expected ratio of 13:3 which was closely fitted with the fitment table 13:3 indicating the presence of inhibitory gene interaction for inheritance of pod shattering in soybean. Among the backcrosses, BC_1 generation which was the test cross studied for 18 plant. Out of this, all were observed susceptible (11 susceptible and 7 intermediate) plants it was cross between susceptible F_1 and susceptible parent. In BC_2 generation of the cross studied for 27 plants, The data showed non-significant chi square value (0.31) for the expected ratio of 3:1. The observed ratio 2.81:1.19 which was closely fitted with the fitment table 3:1. The test cross ratio confirmed the presence of inhibitory gene interaction for the inheritance of pod shattering in soybean.

Table 1 Inheritance of pod shattering resistance in soybean under controlled (oven dry method) condition

Generations	Crosses		
	Cross I	Cross II	Cross III
F_1	I (S)	I (S)	I (S)
Observed F_2 plants			
S	126	117	120
I	115	129	112
(S + I)=S	241	246	232
R	53	43	45
Total	294	289	277
χ^2	0.1 (NS)	0.09 (NS)	1.14 (NS)
d. f.	1	1	1
Expected ratio	13:3	13:3	13:3
Observed ratio (No. observed plants)	13.12 : 2.88 (241 : 53)	13.62 : 2.38 (246 : 43)	13.40 : 2.60 (232 : 45)
Backcrosses			
	BC2	BC_2	BC_2
S	14	12	11
I	5	7	6
(S + I)=S	19	19	17
R	7	8	7
Total	26	27	24
χ^2	0.05 (NS)	0.31 (NS)	0.22 (NS)
d. f.	1	1	1
Expected ratio	3:1	3:1	3:1
Observed ratio (No. observed plants)	2.92 : 1.08 (19 : 7)	2.81 : 1.19 (19 : 8)	2.83 : 1.17 (17 : 7)
With dominant parent	BC_1	BC_1	BC_1
S	15	11	13
I	9	7	8
(S+I)=S	24	18	21
R	0	0	0
Total	24	18	21
Gene action	Inhibitory epistasis	Inhibitory epistasis	Inhibitory epistasis

Where, F_1- First filial generation, F_2- Second filial generation, BC_1 & BC_2 Back cross generations, S-Susceptible, I-Intermediate, R-Resistant, χ^2 -chi square value, d.f.-Degrees of freedom and NS-non significant.

Table 2 Relationship between phenotype and genotype in an F_2 population and backcrosses showing classical inhibitory (dominant and recessive) epistasis for inheritance of pod shattering in soybean

Genotype	Frequency	Phenotype	Total	Ratio
F_2 Population				
S+S+R+R+	1/16	S		
S+S+R+R-	2/16	S		
S+S+R-R-	1/16	S	7 S	
S+S-R-R-	2/16	S		13 S
S-S-R-R-	1/16	S		
S+S-R+R+	2/16	I	6 I	
S+S-R+R-	4/16	I		
S-S-R+R+	1/16	R	3 R	3 R
S-S-R+R-	2/16	R		
				13 : 3 (inhibitory epistasis)
Backcrosses population				
BC_2 Test cross				
S+S-R+R-	¼	I	1 I	
S+S-R-R-	¼	S	2 S	3 S
S-S-R-R-	¼	S		
S-S-R+R-	¼	R	1 R	1 R
				3:1
BC_1 cross with parents having dominant allele				
S+S+R+R+	¼	S	2 S	
S+S+R+R-	¼	S		
S+S-R+R+	¼	I	2 1	All susceptible
S+S-R+R-	¼	I		

Where, +: Dominant allele, -: Recessive allele, BC_1- Back cross generations 1, BC_2- Back cross generations 2, S- Susceptible, I-Intermediate and R-Resistant.

Cross III Kalitur × MACS-450: The F_1s of the cross Kalitur × MACS-450 (S × R) produced were used to record per cent pod shattering at 40°C oven dry and determined as per AVRDC scale it shown as intermediate ranged from 20 to 55% but it was very close to shattering susceptible parents. This indicated that the susceptibility was partially dominant over resistance for soybean pod shattering.

The segregating F_2 generation cross Kalitur × D9712 (S × R) comprised of 277 plants. Out of this, 232 (120 S + 112 I) plants were pod shattering susceptible and 45 were pod shattering resistant/tolerant plants in F_2 ranged from 10-75 in segregating population. Results in this cross according to the chi-square test fitted the two phenotypic classes because the intermediates were behaving as susceptible phenotypes. The data showed non-significant chi-square value (1.14) for the expected ratio of 13 (7 S + 6 I) : 3. The observed ratio was 13.40:2.60 (observed plants was 232:45) as against expected ratio of 13:3 which was closely fitted with the fitment table 13:3 indicating the presence of inhibitory gene interaction.

Among the backcrosses, BC_1 generation which was the test cross studied for 21 plants (Table 1). Out of this, all were observed as susceptible (13 S and 8 I) plants as it was cross between intermediate F_1 and susceptible parent. In BC_2 generation of the cross studied for 24 plants. The data showed non-significant chi-square value (0.22) for the expected ratio of 3:1. The observed ratio was 2.83:1.17 which was closely fitted with the fitment table 3:1. The test cross ratio confirmed the presence of inhibitory gene interaction pod shattering in soybean.

The results are in agreement with Mohammed (2010) and Bhor (2014) who had reported that pod shattering in soybean was controlled by two major genes with inhibitory types of epistasis. Caviness (1963) reported four major genes, Misra *et al.* (1980) reported presence of several genes, Carpenter and Fehr (1986) reported only a few genes, Tsuchiya (1986) reported one or two gene, while Akpan (1988) reported six to twelve genes to be involved in controlling susceptibility to pod shattering in soybean. Tiwari and Bhatnagar (1991)

reported that the shattering character is highly heritable. Analysis of pod shattering in F_1 populations by Tiwari and Bhatnagar (1992) reported some crosses showed susceptibility being dominant while other crosses showed partial dominance for resistance. Tukamuhabwa (2000) and Bhor (2014) reported that pod shattering in soybean is under the control of two genes and is partially dominant over resistance and concluded that inheritance of pod shattering is non-allelic resulting in classical dominant epistasis and it is not influenced by maternal effects. Tukamuhabwa *et al*. (2002) reported for presence of non allelic interaction of genes with partial dominance for the shattering habit in soybean.

Tolerance × susceptible parents produced 13 susceptible: 3 resistant F_2 plants. The F_2 breeding behavior to pod shattering was confirmed by raising test cross generation of each cross, which revealed that the agreement between observed and expected genotypic frequencies of test crosses as χ^2 values were non-significant. From the present study it is concluded that two genes with inhibitory epistasis is involved in governing the tolerant to pod shattering of soybean. The study detected inheritance of resistance to pod shattering in soybean was qualitative, under the control of two genes. The development of soybean cultivars resistant to pod shattering of soybean may prove complicated, because of limited resistant plants observed in F_2 and also close association of pod shattering with moisture content and anatomy of pods. Therefore, it is suggested to develop high resistance lines by using parent MACS-450 and their segregating resistant populations generated in present investigation.

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Crop diversification with castor (*Ricinus communis* L.) for enhancing the productivity, profitability and resource conservation under rice based cropping system

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ABSTRACT

On-farm experimental trials were conducted to find out the efficient, productive and remunerative crop in the existing rice based cropping system for sustaining the productivity and conserving natural resources in Cauvery delta region of Tamil Nadu during summer 2015 and *kharif* 2015. The experiments were laid out in randomized block design and replicated four times with the following cropping sequence *viz.,* rice - rice, rice - blackgram, rice - cotton, rice - sesame, rice - maize and rice - castor. The results revealed that the productivity of succeeding rice during *kharif* 2015 was significantly higher (5.85 t/ha) with rice - castor system while the lowest rice productivity was recorded under rice - rice (5.25 t/ha) cropping system. System productivity in terms of rice equivalent yield was significantly higher (14.1 t/ha) in rice - cotton system followed by rice-blackgram, rice-maize and rice-castor. Significantly higher total biomass addition of 15.5 t/ha was recorded under rice-castor cropping system which was followed by rice-cotton cropping system (10.8 t/ha) which directly influenced organic carbon content (0.46 %), biomass carbon (598 mg/kg) which in turn improved bulk density (1.30). The highest net returns of ₹121360/ha and higher benefit : cost ratio of 3.1 was realized under rice-castor cropping system.

Keywords: Castor, Cropping system, Economic efficiency, Equivalent yield

Cauvery deltaic zone popularly called as rice granary of Tamil Nadu is known for rice cultivation throughout the year during *kuruvai*, *samba* and *thaladi* season. After rice, majority of farmers are growing blackgram, greengram and cotton and very few farmers who have good water sources are opting for rice during summer season. However, owing to paucity of agricultural labour, escalation of wages and declining water table, farmers in the region are getting less net returns, thus, irrigated area under rice is steadily declining. The Cauvery delta zone has two distinct regions. One is old delta which has clay and clay loam soil and the rest is new delta with sandy and sandy loamy soil. The new delta is potential zone for crop diversification. The major production constraint in rice cultivation is frequent delay in release of Cauvery water for cultivation has made rice farming more difficult in the region. Crop diversification with high value low water requiring crop such as castor is the better option during summer as rice fallow (after harvesting of *samba* rice). The advantages of castor over conventional crop are less demanding in terms of land, labour, capital, water and it augurs well for water deficit areas and problem soils (Ramesh *et al.,* 2016; Vaghasia *et al.,* 2016). Moreover, less cost of cultivation, capacity to improve soil health through addition of leaf litter and biological ploughing. Considering all these facts, the experiments were carried out in the farmer's fields to find out the efficient, productive and remunerative crop in the existing rice based cropping system for sustaining the productivity and conserving natural resources.

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MATERIALS AND METHODS

On-farm experimental trials were conducted during summer 2015 and *kharif* 2015 season under All India Co-ordinated Research Project on Castor programme to find out the efficient, productive and remunerative crop in the existing rice based cropping system in Cauvery delta region of Tamil Nadu. The experiment was laid out in randomized block design with three replications. The soil of the experimental field was clay sandy loam and the available nutrient status was low in organic carbon (0.41 per cent), low in nitrogen (222 kg/ha), high in phosphorus (33.5 kg/ha) and medium in potash (235 kg/ha). The experiments consisted of six different cropping sequences *viz.,* rice-rice, rice-blackgram, rice-cotton, rice-sesame, rice-maize and rice-castor. The varieties of the different crops used in the on-farm experiments were ADT 43 for rice, ADT 5 for blackgram, MCU 7 for cotton, TMV 6 for sesame, NK 6240 for maize and YRCH 1 for castor. Field preparation was done with a tractor drawn cultivator followed by laddering to level the main field. For rice, puddling was done prior to transplanting and 25 days old rice seedlings were transplanted manually in ear marked plot during first week of September and harvested during second week of January and

summer crops were sown manually in the respective plots after harvest of rice during second week of February. Seeds of blackgram and sesame were sown manually by broadcasting method while cotton, maize and castor were sown by hand dibbling method. Recommended doses of fertilizers to each crop were applied and need based irrigation was given. All crops were harvested manually at maturity from net plot area. After harvesting, biomass and economic yield of each crop were converted into per hectare. The entire crop residues of summer 2015 season crops were incorporated in the field itself using rotavator before transplanting rice during *kharif* 2015 season. Economic produce of all the crops were obtained manually by their specified processing techniques. To compare the performance of different cropping sequences, economic yield of component crops was converted to rice equivalent yield (REY) based on prevailed market price. System productivity was worked out by dividing equivalent yield of component crops by 365 and expressed as kg/ha/day. To assess the resource use efficiency of the system, land use efficiency (LUE) was calculated from the total duration of crop in cropping system, divided by 365 and production efficiency was calculated by dividing total economic yield (REY) by total duration of crop in cropping system and expressed in kg/ha/day. Economic efficiency was calculated in terms of ₹/ha/day from net return of the cropping system divided by total duration of crop in a cropping system (Tomar and Tiwari, 1990). Total cost of cultivation incurred from field preparation to harvest including the cost of other inputs were worked out for each component crop of the study and expressed as ₹/ha. The income obtained from pod and haulm was worked out for each treatment and expressed as ₹/ha. Net return was obtained by subtracting total cost of cultivation from the gross return and expressed as ₹/ha. Benefit : cost ratio was worked by subtracting total cost of cultivation from gross returns and system profitability was expressed as the ratio of net returns/ha to 365 days.

RESULTS AND DISCUSSION

The productivity of succeeding rice (*kharif* 2015) significantly varied with cropping systems. Significantly higher rice productivity of 5.85 t/ha was recorded under rice-castor system while the lowest in rice-rice (5.25 t/ha) cropping system. Further, rice-castor cropping system had registered 1.73, 4.46, 6.36, 8.33 and 11.43 per cent increased rice productivity over rice-cotton, rice-maize, rice-blackgram, rice-sesame and rice-rice cropping system, respectively. The highest rice grain yield attained under rice-castor system was mainly due to addition of crop residues through leaf litter and incorporation of total biomass besides improving the soil aeration through biological ploughing action. In contrast to this, rice grain yield, soil fertility and productivity are severely affected by double rice cropping system and therefore, rice after rice cropping sequence known to be an exhaustive system (Gangwar *et al.,* 2006). System productivity in terms of rice equivalent yield (REY) was significantly higher (14.18 t/ha) in rice-cotton system followed by rice-blackgram, rice-maize and rice-castor. Higher cotton productivity with higher market price during experimentation period contributed to higher REY in this system. The REY of rice-blackgram, rice-maize and rice-castor systems were intermediary but significantly higher than rice-sesame and rice-rice cropping systems. Rice, sesame and maize are known to be more nutrient exhaustive crops than blackgram, cotton and castor. Castor has deep root system which recycles the nutrients through nutrient pumping action, improve the soil structure, add nutrient by biological nitrogen fixation and through leaf litter and which enhances overall nutrient use efficiency and improves system productivity of succeeding rice grain yield (5.85 t/ha) during *kharif* 2015 season. Similar findings were reported earlier by Dwivedi *et al.* (2003). Significantly higher total biomass addition of 15.54 t/ha was recorded under rice-castor cropping system which was followed by rice-cotton system (10.83 t/ha) which directly influenced organic carbon content (0.46 %), biomass carbon (598 mg/kg) of the soil which in turn improves bulk density (1.30). The lowest values of these parameters were registered under double rice cropping system (Table 2). The results are in concordance with the findings of Ladha and Kundu (1997). The double rice cropping system recorded the lowest production efficiency, land use efficiency, system productivity and profitability. Rice is exhaustive users of plant nutrients and continuous adoption of rice cropping systems results in the removal of nutrients in substantial amounts that often exceed replenishments through fertilizers and manures, leading to deterioration in soil fertility and reduction in the productivity of the system (Biswas *et al.,* 2006). Similar findings were reported by Mukesh Kumar *et al.* (2014).

Regarding, resource use efficiency in terms of land use efficiency and production efficiency have been calculated and presented in Table 1. Rice-castor cropping system occupied the land for maximum duration thus recorded the highest land use efficiency of 76.7 per cent and however, production efficiency of this system (45.7 kg/ha/day) was comparatively less than rice-blackgram, rice-maize, rice-cotton and rice-sesame. The lowest land use efficiency of 54.8 7 per cent was registered under rice-blackgram system but recorded the highest production efficiency (64.8 kg/ha/day). The lowest production efficiency and land use efficiency were recorded in rice-rice cropping system owing to lower crop productivity and utilization of land for shorter period.

With respect to economic analysis of different cropping systems (Table 2) higher cost of cultivation was registered in rice - cotton sequence (₹ 100250/ha) while the lowest cost of cultivation was recorded in rice-sesame cropping system

(₹ 54750/ha). The highest gross returns of ₹ 198520/ha was registered in rice-cotton cropping system followed by rice-maize and rice-castor cropping sequence. The lowest gross returns was noticed under rice-sesame cropping system (₹ 142580/ha). Though, rice-cotton cropping system had recorded higher gross return as compared to other cropping system, it failed to produce higher net return due to higher cost of cultivation. The highest net return of ₹ 121360/ha was recorded under rice-castor cropping system which might be due to higher productivity coupled with less cost of cultivation and steady marketing price. Thus, higher benefit cost ration of 3.1 was realized under rice-castor system over rest of the sequence. Based on above findings, it could be concluded that rice - castor system was more efficient, productive, remunerative and sustainable besides conserving the natural resources and improving the soil fertility.

Table 1 Economic yield of individual crop, REY and resource use efficiency of different rice based cropping systems

Cropping systems	Economic yield (t/ha)		Rice equivalent yield (REY) (kg/ha)	Production efficiency (kg/ha/day)	Land use efficiency (%)	System productivity (kg REY/ha/day)	System profitability (₹/ha/day)
	Summer 2015	*Kharif* rice 2015					
Rice-Rice	5.10	5.25	10500	43.8	65.8	28.8	239.9
Rice-Blackgram	1.50	5.50	12950	64.8	54.8	31.1	284.4
Rice-Cotton	3.50	5.75	14180	51.6	75.3	38.8	269.2
Rice-Sesame	1.10	5.40	10184	46.3	60.3	27.9	240.6
Rice-Maize	7.00	5.60	12940	57.5	61.6	35.5	321.8
Rice-Castor	2.65	5.85	12792	45.7	76.7	35.0	332.5
SEm±	0.23	0.29	-	-	-	-	-
CD (P=0.05)	0.68	0.87	-	-	-	-	-

Table 2 Economic analysis and resource conservation under different rice based cropping systems

Cropping systems	Total biomass addition (t/ha)	Organic carbon (%)	Biomass carbon (mg/kg)	Bulk density (g/cc)	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net income (₹/ha)	Economic efficiency (₹/ha/day)	Benefit cost ratio
Rice-Rice	2.83	0.41	470	1.22	63650	151200	87550	364.8	2.38
Rice-Blackgram	3.10	0.42	498	1.23	55000	158800	103800	519.0	2.89
Rice-Cotton	10.83	0.44	575	1.27	100250	198520	98270	357.3	1.98
Rice-Sesame	3.53	0.41	485	1.21	54750	142580	87830	399.2	2.60
Rice-Maize	7.86	0.43	562	1.23	63700	181160	117460	522.0	2.84
Rice-Castor	15.54	0.46	598	1.30	57730	179090	121360	433.4	3.10
SEm±	4.1	0.007	6.8	0.16	-	-	-	-	-
CD (P=0.05)	12.2	0.02	20.3	0.046	-	-	-	-	-

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Evaluation of seed dressing chemicals for the management of sucking pests in summer groundnut (*Arachis hypogaea* L.)

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ABSTRACT

Field experiments were conducted during summer seasons of 2009-11 to determine the effectiveness of seed treatment with imidacloprid 600 FS @ 2 ml/kg seed, imidacloprid 600 FS @ 4 ml/kg seed, thiamethoxam 70 WS @ 1 g/kg seed, thiamethoxam 70 WS @ 2 g/kg seed, acetamiprid 20 SP @ 2 g/kg seed and carbosulfan 25 DS @ 5 g/kg seed against jassids and thrips in groundnut. Results indicated that significantly lowest population of jassids and thrips was recorded in the treatment of imidacloprid 600 FS @ 4 ml/kg seed and thiamethoxam 70 WS @ 2 g/kg seed, respectively. The highest pod yield was recorded from imidacloprid 600 FS @ 4 ml/kg seed (1962 kg/ha) followed by imidacloprid 600 FS @ 2 ml/kg seed (1947 kg/ha), thiamethoxam 70 WS @ 2 g/kg seed (1917 kg/ha) and thiamethoxam 70 WS @ 1 g/kg seed (1897 kg/h). The highest incremental cost benefit ratio (1: 8.76) was observed in imidacloprid 600 FS @ 2 ml/kg seed followed by imidacloprid 600 FS @ 4 ml/kg (1: 5.47), thiamethoxam 70 WS @ 1 g/kg seed (1:4.13) and thiamethoxam 70 WS @ 2 g/kg seed (1:2.60). Based on the efficacy and economics, the study suggests that seed treatment with imidacloprid 600 FS @ 2 ml/kg or thiamethoxam 70 WS @ 1 g/kg seed can be opted for inclusion in IPM programme against the sucking pests in groundnut.

Keywords: Groundnut, Imidacloprid, Jassids, Thrips

Groundnut (*Arachis hypogaea* L.) is one of the most important oilseed crops grown in India and contributes about 30 per cent of the total domestic supply of oil. Though India ranks first in area under groundnut cultivation, the productivity is quite low (1000 kg/ha) compared to that of USA (3000 kg/ha), China (2600 kg/ha), Argentina (2100 kg/ha) and Indonesia (1550 kg/ha). The reason for low productivity of groundnut is due to biotic and abiotic stresses during crop growth. Pests and diseases are the major biotic stresses for groundnut production (Venkataiah *et al.,* 2015; Divyadharsini *et al.,* 2016). Groundnut crop is attacked by about 90 species of insect pests. The sucking insect pest complex comprising thrips (*Scirtothrips dorsalis* Hood) and leafhopper (*Empoasca kerri* Pruthi) are the major pests of importance on groundnut specially when raised under summer conditions and bunch varieties are severely infested (David and Ramamurthy, 2011). Among the sucking pests attacking the groundnut crop, thrips species occur as a complex, starting from vegetative stage till the harvest of the crop. Both nymphs and adults inhabit the leaf terminals and flowers and cause irregular streaks on the opened leaves, distortion and sometimes contamination of the foliage with fecal matter. Thrips mainly feed by lacerating and sucking the sap from leaves and are known to transmit groundnut bud necrosis virus. In the recent years incidence of thrips on groundnut crop is increasing and known to cause yield loss to the tune of 14 to 40 per cent. Leafhoppers suck the sap from the leaves and petioles and mainly it prefers the first three terminal leaves and feeding symptoms induce yellowing of foliage that begins at the tip, known as hopper burn. heavy infestation on young plants cause stunting and leaf tip turn yellow with a typical 'v-shape' marking. On close examination of infected plants, nymphs can be seen on the underside of infected plants. Objective of the present study is to determine the effectiveness of the seed dressing chemicals in order to develop an effective, environmentally safe and sustainable pest management practice for jassids and thrips in groundnut crop.

MATERIALS AND METHODS

Field experiments were carried out during summer seasons of 2009-11 at Main Oilseeds Research Station, Junagadh on groundnut variety GG-6. Seven treatments were tested in randomized block design with four replications. Treatments *viz*., imidacloprid 600 FS @ 2 ml/kg seed, imidacloprid 600 FS @ 4 ml/kg seed, thiamethoxam 70 WS @ 1 g/kg seed, thiamethoxam 70 WS @ 2 g/kg seed, acetamiprid 20 SP @ 2 g/kg seed, carbosulfan 25 DS @ 5 g/kg seed and control were tested against jassids and thrips in summer groundnut crop. Respective seed treatment of insecticides was given to the seed at the time of sowing. The crop was sown at the spacing of 30 x 10 cm having gross and net plot size was 5.00 × 2.4 m and 4.0 x 1.8 m, respectively. All the agronomical practices were followed as per the recommendations. Observations of thrips and jassid population were recorded at 15 days after germination at an interval of 7 days and continued up to 35 days after

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germination. The groundnut crop was harvested at proper time. The pod and haulm yield for each treatment was recorded separately from the net plot area and was computed as converted into kilogram per hectare. The data on numbers were transformed into square root values and subjected to statistical analysis

RESULTS AND DISCUSSION

Pooled data presented in Table 1 indicated that significantly low population of jassids was recorded in all the treatments over untreated control. However, significantly the lowest population of jassids (0.57 jassids/3 leaves/plant) was recorded in the treatment of imidacloprid 600 FS @ 4ml/kg seed. It was followed by imidacloprid 600 FS @ 2 ml/kg seed, thiamethoxam 70 WS @ 2 g/kg seed, thiamethoxam 70 WS @ 1 g/kg seed, carbosulfan 25 DS @ 5 g/kg seed and acetamiprid 20 SP @ 2 g/kg seed were the next best treatments in reduction of jassids population. Maximum jassids population (1.99 jassids/3 leaves/plant) was recorded in control.

In case of thrips, significantly low population was recorded in all the treatments except acetamiprid 20 SP @ 2 g/kg seed over control. However, significantly the lowest population of thrips (0.57 thrips/3 leaves/plant) was recorded in the treatment thiamethoxam 70 WS @ 2 g/kg seed and it was statistically at par with seed treatment of thiamethoxam 70 WS @ 1 g/kg seed, imidacloprid 600 FS @ 4 ml/kg seed, imidacloprid 600 FS @ 2 ml/kg seed and carbosulfan 25 DS @ 5 g/kg seed. Maximum thrips population (1.49 thrips/3 leaves/plant) was recorded in control. The present findings are in confirmation with the results of Saradava (2004) who reported that thiamethoxam 0.005 per cent proved effective against jassid and thrips in groundnut. Venkanna *et al.* (2010) also indicated that imidacloprid @ 26.7 g a.i./ha proved most effective in controlling jassid and thrips.

Pooled data indicated that all the treatments except carbosulfan 25 DS @ 5 g/kg seed and acetamiprid 20 SP @ 2 g/kg seed gave significantly highest pod and haulm yield over control. Among all the treatments, significantly highest pod yield of 1962 kg/ha and haulm yield of 3066 kg/ha were recorded in the treatment of imidacloprid 600 FS @ 4 ml/kg seed and it was statistically at par with imidacloprid 600 FS @ 2 ml/kg seed, thiamethoxam 70 WS @ 2 g/kg seed and thiamethoxam 70 WS @ 1 g/kg seed.

Considering the increase in the pod yield of groundnut over control (Table 2), it was the highest in imidacloprid 600 FS @ 4 ml/kg seed (191 kg/ha). The treatments *viz.,* imidacloprid 600 FS @ 2 ml/kg seed (176 kg/ha), thiamethoxam 70 WS @ 2 g/kg seed (146 kg/ha) and thiamethoxam 70 WS @ 1 g/kg seed (126 kg/ha) were found next in order with respect of increase in pod yield over control. The remaining treatments *viz.,* carbosulfan 25 DS @ 5 g/kg seed and acetamiprid 20 SP @ 2 g/kg seed were found less than 22 kg/ha increase in yield over control. It is evident from the data presented in Table 2 that the net realization of different treatments varied from ₹ 12 to 6887/ha. The treatment of imidacloprid 600 FS @ 2 ml/kg seed recorded maximum net realization (₹ 6887/ha) followed by imidacloprid 600 FS @ 4 ml/kg seed (₹ 6872/ha), thiamethoxam 70 WS @ 1 g/kg seed (₹ 4314/ha) and thiamethoxam 70 WS @ 2 g/kg seed (₹ 4030/ha). The highest incremental cost benefit ratio (1:8.76) was also observed in imidacloprid 600 FS @ 2 ml/kg seed followed by imidacloprid 600 FS @ 4 ml/kg (1: 5.47), thiamethoxam 70 WS @ 1 g/kg seed (1:4.13) and thiamethoxam 70 WS @ 2 g/kg seed (1:2.60). Considering the effectiveness and economics of insecticides, seed treatment of imidacloprid 600 FS @ 2 ml/kg or thiamethoxam 70 WS @ 1 g/kg seed was found the most effective in reducing the jassids and thrips population in groundnut.

Table 1 Effect of seed dressing insecticides on sucking insect pests in groundnut

Treatment	No. of jassids/3 leaves/plant								No. of thrips/3 leaves/plant					
	2009		2010		2011		Pooled		2009		2011		Pooled	
Imidacloprid 600 FS @ 2 ml/kg seed	1.05*	(0.61)	1.05	(0.60)	1.23	(1.02)	1.11	(0.74)	0.87	(0.25)	1.43	(1.54)	1.15	(0.82)
Imidacloprid 600 FS @ 4 ml/kg seed	0.99	(0.47)	0.99	(0.48)	1.13	(0.78)	1.04	(0.57)	0.84	(0.20)	1.39	(1.44)	1.12	(0.74)
Thiamethoxam 70 WS @ 1 g/kg seed	1.36	(1.35)	1.25	(1.07)	1.44	(1.57)	1.35	(1.33)	0.80	(0.14)	1.35	(1.33)	1.08	(0.66)
Thiamethoxam 70 WS @ 2 g/kg seed	1.26	(1.09)	1.18	(0.90)	1.37	(1.37)	1.27	(1.11)	0.78	(0.11)	1.29	(1.16)	1.04	(0.57)
Acetamiprid 20 SP @ 2 g/kg seed	1.50	(1.75)	1.42	(1.51)	1.63	(2.16)	1.52	(1.80)	1.05	(0.61)	1.71	(2.41)	1.38	(1.40)
Carbosulfan 25 DS @ 5 g/kg seed	1.45	(1.59)	1.37	(1.39)	1.58	(2.01)	1.47	(1.66)	1.01	(0.51)	1.64	(2.20)	1.32	(1.25)
Control	1.60	(2.06)	1.46	(1.64)	1.67	(2.30)	1.58	(1.99)	1.09	(0.69)	1.73	(2.50)	1.41	(1.49)
SEm ±	0.03		0.03		0.03		0.02		0.03		0.04		0.02	
CD (P=0.05)	0.10		0.09		0.08		0.05		0.08		0.10		0.06	

*Square root transformed value; Data in parenthesis are retransformed value

Table 2 Effect of different treatments on yield and economics of groundnut

Treatment	Pod yield (kg/ha)	Pod yield increased over control	Haulm yield (kg/ha)	Total expenditure (₹)	Grass income (₹.)	Net return (₹)	ICBR
Imidacloprid 600 FS @ 2 ml/kg seed	1947	176	3054	888	7775	6887	1 : 8.76
Imidacloprid 600 FS @ 4 ml/kg seed	1962	191	3066	1536	8408	6872	1 : 5.47
Thiamethoxam 70 WS @ 1 g/kg seed	1897	126	3028	1380	5694	4314	1 : 4.13
Thiamethoxam 70 WS @ 2 g/kg seed	1917	146	3047	2520	6550	4030	1 : 2.6
Acetamiprid 20 SP @ 2 g/kg seed	1776	5	2826	864	231	-633	1 : 0.27
Carbosulfan 25 DS @ 5 g/kg seed	1793	22	2840	936	948	12	1 : 1.01
Control	1771	-	2814	-	-	-	-
SEm ±	24.1	-	36.2	-	-	-	-
CD (P=0.05)	68.4	-	102.7	-	-	-	-

ICBR - Incremental Cost Benefit Ratio

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Performance of oilseeds in India - a temporal analysis

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ABSTRACT

The present paper explores the performance of total oilseeds in India, using times series data, collected from 1949-50 to 2014-15. Nine annual oilseeds, which include seven edible oilseeds, *viz.,* groundnut, rapeseed-mustard, soybean, sunflower, sesame, safflower and niger along with two non-edible crops, *viz.,* castor and linseed are grown in the country, constitutes total oilseeds in the study. The total period from 1949-50 to 2014-15 was divided into four sub-periods i.e. period I, II, III and IV. An attempt was made to analyze the trends, Compound Annual Growth Rate (CAGR), decomposition analysis, instability analysis in the area, production, yield of total oilseeds. After analysis of the performance of oilseeds, it was concluded that there was a noteworthy performance in yield aspect of total oilseeds at the national level. Though there was an upward and significant growth in terms of the area, production and yield of total oilseeds over the study period, it was sluggish. There exists a gap between domestic demand and supply of oilseeds, which obligates us to import edible oils. The government has to implicate technological breakthroughs and enhance the productivity of oilseeds to offset the gap between production and consumption of oilseeds.

Keywords: CAGR, Decomposition analysis, Instability analysis, Oilseeds, Trends

India occupies a prominent place in global oilseeds scenario with 12-15 per cent of the area, 6-7 per cent of vegetable oil production and 9-10 per cent of the total edible oil consumption and 13.6 per cent of vegetable oil imports (FAO, 2014). Nine annual oilseeds, which include seven edible oilseeds *viz.,* groundnut, rapeseed-mustard, soybean, sunflower, sesame, safflower and niger along with two non-edible crops *viz*., castor and linseed are grown in the country, constitutes total oilseeds. In the case of major oilseeds, India ranks first in the production of groundnut, third in rapeseed-mustard and fifth in soybean (Sarada *et al.,* 2015). The country has achieved self-sufficiency in food grains production, in fact, it has become surplus in rice and wheat with mounting food stocks, but it is facing serious shortages of oilseeds (Govindaraj *et al.,* 2016). Although India is the 4th largest edible oil economy in the world and contributes about 10 per cent of the world oilseeds production, 6-7 per cent of the global production of vegetable oil and nearly 7 per cent of protein meal, India is one of the largest importers of edible oils in the world. Despite having the largest area under oilseeds in the world, India currently imports about 58 per cent of total oil requirement (12 million tonnes) at an exchequer of ₹ 68,000 crores (2014-15) (SEAI, 2016). Several studies were conducted in India quoting the performance of oilseeds. Swain (2007) studied the trends and variability in the growth of oilseeds production in Rajasthan. The study concluded that production of most of the oilseeds has increased mainly due to the area expansion. Thus he suggested that the level of oilseeds production can be increased in future only by increasing the yield rather than the area under oilseeds in Rajasthan. Rao *et al.* (2012) studied the performance of safflower in India using trend analysis, compound annual growth rates, instability analysis and decomposition analysis. They divided the study period into three based on inception of AICRP on safflower, TMO and trade liberalization and portrayed the scenario of safflower during these periods. Rambabu *et al*. (2014) examined the trends in the area, production, productivity of groundnut in Andhra Pradesh over a period of 1995-96 to 2010-2011. The specific objectives of the present study are to study the trends, Compound Annual Growth Rates (CAGR) in area, production and productivity of total oilseeds in India, to examine the effect of area, productivity and interaction on total oilseeds production and to estimate the instability analysis of total oilseeds.

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MATERIALS AND METHODS

The present study utilizes the time series data on area, production and productivity of total oilseeds, that was collected from various publications, *viz*., Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, Agricultural Statistics at a glance and Bureau of Economics and Statistics of Andhra Pradesh state. The total period from 1949-50 to 2014-15 was divided into four sub-periods.

Period-I	Before inception of AICRP on Oilseeds	1949-50 to 1965-66
Period-II	Establishment of AICRP on Oilseeds to the Genesis of Technology Mission on Oilseeds (TMO)	1966-67 to 1985-86
Period-III	TMO initiation to liberalization	1986-87 to 1999-2000
Period-IV	Post liberalization	2000-01 to 2014-15

Estimation of Compound Growth Rates (CGR): In order to estimate the CGR, the exponential time trend equation of the form:

$Y=a\ b^t$ ----------(1)
was used
It becomes linear when converted to log form, i.e.,
$Ln\ Y=Ln\ a + t\ Ln\ b_1$ where---------- (2)
Y: Variable whose growth rate is being computed
t: Time trend (1, 2…n)
a and b are regression coefficients to be estimated.

This form implies a constant growth rate over time. There will be a constant deceleration if $b < 0$. A value of $b=0$ indicates absence of any trend and a positive value for b indicates a constantly accelerating growth.

Using the compounding formula,

$Y_t=Y_0\ (1+r)^t$ ---------- (3a)
or
$Ln\ Y_t=Ln\ Y_0 + t\ Ln\ (1+r)$ ---------- (3b)
or
$Ln\ Y_t=A + tb$ where ---------- (3c)
$A = Ln\ Y_0$ and $B = Ln\ (1+r)$---------- (4)

This equation is the log linear form of the exponential function and gives CGR when differentiated with respect to t as follows:

$1/Y_t.dY_t/dt = Ln(1+r)$ ---------- (5)
$e^B = 1 + r$ ---------- (6)
$r = e^B - 1$ ---------- (7)

Thus the CGR (per cent) is given by $(e^B - 1) \times 100$
In this study, Y represents the area or production or productivity of the crops.

Estimating the effect of area, productivity and interaction on total oilseeds production: The following procedure was adopted to estimate the effect of area, productivity and their interaction on the production of total oilseeds:

$P_o = A_o * Y_o$
$P_n = Y_o * Y_n$
$P = P_n - P_o$ (Change in production)
A_o=Area in the base year
A_n=Area in the current year
Y_o=Yield in the base year
Y_n=Yield in the current year
ΔA=Change in Area (A_n-A_o)
ΔY=Change in Yield (Y_n-Y_o)

Finally,

$$P = P_n - P_o = \underbrace{A_o*\Delta Y}_{\text{Yield effect}} + \underbrace{Y_o*\Delta A}_{\text{Area effect}} + \underbrace{\Delta A*\Delta Y}_{\text{Interaction effect}}$$

The change in production when more pronounced through yield effect indicates that the productivity has contributed to the production.

In the present study, the estimation of the effect of area, productivity and their interaction on the production of total oilseeds was worked for the four respective periods as mentioned earlier. The triennium averages of the respective base and current years were considered for the estimation to minimize and/or eliminate the biases since the majority of total oilseeds is chiefly confined to cultivation under rainfed situations.

Instability analysis: Linear trend was fitted to the original data of the area, production and productivity of total oilseeds, for the study period. The trend coefficients were tested for their significance. Whenever the trend of series found to be significant; the variation around the trend rather than the variation around mean was used as an index of instability. The formula suggested by Cuddy and Della (1978) was used to compute the degree of variation around the trend. That is Co-efficient of variation was multiplied by the square root of the difference between the unity and coefficient of multiple determinations (R^2) in the cases where R^2 was significant to obtain the Instability Index.

RESULTS AND DISCUSSION

Trends in the area, production and yield of total oilseeds: Area, production and yield details of total oilseeds from the period I to period IV were furnished in Tables 1 to 4.

From the Table 1, it was observed that, there was an increasing trend in both area and production with minor fluctuations, while, the trend of yield component was increasing with lower fluctuations, in period I.

In period II, as portrayed in Table 2, area, production and yield of total oilseeds registered similar increasing trend with greater fluctuations in production component when compared to the period I.

In period III, area, production and yield of total oilseeds recorded an increasing trend with slight decreasing

fluctuations in 1989-99 and 1999-2000 (Table 3). In period IV, all the three components recorded a highly fluctuating upward trend (Table 4).

Table 1 Trend in area, production and yield of total oilseeds in India over the Period-I (from 1949-50 to 1965-66)

Years	Area ('000 ha)	Production ('000 tonnes)	Yield (kg/ha)
Period-I			
1949-50	10070	5260	522
1950-51	10730	5130	478
1951-52	11690	5030	430
1952-53	11180	4730	423
1953-54	10990	5370	489
1954-55	12520	6400	511
1955-56	12020	5650	470
1956-57	12490	6360	509
1957-58	12660	6350	502
1958-59	13000	7300	562
1959-60	13950	6560	470
1960-61	13770	6980	507
1961-62	14770	7280	493
1962-63	15340	7390	482
1963-64	14820	7130	481
1964-65	15260	8560	561
1965-66	15910	6510	409

Table 2 Trend in area, production and yield of total oilseeds in India over the Period-II (from 1966-67 to 1985-86)

Years	Area ('000 ha)	Production ('000 tonnes)	Yield (kg/ha)
Period-II			
1966-67	15000	6430	429
1967-68	15670	8300	530
1968-69	14470	6850	473
1969-70	14810	7330	495
1970-71	16640	9630	579
1971-72	17270	9080	526
1972-73	15790	7140	452
1973-74	16900	9390	556
1974-75	17310	9150	529
1975-76	16920	10610	627
1976-77	16470	8430	512
1977-78	17170	9660	563
1978-79	17710	10100	570
1979-80	16940	8740	516
1980-81	17600	9370	532
1981-82	18910	12080	639
1982-83	17760	10000	563
1983-84	18690	12690	679
1984-85	18920	12950	684
1985-86	19020	10830	569

Compound Annual Growth Rates (CAGR) of area, production and yield of total oilseeds: The CAGR of the area, production and yield of total oilseeds in period I to period IV were worked out and presented in Table 5.

Table 3 Trend in area, production and yield of total oilseeds in India over the Period-III (from 1986-87 to 1999-2000)

Years	Area ('000 ha)	Production ('000 tonnes)	Yield (kg/ha)
Period-III			
1986-87	18630	11270	605
1987-88	20130	12650	628
1988-89	21900	18030	823
1989-90	22800	16920	742
1990-91	24150	18610	771
1991-92	25890	18600	718
1992-93	25240	20110	797
1993-94	26900	21600	803
1994-95	25300	21420	847
1995-96	25960	22110	852
1996-97	26340	24390	926
1997-98	26120	21320	816
1998-99	26230	24750	944
1999-00	24280	20720	853

Table 4 Trend in area, production and yield of total oilseeds in India over the Period-IV (from 2000-01 to 2014-15)

Years	Area ('000 ha)	Production ('000 tonnes)	Yield (kg/ha)
Period-IV			
2000-01	22770	18400	808
2001-02	22640	20660	913
2002-03	21150	14840	702
2003-04	23670	25190	1064
2004-05	27520	24350	885
2005-06	27860	27980	1004
2006-07	26510	24290	916
2007-08	26690	29760	1115
2008-09	27600	27700	1006
2009-10	25959	24882	958
2010-11	27224	32479	1193
2011-12	26308	29799	1133
2012-13	26484	30940	1168
2013-14	28051	32749	1168
2014-15	25596.2	27510.8	1075

Table 5 Comparison of Compound Annual Growth Rates (CAGR) of area, production and yield of total oilseeds in India over the Period-I to Period-IV

Particulars	CAGR (%)		
	Area	Production	Yield
Period-I	2.71	2.86	0.14^{NS}
Period-II	1.22	2.68	1.44
Period-III	2.06	4.66	2.54
Period-IV	1.26	3.89	2.59

Note: All are significant at 1 per cent, except the yield in period-I

In the period I, production recorded the highest growth rate of 2.86 per cent, followed by area (2.71 %) and yield (0.14 %). The growth rate of yield was to be non-significant. In period II, production registered the highest growth rate of 2.68 per cent, followed by yield (1.44 %) and area (1.22 %). When compared to the period I, it was observed that growth rates of both production and area have declined, while the growth rate in yield was increased. In period III, highest growth rates were observed in production (4.66 %), followed by yield (2.54 %) and area (2.06 %). When compared to period II, growth rates of all the three components was increased. In period IV, production registered the highest growth rate of 3.89 per cent, while it was followed by growth rates of yield (2.59 %) and area (1.26 %). It was conspicuous that there was significant raise CAGR of yield component from 0.148 per cent in period I to 2.59 per cent in period IV. The results of the growth rates inferred that government policies and programmes like AICRP on Oilseeds, Technology Mission on Oilseeds, liberalization showed a positive and significant impact on the productivity of total oilseeds.

Effect of the area, productivity and interaction on total oilseeds production: The contribution of area and productivity to the total production of total oilseeds were analyzed using decomposition analysis and presented in Table 6.

It was evident from the result that, the production of oilseeds was influenced by the yield effect, which was 58.69, 50.41 and 44.74 per cent in period IV, period II and period III, respectively. Contrary to that, in period I, production of oilseeds was influenced by the area effect, with 95.24 per cent.

In the period I, production was chiefly contributed by area effect. However, a meager contribution of 3.37 per cent is only contributed by yield effect. This inferred that the production of total oilseeds was stunted due to the restriction of total oil oilseeds cultivation to marginal lands coupled with poor management practices and incidence of pests and diseases. Lower contribution of yield effect concluded that the technology has not made any positive impact on the total oilseeds production during this period. In period II, total oilseeds production was contributed majorly (50.41 %) by yield effect, while 36.75 per cent of contribution was made by area effect. This inferred that AICRP on Oilseeds enhanced total oilseeds production through technology implications. In period III, the production of total oilseeds was influenced majorly (44.74%) by yield effect, while the area effect also contributed to 43.48 per cent. This scenario gives a clear indication that due to trade liberalization there was the almost equal contribution of both area and yield effect. In period IV, it was observed that yield effect was more pronounced than area effect in contribution to total oilseeds production, which reflected a positive impact of technologies and trade liberalization on total oilseeds production.

Instability in the area, production and yield of total oilseeds: The details pertaining to the instability of total oilseeds was estimated for area, production and yield components and were presented in Table 7.

A perusal of Table 7, showed that in period I, the area was stable, when compared to production and yield components. High level of instability was observed in yield component, with an instability index of 1.00. Period II also registered similar instability scenario, with the stable area, followed by relatively unstable production and highly unstable yield, with an instability index of 0.72. It was also noticed that, though instability in the area, production components was increased from the period I to period IV, there was a decline in instability from the period I to period II with respective to yield component. In period III, production component was stable, when compared to area and yield components. Highest instability was noticed in the area (instability index of 0.64), which is followed by yield (instability index of 0.57). It was also observed that there was an increase of instability in area and production, a decline of instability in yield component when compared to period II. In period IV, area registered highest instability (instability index of 0.77), followed by yield and production, with instability indices of 0.65 and 0.63, when compared to period III, there was an increase of instability in all the three components *viz*., area, production, and yield. At a glance, over the study period from the period I to IV, it was noticed that, though there were fluctuations in instability of all three components, there was a continuous increasing trend in instability of area, while it was in declining in yield component.

Table 6 Decomposition analysis of area, production and yield of total oilseeds in India over the Period I to Period IV

	Yield effect	Area effect	Interaction effect
Period-I	3.37	95.24	1.40
Period-II	50.41	36.75	12.83
Period-III	44.74	43.48	11.78
Period-IV	58.69	29.35	11.97

Table 7 Instability analysis of area, production and yield of total oilseeds in India over the Period-I to Period-IV

Particulars	Area	Production	Yield
Period-I			
Mean	13010.00	6352.35	488.18
Standard Deviation	1791.70	1039.96	41.96
Coefficient of Variation	13.77	16.37	8.60
R^2	0.95	0.75	0.01
Instability Index	0.22	0.50	1.00
Period-II			
Mean	16998.50	9438.00	551.15
Standard Deviation	1352.80	1814.10	68.03
Coefficient of Variation	7.96	19.22	12.34
R^2	0.79	0.65	0.47
Instability Index	0.45	0.59	0.72
Period-III			
Mean	24276.43	19464.29	794.64
Standard Deviation	2522.04	3888.97	97.38
Coefficient of Variation	10.39	19.98	12.25
R^2	0.60	0.71	0.67
Instability Index	0.64	0.54	0.57
Period-IV			
Mean	25735.48	26101.99	1007.19
Standard Deviation	2152.89	5125.64	143.64
Coefficient of Variation	8.37	19.64	14.26
R^2	0.41	0.60	0.58
Instability Index	0.77	0.63	0.65

Conclusions and policy implications: In period I, before the inception of AICRP on oilseeds, the performance of total oilseeds at the national level was satisfactory, except in the yield component. There was a scope of enhancing the yield of total oilseeds, which emphasized the inception of AICRP on Oilseeds. In period II, after the inception of AICRP on Oilseeds, the growth rates of yield component of total oilseeds at national level enhanced, which inferred a positive impact of oilseeds at the national level. In period III, Genesis of TMO had almost doubled the growth rates of production component and a significant rise in yield performance was also noticed. This scenario explained the appreciable impact of TMO on the overall performance of total oilseeds. In period IV, post liberalization period brought a decline in performance of area and production components. However, yield performance was increased, when compared to previous periods.

After analysis of the performance of oilseeds, it was concluded that there was a noteworthy performance in yield aspect of total oilseeds at the national level. Though there was an upward and significant growth in terms of area, production and yield of total oilseeds in India, it was sluggish. There exist a gap between domestic demand and supply of oilseeds (Jha *et al.,* 2012), which obligates us to

import edible oils. It can be suggested that government has to intervene and enhance the productivity of oilseeds to offset the gap between production and consumption of oilseeds by adopting proper strategies, technological breakthroughs should be implicated in order to improve the yield of total oilseeds on par with total food grains, socio-economic impact assessment studies, supply chain management studies, value chain analysis studies should be conducted from agricultural economics perspective, oilseeds farming and appropriate measures should be adopted to aid in coordinated researches and care should be taken on value addition which enhances the revenue from oilseeds.

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Physio-biochemical evaluation of soybean (*Glycine max* L.) genotypes exhibiting variable seed coat colour

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ABSTRACT

Eighteen promising soybean genotypes having different seed coat colour i.e. yellow, green, brown and black were examined for physio-biochemical differences. The highest mean crude protein content was recorded in brown (42.86%), followed by yellow coloured seeds. The yellow coloured seeds recorded the highest mean crude fat content (19.86%). The mean crude fibre content was highest in brown seeds (6.36%), followed by black coloured seeds. Mean seed coat lignin (16.60%), trypsin inhibitor (62.81 TIU g^{-1}) in defatted flour and seed coat peroxidase activity (530 ηmoles H_2O_2 decomposed mg^{-1} protein min^{-1}) was highest in black coloured seeds. The lowest mean per cent mechanical damage was recorded in black coloured genotypes by ferric chloride test and in brown coloured genotypes by sodium hypochlorite test. The highest seed coat proportion, mean mechanical strength and the lowest mean EC was recorded in black coloured seeds. Mean per cent germination, seed vigour index-I as well as seed vigour index-II and hundred seed weight were recorded highest in yellow seed coat coloured soybean genotypes.

Keywords: Anti-nutritional factors, Physio-biochemical parameters, Seed colour, Soybean

Soybean (*Glycine max* L.) has become a miracle crop of the twentieth century and is often designated as a 'Golden bean' because of its triple use as food, feed and industrial raw material. The seeds of soybean are very nutritious those fully dependent on vegetarian diet on an account of its richness in protein, fat, carbohydrates, minerals and salts. It also provides vitamin A, B and D. Soybean seed also contains some anti-nutritional factors like trypsin inhibitors. The soybean seeds found in variable seed colour like yellow, black, white, green etc. having different biochemical composition. Raut *et al.* (1998) reported highest oil content in yellow-coloured seeds, followed by green and black. Since coating of the soybean seed is very thin and low in lignin content provides little protection to the fragile radicle which lies in a vulnerable position directly beneath the seed coat. Due to this fact, mechanical damage is one of the causes of great loss in soybean seed quality during harvest and processing (Franca Neto and Henning, 1984). The occurrence of genetic variability in seed resistance to mechanical damage among different soybean cultivars has already been demonstrated (Carbonell and Krzyzanowski, 1995).

In addition to lignin, peroxidase played an important role in various metabolic steps during lignin and suberin formation (Quiroga *et al*., 2000). The predominant trypsin inhibitors in soybeans are located with the main storage protein in cotyledon (Horisberger *et al*., 1986). Arefrad *et al*. (2013) reported that the genotypes with low levels of trypsin and chymotrypsin inhibitors especially for Bowman-Birk Protease Inhibitor (BBI) protein could have a significant role from nutritional point of view. Although soybean protein products require heat processing to achieve maximum nutritional value, partially through trypsin inhibitor denaturation, trypsin inhibitor also display anti-carcinogenic properties. Thus, in view of above, the present research was undertaken on physio-biochemical evaluation of soybean genotypes exhibiting variable seed coat colour.

The seed materials of 18 soybean genotypes were collected immediately after the harvesting from Agricultural Research Station, Digraj, Sangli District, Maharashtra. The collected seeds were categorized into yellow, black, brown and green on the basis of seed coat colour. The biochemical parameter like crude protein, crude fat and crude fibre were determined according to method AOAC (2005). The seed coat lignin content was determined as per jute titration method given by Hussain *et al*. (2002). Trypsin inhibitor assay was performed as per the method of Erlanger *et al.* (1961). The peroxidase activity was assayed as per the procedure given by Cakmak and Horst (1991) with modifications by Santos *et al.* (2002).

Seed hardness or mechanical strength of 100 seeds in four replications of each treatment was measured with the help of Universal testing machine (Make-Germany) and hardness was expressed in Newton. Standard procedures were used for physiological analyses of seed *viz*., germination (%) (Anonymous, 1999), seed vigour index (SVI) (Abdul-Baki and Anderson, 1973), electrical conductivity (EC) (dSm^{-1}) (Loeffler *et al.*, 1988), mechanical damage determination (%) by ferric chloride test (Agrawal, 1995) and sodium hypochlorite test (Van *et al.,* 2000), seed coat proportion (%) (Hoy and Gamble, 1985), seed density (Deshpande *et al.*, 1993) and 100-seed weight (g). Physio-biochemical analyses were carried out with three replications. Statistical analysis carried out using completely randomised design.

The data on biochemical evaluation of soybean seeds based on seed coat colour are reported in Table 1. The crude protein content in various soybean genotypes was ranged from 40.50 to 43.63 per cent. The significantly highest mean crude protein content was recorded in brown coloured seeds, followed by yellow and black and the lowest in green. The highest crude protein content of 43.63 per cent was recorded in brown coloured soybean genotype KDS-1035. Results are in agreement with the literature values for crude protein content, ranged from 37.0-45.0 per cent (Yan-sheng *et al*., 2012), 38-42 per cent (Guillon and Champ, 2002).

The crude fat content in the seeds of different soybean genotypes ranged between 17.57 to 20.11 per cent. The statistically highest mean crude fat content was observed in all the yellow coloured seeds, followed by black, brown and green. The highest of 20.11 per cent crude fat content was recorded in KDS-726. The results are in agreement with Raut *et al.* (1998) who showed that highest mean oil content in yellow coloured soybean seeds, followed by green and black seeds. The crude fibre content in the seeds of various soybean genotypes ranged between 5.11 to 6.80 per cent. The highest mean crude fibre content was observed in brown seeds, followed by black, yellow and green. The significantly highest crude fibre content of 6.80 per cent in a brown coloured seeds of genotype KDS-1041, whereas the lowest of 5.11 per cent was recorded in green coloured genotype EC-456600. Redondo-Cuenca *et al.* (2006) reported that the fibre content in yellow coloured soybean seeds were higher than green coloured soybean seeds.

The seed coat lignin content in the various soybean genotypes ranged between 5.06 to17.38 per cent. The highest mean seed coat lignin was recorded by black seeds (16.6%), followed by brown (13.50 %), whereas nearly half of lignin content was observed in green and yellow seeds. The black coloured genotype KDS-1034 recorded significantly highest seed coat lignin of 17.38 per cent, whereas the lowest of 5.06 per cent in yellow coloured genotypes KDS-344 and JS-9305. The higher lignin content observed in black coloured genotypes exhibited higher peroxidise activity may be due to role of peroxidise in lignifications process (Quiroga *et al.*, 2000). Higher lignin content is required for storage point of view.

The seed coat peroxidase activity in the seed coat of various soybean genotypes was ranged from 398-540 ηmoles H_2O_2 decomposed mg^{-1} protein min^{-1}. In present investigation, the highest mean seed coat peroxidase activity was observed in black, followed by brown, and lowest in green and yellow seed coat. The statistically highest seed coat peroxidase activity of 540 and lowest 398 ηmoles H_2O_2 decomposed mg^{-1} protein min^{-1} was recorded in black seed coat coloured genotype Kalitur and yellow coloured genotype KDS-726, respectively. The values reported by Capeleti *et al*. (2005) for seed peroxidase activity (162-586 ηmol $min^{-1}g^{-1}$) are in agreement with present study.

The trypsin inhibitor in the grains of various soybean genotypes ranged between 49.70-64.69 TIU g^{-1} of defatted flour. The highest mean trypsin inhibitor content was recorded in black coloured genotypes, followed by brown, whereas lowest in green and yellow seeds. The lower values for trypsin inhibitor was recorded in most of the yellow genotypes among them KDS-726 exhibited of 49.70 TIU g^{-1} defatted flour. Whereas, the statistically highest trypsin inhibitor of 64.69 TIUg-1 defatted flour was recorded in black coloured soybean genotype Birsa Soya 1. Guillamon *et al*. (2008) studied trypsin inhibitor in the soybean seeds was ranged from 43-84 TIU g^{-1} defatted flour. Valdebouze *et al*. (1980) showed that trypsin inhibitor in whole soybean seed was 52.20 TIU g^{-1} and defatted flour was 64.80 TIU g^{-1}. The higher trypsin inhibitor containing black and brown coloured genotypes are better for seed storage point of view and low trypsin inhibitor containing yellow and green genotypes are better for human consumption as it inhibits trypsin secreted in small intestine.

The data on physiological evaluation of soybean seeds based on seed coat colour reported in Table 2a and b. The highest mean mechanical strength of 101.35 N was observed in black seeds, followed by brown, yellow and green. The highest mechanical strength of 108.49 N was recorded by a black coloured genotype Birsa Soya 1, whereas the lowest mechanical strength of 62.31 N was recorded in a yellow seed coat coloured genotype KDS-730. Values for mechanical strength are much higher in black and brown than yellow and green.

The highest mean per cent germination was recorded in yellow coloured soybean seeds, followed by green, brown and black. The significantly highest per cent germination 90 was recorded in the yellow coloured genotypes seeds of KDS-753 and KDS-344, the lowest of 83 in brown coloured genotype KDS-1042 and also in black coloured genotypes, Kalitur and LVS-2011.117. Lower per cent germination may be due to higher lignin and mechanical strength in black and brown seeds. Both mean seed vigour index (SVI) I and II were the highest in yellow coloured seeds, whereas the lowest in black coloured seeds. The yellow coloured genotype KDS-753 recorded significant highest values for SVI-I (1591) and JS-9305 for SVI-II (89).

The electrical conductivity (EC) of various soybean genotypes ranged from 0.29-0.58 dSm^{-1}. The mean electrical conductivity was lowest in black and brown coloured genotypes, whereas the highest in green and yellow seeds. As regard to the EC in different genotypes, the lowest of 0.29 dSm^{-1} was recorded in a black coloured genotype Birsa Soya 1, whereas significantly highest of 0.58 dSm^{-1} was recorded in a yellow coloured genotype KDS-753. The higher EC represents higher seed damage.

The seed coat proportion in the various soybean genotypes ranged between 8.32 to 11.20 per cent. The highest seed coat proportion of 10.38 per cent was recorded

in black coloured genotypes, followed by brown, green and yellow coloured soybean genotypes. The significantly highest seed coat proportion of 11.20 per cent was recorded in a black coloured genotype Birsa Soya 1, whereas the lowest seed coat proportion of 8.32 per cent was found in a green coloured genotype EC-34147. Kuchlan *et al.* (2010) reported that the seed coat proportion in soybean seeds ranged from 7.07 to 11.25 per cent. The highest mean seed density was observed in green and yellow seeds, followed by brown and black seeds. The highest seed density of 1.19g/cm^3 was recorded in yellow (KDS-753, KDS-726), green (EC-34147), brown (KDS-1035, KDS-1031) and black (Birsa Soya 1) coloured genotypes. No variation was seen among the different colours of seed. Kuchlan *et al.* (2010) concluded that the seed density of soybean varieties ranged from 1.13 to 1.19 g/cm^3.

The mean 100-seed weight in the various soybean genotypes ranged between 9.09-13.60 g. The highest mean 100-seed weight was observed in yellow seeds, followed by green, brown and black. However, not significantly difference observed among the mean values. The yellow seed coat coloured genotype KDS-726 recorded significantly highest 100 seed weight of 13.60 g, whereas the lowest of 9.09 g was recorded in a black seed coat coloured genotype LVS-2011.117. Kuchlan *et al*. (2010) reported that the 100-seed weight of soybean seed ranges from 8.37 to 14.83.

The lowest mean per cent mechanical damage was recorded in black coloured seeds by $FeCl_3$ test, whereas the lowest mean per cent mechanical damage was observed in brown coloured soybean seeds by sodium hypochlorite test. The highest mean per cent mechanical damage was observed in yellow coloured soybean genotypes by both the tests. As regards to $FeCl_3$ test, the statistically lowest damage was recorded in most of the black and brown coloured genotypes. Similarly, results were noticed in sodium hypochlorite test. The highest per cent mechanical damage was recorded in yellow coloured genotype KDS-344 in both the tests.

Table 1 Biochemical evaluation of soybean seeds based on seed coat colour

Genotypes	Crude protein (%)	Crude fat (%)	Crude fibre (%)	Lignin (%)	Peroxidase (ηmoles H_2O_2 decomposed mg^{-1} protein min^{-1})	Trypsin inhibitor (TIU g^{-1}) defatted flour
Yellow colour seed						
KDS-753	41.87	19.67	5.50	5.22	421.15	50.53
KDS-730	41.03	19.67	5.60	7.33	420.00	50.24
JS-9305	43.07	20.03	5.90	5.06	433.00	51.70
KDS-726	43.38	20.11	5.20	9.23	398.00	49.70
KDS-344	43.30	19.80	5.20	5.06	401.67	51.80
Mean	42.53	19.86	5.48	6.38	414.76	50.79
Green colour seed						
EC-456600	40.50	18.30	5.11	6.72	422.00	53.85
EC-34147	42.32	18.13	5.60	6.89	420.00	51.85
EC-528628	41.00	18.80	5.50	6.58	432.33	50.60
Mean	41.27	18.41	5.40	6.73	424.78	52.10
Brown colour seed						
KDS-1025	43.00	17.57	6.30	13.05	504.00	61.67
KDS-1035	43.63	18.40	6.50	11.67	516.00	57.67
KDS-1042	42.60	19.12	6.40	14.71	511.00	59.30
KDS-1041	42.37	19.13	6.80	13.52	521.00	60.17
KDS-1031	42.70	18.61	5.80	14.56	503.00	57.46
Mean	42.86	18.57	6.36	13.50	511.00	59.25
Black colour seed						
Birsa Soya 1	42.00	18.21	6.40	15.67	533.00	64.69
Kalitur	43.10	18.77	5.50	16.64	540.00	62.87
KDS-1034	41.10	19.07	6.50	17.38	514.00	62.97
VLS-65	43.30	18.82	6.50	16.11	530.00	61.87
LVS2011.117	42.20	18.68	6.30	17.19	533.00	61.66
Mean	42.34	18.71	6.24	16.60	530.00	62.81
Range	40.50-43.63	17.57-20.11	5.11-6.80	5.06-17.38	398-540	49.70-64.69
S.E±	0.42	0.18	0.06	0.10	0.70	0.36
CD (P=0.05)	1.20	0.54	0.17	0.31	2.09	1.11

Table 2a Physiological evaluation of soybean seeds based on seed coat colour

Genotypes	Mechanical strength (N)	Germination (%)	Seed vigour index		Electrical conductivity (dSm^{-1})
			SVI-1	SVI-2	
Yellow colour seed					
KDS-753	78.07	90.00	1591.00	83.17	0.58
KDS-730	62.31	89.00	1561.00	79.87	0.56
JS-9305	63.00	89.00	1571.00	89.00	0.56
KDS-726	91.00	89.00	1521.00	83.00	0.58
KDS-344	90.93	90.0	1501.67	84.00	0.55
Mean	77.06	89.40	1549.00	83.80	0.57
Green colour seed					
EC-456600	65.00	88.00	1561.00	85.00	0.53
EC-34147	76.20	89.00	1531.00	82.00	0.54
EC-528628	80.97	86.00	1509.00	82.00	0.53
Mean	74.06	87.66	1533.67	83.07	0.53
Brown colour seed					
KDS-1025	99.33	85.00	1481.00	80.00	0.32
KDS-1035	107.67	84.00	1470.00	82.00	0.33
KDS-1042	98.00	83.00	1501.00	79.00	0.30
KDS-1041	86.00	87.00	1502.67	81.00	0.31
KDS-1031	98.20	84.00	1491.00	85.50	0.31
Mean	97.84	84.60	1489.20	81.40	0.31
Black colour seed					
Birsa Soya 1	108.49	84.00	1491.00	78.0	0.29
Kalitur	97.03	83.00	1461.00	79.53	0.30
KDS-1034	103.07	85.00	1471.00	78.00	0.31
VLS-65	97.07	86.00	1421.00	80.60	0.31
LVS-2011.117	101.07	83.00	1401.67	81.00	0.30
Mean	101.35	84.20	1449.00	79.42	0.30
Range	62.31-108.49	83-90	1401-1591	78-89	0.29-0.58
S.E±	0.84	0.71	0.73	0.70	0.01
CD (P=0.05)	2.40	2.10	2.15	2.10	0.03

In conclusion, within eighteen promising soybean genotypes examined for physio-biochemical parameters, the yellow coloured soybean genotypes recorded the highest crude protein, germination percentage, SVI-I and II, hundred seed weight and seed density with lower trypsin inhibitor. Whereas, the black coloured soybean genotypes recorded highest seed coat lignin, peroxidise activity, trypsin inhibitor, seed coat proportion and mechanical strength with lowest electrical conductivity and mechanical damage. The brown coloured soybean genotypes recorded highest crude protein, crude fibre and lowest mechanical damage. Overall, the yellow and green seeds were found nutritionally better, while black and brown seeds may be good for storage. Based on seed coat colour large number of germplasm could be screened for particular biochemical trait such as lignin, mechanical strength etc. Thus, present study will be useful in developing new soybean varieties with desirable traits.

Table 2b Physiological evaluation of soybean seeds based on seed coat colour

Genotypes	Seed coat proportion (%)	Seed density (g/cm3)	100-seed weight (g)	Mechanical damage	
				By ferric chloride test (%)	By sodium hypochlorite test (%)
Yellow colour seed					
KDS-753	8.53	1.19	12.75	16.00	14.00
KDS-730	9.63	1.17	9.98	10.00	10.00
JS-9305	9.20	1.17	10.14	16.00	14.00
KDS-726	8.87	1.19	13.60	16.00	14.00
KDS-344	8.72	1.18	10.50	17.00	14.00
Mean	8.99	1.18	11.39	15.00	13.20
Green colour seed					
EC-456600	9.34	1.18	11.26	16.00	14.00
EC-34147	8.32	1.19	12.14	14.00	13.00
EC-528628	9.75	1.17	10.60	10.00	11.97
Mean	9.14	1.18	11.33	13.33	12.99
Brown colour seed					
KDS-1025	10.17	1.13	9.48	10.00	8.00
KDS-1035	10.19	1.19	12.70	8.00	6.00
KDS-1042	9.70	1.18	10.60	9.77	8.00
KDS-1041	10.06	1.18	10.60	8.00	10.00
KDS-1031	9.96	1.19	12.17	7.90	8.00
Mean	10.02	1.17	11.11	8.73	8.00
Black colour seed					
Birsa Soya	11.20	1.19	12.00	8.00	10.00
Kalitur	10.13	1.15	9.56	8.00	7.00
KDS-1034	10.45	1.17	11.00	8.00	10.00
VLS-65	9.93	1.18	11.23	10.00	9.00
LVS2011.117	10.17	1.15	9.09	8.00	6.00
Mean	10.38	1.16	10.46	8.40	8.20
Range	8.32-11.20	1.15-1.19	9.09-13.60	7.90-17	6-14
S.E±	0.11	0.010	0.11	0.24	0.21
CD (P=0.05)	0.32	0.03	0.33	0.65	0.60

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Study on genetic divergence analysis of indigenous and exotic lines of linseed (*Linum usitatissimum* L.) based on morphological and quality traits

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ABSTRACT

Thirty genotypes of linseed were analysed for sixteen morphological traits to investigate the genetic diversity between and within the genotypes. Field data was initially subjected to analysis of variance. There were highly significant differences among the genotypes for all the traits indicating the presence of adequate variability among the genotypes and the possibility to undertake cluster analysis. The phenotypic divergence and relative importance were estimated by multivariate analysis. The cluster analysis based on Tocher's method classified the genotypes into nine major groups. The maximum distance was found between clusters VI and VIII. The genotypes from these clusters can be utilized for the improvement of linseed yield and obtaining good segregants in linseed breeding programs.

Keywords: D^2-statistics, Genetic diversity, Morphological and quality traits, Linseed

Linseed or flax seed (*Linum usitatissimum* L., 2n = 2x = 30), is an annual self-pollinated crop which is commercially grown as a source of stem fibre and seed oil. The genus *Linum* belongs to the family Linaceae and to order Geraniale and is the only species in the family having both cultivated and wild species. The species is believed to have originated in either the Middle East or Indian regions and spread throughout Asia and Europe, prior to its introduction into the New World (Soto-Cerda *et al.,* 2013). Almost all the species are annual herbs and some are shrubs. Linseed is the only species with non-dehiscent or semi-dehiscent capsules suitable for modern cultivation. Linseed contains about 35-45 per cent oil which is high in un-saturated fatty acids, especially linolenic acid and 20-25 per cent protein (Arora *et al.,* 2003). The seed oil is utilized for the fabrication of various biodegradable products such as high quality drying oil, paints, varnishes and linoleum flooring. In addition, interest in flax oil and seeds as food products has increased due to their health benefits (Biradar *et al*., 2016). Assessment of genetic divergence helps in reducing the number of breeding lines to be maintained and the progenies derived from diverse parents are expected to show a broad spectrum of genetic variability and provide a greater scope for isolating superior recombinants/segregants. Cluster analysis had traditionally been used to distinguish the accessions from each other, their relationships and to get useful information on estimates of genetic diversity. In order to get transgressive segregation, genetic distance between parents is necessary. Effective hybridization program between genetically diverse parents will lead to considerable amount of heterotic response in F_1 hybrids and broad spectrum of variability in segregating generations. Initial diversity assessments in flax were carried out using morphological parameters (Bibi *et al.,* 2013). Flax germplasm collections contain thousands of accessions of *L. usitatissimum* and related species, of which, subsets were assessed for the extent of genetic diversity for morphological traits. Several workers studied the genetic diversity, clustering pattern, relative contribution of different characters toward divergence and effectiveness of selection characteristics (Sivaraj *et al.,* 2012; Tyagi *et al.,* 2014; Dikshita and Sivaraj, 2015; Paul *et al.,* 2016). The present studies were thus planned to estimate genetic diversity in linseed germplasm using cluster analysis on the basis of morphological traits and to identify the best parent lines for using in future breeding programs.

A total of 30 genotypes comprising of 14 Indian and 16 exotic linseed lines/varieties from various countries of linseed were used in the present study (Table 1). All the genotypes, including three checks *viz.,* Him Alsi 1, Himani and Nagarkot were raised at the experimental farm of the Department of Crop Improvement, CSK HPKV, Palampur, Himachal Pradesh during *rabi* season of 2013-14 for recording the morphological data. The experiment was laid out in randomized block design with 3 replications having plot size of 1m × 0.75 m. Row to row and plant to plant distance was kept at 25 cm× 10 cm. Data were recorded on sixteen different quantitative traits namely, days to 50 per cent flowering, days to maturity, plant height (cm), technical height (cm), number of primary branches per plant, number of secondary branches per plant, aerial biomass, straw yield, retted straw yield, fibre yield, capsules per plant, seeds per capsule, 1000-seed weight (g), seed yield per plant (g), harvest index (%) and oil content (%). Five competitive plants were tagged randomly from each genotype in each replication for recording field observations for all the traits except for days to 50 per cent flowering and days to maturity which was observed on plot basis. The data recorded for each genotype at each environment were subjected to

statistical analysis. Harvest index in percent was calculated by dividing the grain yield per plant in grams by the biological yield per plant in grams. Biochemical analysis was done using NMR for oil content analysis. The phenotypic divergence among the accessions was estimated by the multivariate techniques by following Tocher's cluster analysis and Mahalanobis D^2-statistics to measure the genetic distance.

The analysis of variance revealed sufficient variability due to genotypes for all the traits (Table 2) indicating thereby wide range of genetic variability and scope for selection for these traits. Significant variation for all the characters was also observed by earlier workers (Bibi *et al.,* 2013; Tyagi *et al.,* 2014; Sharma and Paul, 2016; Paul *et al.,* 2016). The cluster formation distinguished the genotypes into nine diversity classes, different members within a cluster being assumed to be more closely related in terms of traits under consideration with each other than those members in different clusters (Fig. 1). Distribution of different groups revealed that there were eleven genotypes in clusters I, five genotypes in cluster II, six genotypes in cluster IV, three genotypes in cluster VI. Clusters III, V, VII and IX had one genotype each (Table 5). Different clustering pattern were also reported on linseed by some earlier workers (Srivastava *et al.,* 2009; Kant *et al.,* 2011; Paul *et al.,* 2016). Genotypes from same geographical locations fell into different clusters as well as genotypes from different geographical locations fell into same cluster indicating that clustering of populations did not follow their geographic distribution. Similar observations have been reported by Tadesse *et al.* (2009) and Paul *et al.* (2016).

Table 1 List of 30 germplasm accessions

Genotype	Source/Pedigree	Genotype	Source/Pedigree
Himalini	K2 × Kangra Local	Mariena	Exotic collection
Janaki	Palampur	Ariane	Exotic collection
Jeewan	Sumit × LC-216	Giza-5	Exotic collection
Surbhi	LC-216 × LC-185	Giza-6	Exotic collection
Him Alsi-1	K2 × TLP-1	Giza-7	Exotic collection
Binwa	Flak-1 × SPS 47/7-10-3	Giza-8	Exotic collection
Baner	EC-21741 × LC-214	Faking	Exotic collection
Bhagsu	RL-50-3 × Surbhi	Aoyagi	Exotic collection
KL-241	Giza-7 × KLS-1	Flak-1	Exotic collection
KL-257	LC-2323 × KLS-1	Canada	Exotic collection
KL-263	KL-223 × KL-224	B-509	Exotic collection
Hearmies	Exotic collection	Belinka-60	Exotic collection
Nataja	Exotic collection	Nagarkot	New River × LC-216
Viking	Exotic collection	Him Alsi-2	EC-21741 × LC-216
Rejeena	Exotic collection	Himani	DPL-20 × KLS-1

Table 2 Analysis of variance for different characters

Characters	Mean Sum of Squares		
	Replication	Genotypes	Error
	2	29	59
Days to 50% flowering	2.13	165.38*	1.62
Days to 75% maturity	3.68	65.41*	5.23
Primary branches/plant	0.06	1.02*	0.12
Secondary branches/plant	0.14	1.63*	0.05
Plant height (cm)	10.70	210.96*	11.72
Technical height (cm)	13.39	132.81*	12.35
Straw yield/plant (g)	0.06	0.26*	0.04
Retted straw yield/plant (g)	0.05	0.88*	0.08
Fibre yield/plant (g)	0.00	0.64*	0.01
Aerial biomass/plant (g)	0.15	0.46*	0.08
Seeds/capsule	0.05	0.76*	0.04
Capsules/plant	0.78	18.75*	7.74
Seed yield/plant (g)	0.02	0.14*	0.03
Harvest index (%)	1.02	38.37*	8.20
1000-seed weight (g)	0.04	4.57*	0.03
Oil content (%)	0.31	14.96*	0.27

Table 3 Intra- (bold) and inter-cluster divergence (D^2 values) among nine clusters of linseed

Clusters	I	II	III	IV	V	VI	VII	VIII	IX
I	10.06	12.46	11.72	14.69	13.68	20.89	15.10	16.91	16.06
II		8.93	16.29	18.39	16.49	17.5	17.79	21.93	21.11
III			0.00	10.04	10.25	20.74	9.97	14.38	11.53
IV				12.65	14.00	21.91	13.90	17.16	15.26
V					0.00	16.83	9.36	9.79	11.79
VI						11.86	17.07	23.91	22.12
VII							0.00	15.12	14.03
VIII								0.00	12.57
IX									0.00

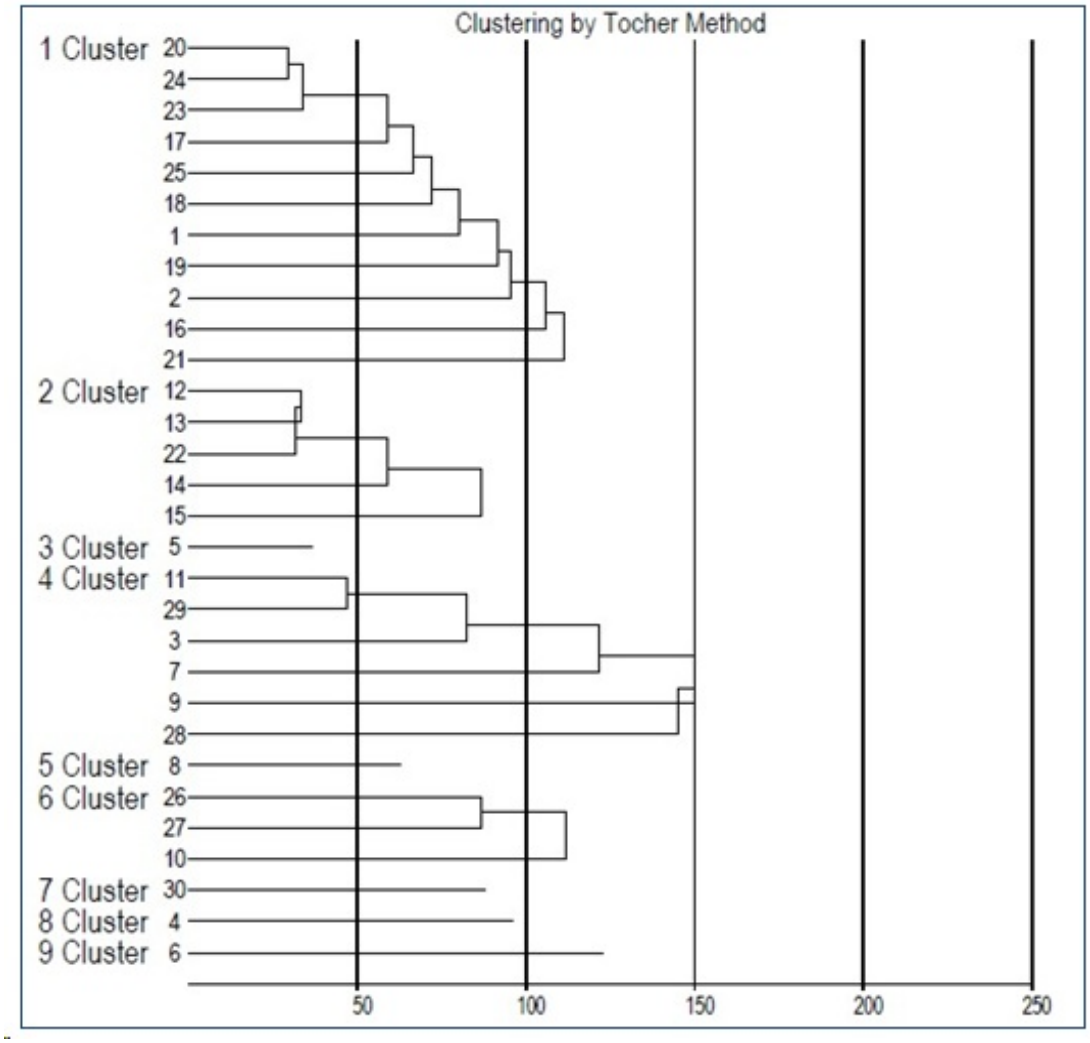

Fig. 1. Dendrogram showing grouping of 30 linseed genotypes generated using D^2 cluster analysis

Table 4 Cluster means for 30 genotypes studied for sixteen quantitative traits

Clusters/Characters	I	II	III	IV	V	VI	VII	VIII	IX	Mean	Minimum	Maximum
Days to 50% flowering	119.82	127.33	115.33	121.39	113.00	133.89	114.33	111.33	114.33	118.97	111.33	133.89
Days to 75% maturity	187.21	188.27	195.00	189.89	184.33	184.33	187.00	182.33	175.00	185.93	175	195
Primary branches/plant	5.10	5.48	5.67	5.74	5.20	5.29	6.20	5.40	6.67	5.64	5.1	6.67
Secondary branches/plant	3.59	3.12	4.13	4.92	4.25	4.21	4.07	4.53	4.53	4.15	3.12	4.92
Plant height (cm)	83.58	89.57	86.78	76.96	75.79	82.52	72.50	58.23	77.21	78.13	58.23	89.57
Technical height (cm)	50.98	53.23	56.79	48.22	41.82	48.99	48.11	32.87	44.48	47.28	32.87	56.79
Straw yield/plant (g)	3.21	3.09	3.03	3.08	2.73	3.04	3.10	2.37	3.18	2.98	2.37	3.21
Retted straw yield/plant (g)	2.20	2.38	2.95	2.27	2.23	2.23	2.16	1.90	4.59	2.55	1.9	4.59
Fibre yield (g)	1.18	1.43	0.52	0.54	0.63	0.52	0.50	0.48	0.52	0.70	0.48	1.43
Aerial biomass/plant (g)	4.68	4.46	4.88	4.76	4.16	4.43	4.93	3.84	4.84	4.55	3.84	4.88
Seeds/capsule	7.62	7.23	8.23	7.70	8.33	7.48	7.33	8.00	8.33	7.81	7.23	8.33
Capsules/plant	29.17	30.89	31.20	32.73	32.53	31.56	33.87	31.13	31.07	31.57	29.17	33.87
Seed yield/plant (g)	1.42	1.32	1.77	1.61	1.35	1.32	1.78	1.42	1.63	1.51	1.32	1.78
Harvest index (%)	30.41	29.63	36.17	33.70	32.50	29.64	36.09	37.02	33.59	33.19	29.63	37.02
1000-seed weight (g)	7.77	6.78	8.10	8.16	6.31	4.45	6.09	6.87	7.56	6.90	4.45	8.16
Oil content (%)	38.75	36.26	38.39	37.60	38.93	36.11	37.18	42.54	43.82	38.84	36.11	43.82

Table 5 Genotypes present in particular cluster

Clusters	No. of genotypes	Genotypes
I	11	Himalini, Giza-7, Giza-8, Aoyagi, Flak-1, Ariane, Mariena, Giza-5, Giza-6, Janaki, Canada
II	5	Hearmies, Nataja, Viking, Rejeena, Faking
III	1	Him Alsi-1
IV	6	Jeewan, Baner, KL-241, KL-263, Nagarkot, Him Alsi-2
V	1	Bhagsu
VI	3	KL-257, B-509, Belinka-60
VII	1	Himani
VIII	1	Surbhi
IX	1	Binwa

Table 6 Per cent contribution towards total genetic divergence

S.No.	Character	Contribution (%)
A	**Morphological traits**	
1	Days to 50% flowering	8.51
2	Secondary branches/plant	1.38
3	Seeds/capsule	2.53
4	Capsules/plant	7.59
5	Seed yield/plant (g)	1.84
6	Harvest index (%)	5.29
7	1000-seed weight (g)	32.64
B	**Fibre traits**	
1	Straw yield/plant (g)	0.23
2	Fibre yield/plant (g)	21.38
3	Aerial biomass/plant (g)	9.43
4	Straw yield/plant (g)	0.23

The pairwise generalized squared distances (D^2) among the eight clusters is presented in Table 3. The average intra-cluster distance ranged from 0.00 (cluster III, V. VII. VIII & IX) to 12.65 (cluster IV), while inter-cluster distance ranged from 9.36 (between clusters V and VII) to 23.91 (between clusters VI and VIII). The maximum distance was found between clusters VI and IX ($D^2 = 3.91$). The second most divergent clusters were VI and IX ($D^2 = 22.12$) followed by clusters II and VIII ($D^2 = 21.93$). Fulkar *et al.* (2007) reported maximum inter cluster distance between cluster II and X, Tadesse *et al.* (2009) reported between cluster I and IV, cluster I and III and minimum for cluster VIII and IX and IX and X. Maximum segregation and genetic recombination is expected from crosses that involve parents from the clusters characterized by maximum distances. It is assumed that genotypes in clusters with minimum distances are closely related among themselves.

Sinha and Wagh (2013) grouped linseed genotypes into three clusters and suggested that intercrossing of genotypes from different clusters may help in obtaining new lines with higher yield. Genotypes tended to group together in separate clusters on the basis of low, moderate or high mean values for different traits (Table 4). Cluster means revealed considerable differences among the clusters. Pali and Mehta (2015) in their study reported that cluster III and cluster V was most diverse to each other. Hence, crossing between these clusters would help to accumulate favourable and desirable alleles for further improvement in seed yield and its component in flax.

Cluster I comprised genotypes with greater straw yield/plant and low primary branches/plant, capsules/plant. Cluster II consisted mainly of greater plant height, fibre yield with less number of secondary branches per plant, seeds/capsule, seed yield/plant and harvest index (%). So cluster II represent the genotypes which are good for fibre traits. Cluster III comprised mainly of early maturing genotypes with longer technical height and high aerial biomass. Cluster IV comprised of genotypes with more number of secondary branches per plant and 1000-seed weight. Cluster V mainly comprised of genotypes with more number of seeds per capsule. Cluster VI mainly comprised genotypes with late flowering with low yield potential, 1000-seed weight and oil content (%). Cluster VII mainly comprised genotypes with maximum seeds per capsule and high yielding potential.

Cluster VIII comprised mainly of early flowering, higher harvest index with lesser plant height, technical height, straw yield/plant, retted straw yield/plant and fibre yield. Cluster IX comprised genotype of late maturing with lesser number of primary branches/plant, retted straw yield/plant, seeds/capsule and oil content. On comparing the clustering pattern it has been found that high yielding genotypes found in IV cluster (HimAlsi 1, Nagarkot and KL-241) while, high fibre yielding genotypes were found in I (Giza-8, Flak-1, Ariane and Mariena) and II cluster (Hearmies, Nataja, Viking and Faking) showing wide divergence i.e. inter-cluster divergence, which is desirable for future hybridization programme for getting desirable transgressive segregants to develop dual type cultivars. The chances of developing good segregants by crossing the genotypes of the same cluster having low value for intra-cluster distance are very less. Therefore, it is suggested to attempt crosses between the genotypes of clusters separated by large inter-cluster distances.

Factor responsible for the differentiation of all genotypes in different clusters at genotypic level attributed to the percentage contribution of quantitative traits towards genetic distance. 1000-seed weight contributes maximum (32.64%) total genetic divergence between genotypes followed by capsules per plant. For fibre traits aerial biomass weight contributes maximum towards total genetic distance between genotypes (Table 6). Srivastava *et al.* (2009) in their study on genetic divergence reported that seed yield per plant contributed maximum towards genetic divergence followed by number of capsules per plant and days to flowering. Whereas, Paul *et al.* (2016) in their study reported that 1000-seed weight followed by capsules per plant contributes maximum towards genetic divergence. Hence, it is suggested that said diversity could be utilized for improvement in linseed by crossing best performing lines of different clusters, followed by selection in segregating generations.

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Physiological and biochemical basis of cold storage in groundnut (*Arachis hypogaea* L.) seeds

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ABSTRACT

A study to determine the optimum seed moisture content and storage temperature for groundnut seeds under cold storage conditions in comparison to ambient conditions revealed that the seeds stored at -20ºC with 6 per cent moisture content maintained the seed physiological qualities like germination and vigour index at higher level with minimum loss in biochemical parameters like protein and oil content and less reduction in the activities of dehydrogenase, catalase, peroxidise and lipoxygenase enzymes than the seeds under ambient storage. The supremacy of cold storage was also supported by structural study of seed coat changes through scanning electron microscope and seed health study.

Keywords: Cold storage, Groundnut, Seed health, Seed vigour

Groundnut (*Arachis hypogaea* L.) is an important oilseed crop and as other oilseed crops, groundnut seeds also loose its quality and viability very quickly during storage. Generally oilseeds contain more of polyunsaturated fatty acids which undergo rapid deterioration owing to lipid autoxidation and fungal activity which leads to faster deterioration. Seeds of different plant species loose viability to a various degree even though they are kept at same storage conditions. Seed deterioration is an inevitable process; it is associated with lot of physiological, biochemical and seed structural changes. Once deterioration started it cannot be stopped, but by maintaining the optimum seed moisture content and storage in cool and dry environment, the rate of deterioration process can be minimized. The fact was reported by many scientists that dry and cold conditions will increase shelf life of biological material; lower temperature and humidity resulted in delayed seed deteriorative process and ageing thereby leading to extended viability period (Mohammadi *et al.,* 2011). Seed moisture and storage temperature are the important factors which affects the quality and quantity of stored product (Vijay *et al.,* 2009). The basic objective of cold storage is to keep the storage temperature below the usual ambient temperature, thereby minimizing the biochemical reactions which leads to deterioration, maintenance of physiological quality and prevention of insects and fungi development. Based on these aspects a study was carried out in groundnut seeds to determine the optimum seed moisture content and storage temperature to prolong the shelf life of groundnut seeds.

Freshly harvested seeds of groundnut cv. CO 6 obtained from Department of Oilseeds, Tamil Nadu Agricultural University (TNAU), Coimbatore formed the base material for the study. The cold storage facility at Department of Plant Genetic Resources, TNAU, Coimbatore was utilized for the study. The laboratory studies were carried out in the Department of Seed Science and Technology, TNAU, Coimbatore during 2011-12. The seeds with 6 and 8 per cent moisture were vacuum packed in tri-laminated aluminium foil pouches using the vacuum sealer model AUDIONVAC VMS 153 with a pressure of -0.95 bars and kept in the cold storage units maintained at temperatures of +5, -5 and -20ºC with relative humidity below 25 per cent, respectively. The seeds with the same moisture content was packed in cloth bag and stored under ambient condition which served as a check. The physiological parameters *viz.,* germination and vigour index were evaluated as per the ISTA (2010) at bimonthly interval. With reference to biochemical parameters, the electrical conductivity of the seed leachate was measured in an electrical conductivity meter and the conductivity of the leachate was expressed as dSm^{-1}. The protein content was determined by using the method given by Alikhan and Young (1973). Oil from groundnut seeds was extracted with petroleum ether (40-60ºC) in Soxhlet extractor and the oil content was expressed in percentage (Sadasivam and Manickam, 1995). Estimation of free fatty acid content was done as per the method described by Christiansen and Moore (1961). Catalase activity was measured by monitoring the decrease in absorbance at 240 nm in 50 mM phosphate buffer (pH 7.5) containing 20 mM H_2O_2 and peroxidase activity was measured by monitoring the increase in absorbance at 470 nm in 50 mM phosphate buffer (pH 7.0) containing 1 mM guaiacol and 0.5 mM H_2O_2. Lipid peroxidation formation was studied by the thibarbituric acid (TBA) colour reaction. The absorbance of the clear supernatant was measured in a LCD type JASCO spectrophotometer at 520 nm. The lipoxygenase activity was evaluated as per Hildebrand *et al.* (1991). The seed coat changes were studied using scanning electron microscope (SEM). The pathogen infection was also recorded as per ISTA (2010). The statistical analysis of variance for all the characters was worked out.

The groundnut seeds stored at cold storage conditions of different temperature (+5, -5,-20ºC) maintained the moisture as that of the initial moisture content (6 and 8%) up to the end of storage period of ten months, while the seeds stored at ambient condition gained moisture content to the tune of 0.3 per cent increment at the end of storage period. In general increase in moisture content during storage leads to increase in the seed deteriorative changes which resulted in the loss of seed quality and viability. Yoga (2003) reported that groundnut seeds could be stored for six months under ambient storage conditions. Sastry *et al.* (2007) reported that, peanut seed storage at 35ºC with lower seed moisture content (1.7 and 3.4%) both in air and vacuum enabled seeds to retain viability even after 288 weeks, while seeds with 10.1 per cent moisture content stored at 50ºC lost viability within 10 days. However, seeds with 3.4 per cent moisture content retained the viability up to 20 weeks, emphasizing the importance of lower seed moisture content during storage.

In this study, the groundnut seeds stored at -20ºC with low moisture content of 6 per cent recorded higher germination percentage and vigour index than the seeds stored at ambient condition with 8 per cent moisture irrespective of the storage conditions at the end of ten months of storage. The germination expressed a decreasing trend with advancement in storage period from 90 to 81 per cent. The percentage increase of germination at cold storage (-20ºC) over ambient condition was 12 per cent. The maximum germination (88%) was recorded at -20ºC and minimum (77%) at ambient condition. Among the moisture contents, the seeds with 6 per cent moisture content recorded higher germination (85%) than the seeds with 8 per cent moisture content (83%) irrespective of the storage conditions (Fig. 1). Similar result was recorded in groundnut seeds stored at low temperature which registered maximum germination than the seeds stored in ambient condition by Corbineau *et al.* (2002). Rajagopal and Chandran (2002) revealed that the germination and seedling vigour of groundnut seeds declined with increase in storage period.

In the present studies changes in biochemical properties, electrical conductivity of seed leachate, free fatty acid and enzymatic activity were evaluated. A steady increase in electrical conductivity was observed from initial (0.181 dSm^{-1}) to the final period of storage (0.278 dSm^{-1}). The electrical conductivity obtained by the seeds stored at ambient condition was the maximum (0.330 dSm^{-1}), while the seeds stored at -20ºC recorded the minimum (0.184 dSm^{-1}). Many biochemical investigations have proven that lipid peroxidation and fat activity (free fatty acid percentage) are the major causes of seed deterioration, including cellular membrane disruption. As seed quality declined there was a concurrent increase in the levels of free fatty acids. The seeds stored at -20ºC recorded the lowest free fatty acid content (0.25%), while the seeds stored at ambient condition recorded highest free fatty acid content (0.40%). Seeds stored with 6 per cent moisture content recorded the lowest free fatty acid content (0.29%) than the seeds with 8 per cent (0.30%) moisture content. In the present study, with increase in free fatty acid content there was a concurrent rise in seed leachate electrical conductivity suggesting that membrane integrity was declining (Table 1).

Bailly *et al.* (1996) reported loss of seed viability was also associated with decrease in catalase activity in sunflower. In the present investigation, the catalase activity decreased during storage. With reference to storage conditions, the seeds stored at cold storage (-20ºC) maintained maximum catalase activity (1.810 µg H_2O_2 mg^{-1} min^{-1}) than the seeds at ambient condition (1.0µg H_2O_2 mg^{-1} min^{-1}). Between the moisture contents, seeds stored with 6 per cent moisture content recorded the maximum catalase activity (0.85µg H_2O_2 mg^{-1} min^{-1}) than the seeds stored with 8 per cent moisture content (0.83 µg H_2O_2 mg^{-1} min^{-1}). This was in line with the findings of Bao *et al.* (2011) where they reported that antioxidant enzyme (peroxidase and catalase) activities were comparatively much lower with storage at room temperature than at 4ºC after 6-12 months. The peroxidase activity of groundnut seed decreased during storage from 0 to 10 months. Similar findings of decreased peroxidase activity during ageing have also been reported by Sung and Jeng (1994) in peanut seed. Furthermore, these workers noted a good correlation between seed vigour and peroxidase activity. Sung (1996) reported seed protective mechanisms involving several free radical and peroxide-scavenging enzymes like superoxide dismutase, catalase, ascorbate peroxidase and peroxidase in soybean.

Oxidation of membrane bound and storage lipids by lipoxygenase would produce free fatty acid and free radicle, so lipoxygenase served as a measure of seed deterioration (Bailly *et al.,* 2002). Lipoxygenase might be involved in seed deterioration (Bewley, 1986) because it catalyzes the incorporation of molecular oxygen into fatty acids containing a Z, Z-l, 4-pentadiene moiety and generates free radicals (Vick and Zimmerman, 1987). The groundnut seed with 8 per cent moisture recorded maximum lipoxygenase activity (0.372 g mol s^{-1} mg^{-1}) than the seeds stored with 6 per cent moisture content (0.530 g mol s^{-1} mg^{-1}). The seeds of groundnut stored at -20ºC recorded lower lipoxygenase activity (0.348 g mol s^{-1} mg^{-1}) than the seeds stored at ambient condition (0.554 g mol s^{-1} mg^{-1}), indicating the less seed deterioration changes at cold storage (Fig.2).

To study the seed structural changes, the seed coat of seeds of cold storage (-20°C) and ambient storage were examined under the scanning electron microscope (SEM). The changes in seed coat with reference to storage temperature revealed that in seeds of groundnut the seed coat changes were associated with the expression of shrunken and cracking of seed coat (Fig.3). However, the seeds of cold storage expressed minimum seed coat changes at the end of storage period. The study on seed health status for stored

seed of groundnut revealed that, at cold storage conditions of -20ºC and -5ºC, the fungal activity was nil, while seeds of ambient storage and cold storage of 5ºC showed the symptom of infection with *Aspergillus flavus* and *Rhizopus* sp., the infection due to *A. flavus* was comparatively higher than *Rhizopus* sp. Novas and Cabral (2002) they reported that, groundnut fungal colonization and the high seed lipid content lead to the acceleration of seed deterioration during storage by decreasing germination and vigour index.

Fig.1. Influence of seed moisture, temperature and period of storage on germination (%) and seedling growth of groundnut cv. CO 6

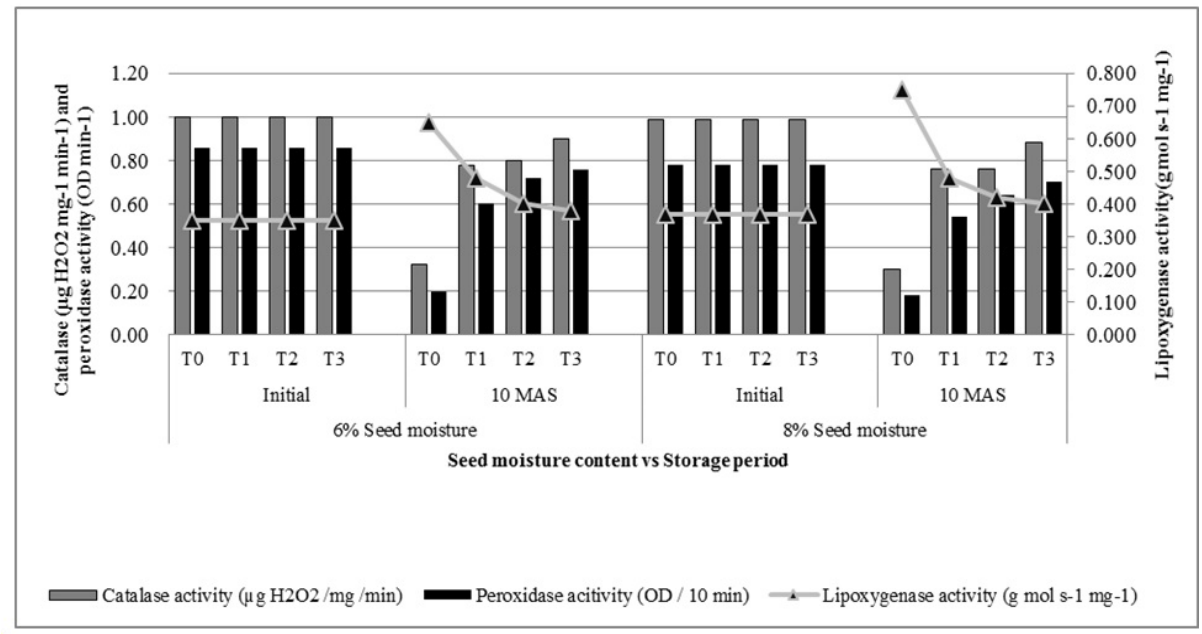

Fig.2. Influence of seed moisture, temperature and period of storage on catalase, peroxidase and lipoxygenase activity in groundnut cv. CO 6

Table 1 Influence of seed moisture, temperature and period of storage on free fatty acid content (%) of groundnut cv. CO 6

Storage periods (P)	Seed moisture content (M)										PxT interaction				Mean
	6%					8%									
	Storage temperature (T)														
	Ambient	5°C	-5°C	-20°C	Mean	Ambient	5°C	-5°C	-20°C	Mean	Ambient	5°C	-5°C	-20°C	
0	0.247	0.247	0.247	0.247	0.247	0.254	0.254	0.254	0.254	0.254	0.251	0.251	0.251	0.251	0.251
2	0.350	0.258	0.250	0.249	0.277	0.376	0.268	0.256	0.254	0.289	0.363	0.263	0.253	0.252	0.283
4	0.310	0.264	0.254	0.250	0.270	0.335	0.272	0.260	0.256	0.281	0.323	0.268	0.257	0.253	0.275
6	0.400	0.275	0.262	0.254	0.298	0.466	0.279	0.268	0.260	0.318	0.433	0.277	0.265	0.257	0.308
8	0.485	0.290	0.274	0.262	0.328	0.500	0.294	0.278	0.268	0.335	0.493	0.292	0.276	0.265	0.331
10	0.532	0.345	0.285	0.274	0.359	0.620	0.310	0.282	0.275	0.371	0.576	0.328	0.284	0.272	0.365
Mean	0.387	0.280	0.262	0.256	0.296	0.425	0.280	0.266	0.260	0.308	0.406	0.280	0.264	0.258	0.302
	P	M	T			PxX	Mx T				P x T	P x M x T			
SEd	0.001	0.001	0.001			0.002	0.002				0.003	0.004			
CD (P=0.05)	0.003**	0.002**	0.003**			0.004**	0.004**				0.006**	0.009**			

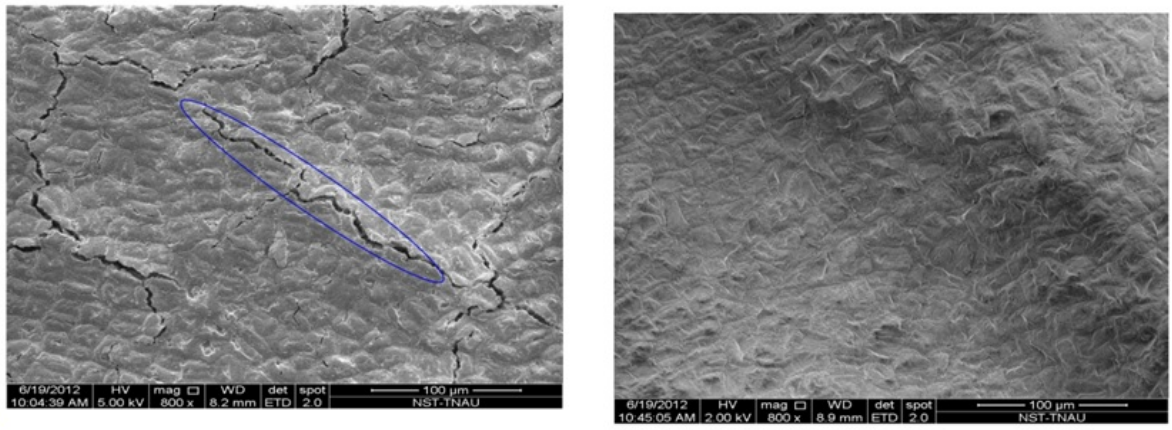

Fig. 3. SEM image of 10 month stored seeds of groundnut cv.CO 6 (Encircled: Cell wall damage)

Thus it is concluded that, physiological changes such as reduction in the germination, root length, shoot length and vigour index with advancement in storage period was associated with changes in biochemical parameters such as reduction in oil and enzyme activity, increase in free fatty acid and lipoxygenase enzyme activity. The prominent structural changes observed in seeds under ambient condition are cracking of seed coat and cell wall damage. All these changes related with seed quality deterioration were maintained at minimum in seeds under cold storage than the seeds under ambient storage which revealed the suitability of cold storage over ambient storage for groundnut seeds. The seeds of groundnut with 6 per cent moisture content stored at -20ºC maintained seed physiological and biochemical qualities at higher level with minimum structural changes up to ten months of storage.

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Agronomic evaluation of groundnut varieties under rainfed conditions of Dharmapuri District, Tamil Nadu

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ABSTRACT

An experiment was conducted to assess the agronomic performance of groundnut varieties *viz.,* CO-6, Kadiri-9, ICGV-91114 in comparison with farmer's preferred variety TMV-7 under rainfed condition in farmers' fields in Dharmapuri district, Tamil Nadu during *kharif* 2015. The result showed that the variety Kadiri-9 exhibited superiority in respect of higher dry matter production (40.3 g/plant), number of pods per plant (28.8) and pod yield (1632 kg/ha) and accrued higher net income (₹.26670/ha) and benefit cost ratio (2.03). The varieties ICGV-91114, TMV-7 and Kadiri-9 were early in terms of days to 50 per cent flowering and maturity. The varieties CO-6 and Kadiri-9 were found tolerant to major pests and diseases like leaf miner, collar rot and late leaf spot.

Keywords: Groundnut, Performance, Pod yield, Varieties

India is the second largest producer of groundnut (*Arachis hypogaea* L.) after Brazil, accounting for 22.98 per cent of the total area and 14.52 per cent of the production of the world. It occupies an area of 5.30 million ha with a production of 5.50 million tonnes and productivity of 1040 kg/ha. About 70 per cent of the area and production have been concentrated in the four states of Gujarat, Andhra Pradesh, Tamil Nadu and Karnataka (Madhusudhana, 2013). Tamil Nadu is one of the leading groundnut producing states with an area, production and yield of 3.85 lakh hectares, 10.61 lakh tonnes and 2751 kg/ha, respectively. In Dharmapuri district, groundnut is grown in an area of 20000 ha with a production of 28000 tons and a productivity of 1340 kg/ha. About 80 per cent of the area under groundnut is being cultivated under rainfed conditions during *kharif* season (Vindhiyavarman *et al.,* 2014). Under such conditions, crop productivity is mainly influenced by onset of monsoon, amount and distribution of rainfall (Sahu *et al.,* 2004; Chandrika *et al.,* 2008). Generally the crop suffers due to mid and end season drought leading to drastic reduction in pod yield of groundnut (Nigam *et al.,* 2005; Pimratch *et al.,* 2008).

Cultivation of early maturing, disease and drought tolerant varieties have major role in achieving higher yield in groundnut under rainfed conditions (Reddy *et al.,* 2003). A large variation in growth and yield of groundnut among the different cultivars were reported by Patidar *et al.* (2014), Bhargavi *et al.* (2016) and Chandran *et al.* (2016). In Dharmapuri district, farmers are cultivating local varieties with their own seed year after year and thus low yield. Knowledge on the varietal preferences for different situations among farmers is lacking. Hence, an on-farm trial was conducted with an aim to evaluate different groundnut varieties for their agronomic performance under rainfed situations and suggest best suited improved and high yielding variety for Dharmapuri district in Tamil Nadu.

An on-farm trial was conducted in selected five farmers' fields of Dharmapuri district during *kharif* 2015. The varieties include CO-6, Kadiri-9, ICGV-91114 and farmer's preferred variety TMV-7. The variety CO-6 is a semi-spreading type, foliar disease and drought tolerant variety released from Tamil Nadu Agricultural University, Coimbatore. Kadiri-9 is a spanish bunch, early high yielding and multiple resistance variety developed from Acharya N.G. Ranga Agricultural University, Guntur. ICGV-91114, a spanish variety having tolerance to mid season and end of season drought released from International Crop Research Institute for the Semi Arid Tropics, Hyderabad. Depending on the onset of rainfall, sowing was done during the last week of July. The seed was sown by hand dibbling at a spacing of 30 cm x 10 cm. At the time of sowing, basal application of farmyard manure @ 12.5 t/ha, phosphorus @ 10 kg/ha and gypsum @ 200 kg/ha was done. Nitrogen @ 10 kg/ha and potassium @ 45 kg/ha was applied. One hand weeding on 20 DAS and second weeding cum earthing up during 40-60 DAS depending upon the moisture content, was carried out. During earthing up, top dressing with gypsum @ 200 kg/ha was done. Plant protection measures were taken up as and when needed. At the time of harvest, growth parameters *viz*., plant population, days to 50% per cent flowering, dry matter production and yield parameters *viz*., number of pods and dry pod yield were recorded. Incidence of major insect pests and severity of diseases were also observed. Economic analysis was done by calculating cost of cultivation, gross returns, net returns and benefit: cost ratio. The statistical analysis of the data was performed in randomized block design considering locations as replication using web assisted statistical package software developed by ICAR.

At harvest, among the varieties tested, Kadiri-9 recorded

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the higher plant population (32.8 No./m^2) and was followed by CO-6 and ICGV-91114 (Table 1). The lower plant population of 21.8 No./m^2 was observed in TMV-7. It might be due to the reason that the improved variety Kadiri-9 might have not been affected by dry spell which was experienced for three weeks period during the flowering stage. The morphological characteristics *viz*., presence of smaller and thick leaflets, greenness of leaves at maturity and narrow leaflet angles during peak sunshine hours might have contributed to drought tolerance in Kadiri-9. Rizza *et al.* (2004) reported that small plant size, reduced leaf area and early maturity are the drought resistance traits in barley which reduced the total seasonal evapo-transpiration. Similar results were reported by Blum (2005) and Lonbani and Arzani (2011) in wheat. The days taken for 50 per cent flowering and maturity were less in ICGV-91114 (37 and 104 days) and it was closely followed by TMV-7 (38 and 108 days) and Kadiri-9 (40 and 113 days). The number of days taken for 50 per cent flowering and maturity was higher in CO-6 (52 and 138 days), respectively. Under rainfed situations, Kadiri-9 produced maximum dry matter (40.3 g/plant) and it was closely followed by CO-6, while minimum dry matter production (27.2 g/plant) in TMV-7. The per cent damage of major pests and disease incidence was illustrated in Fig. 1. The per cent damage of leaf miner (19.2 %) and collar rot disease incidence (16.5 %) was higher in ICGV-9114 and lower in CO-6 (8.0 % and 8.5 %, respectively). The per cent damage of *Spodoptera litura* (13.5%) and late leaf spot disease incidence (18.6 %) was higher in TMV-7, while lower in CO-6 (9.2 %) and Kadiri-9 (7.3), respectively. Similar studies were reported in groundnut varieties by Praveena *et al.* (2011) and Veeranna and Shreenivasa (2013).

Table 1. Growth parameters, yield and economics of different groundnut varieties

Treatments	Plant population at harvest (No./m^2)	Days to 50% flowering	Days to maturity	Dry matter production (g/plant)	Number of pods (No./plant)	Dry pod yield (kg/ha)	Percent yield increase over TMV 7	Net income (₹/ha)	Benefit: cost ratio
CO- 6	30.0	52	138	39.0	26.0	1576	26.7	24846	1.96
Kadiri- 9	32.8	40	113	40.3	28.8	1632	31.2	26670	2.03
ICGV- 91114	26.8	37	104	33.1	21.4	1382	11.1	18644	1.72
TMV- 7	21.8	38	108	27.2	17.5	1244	-	14088	1.54
CD (P=0.05)	3.7	3.1	6.4	2.8	3.1	80.57	-	2752	0.09

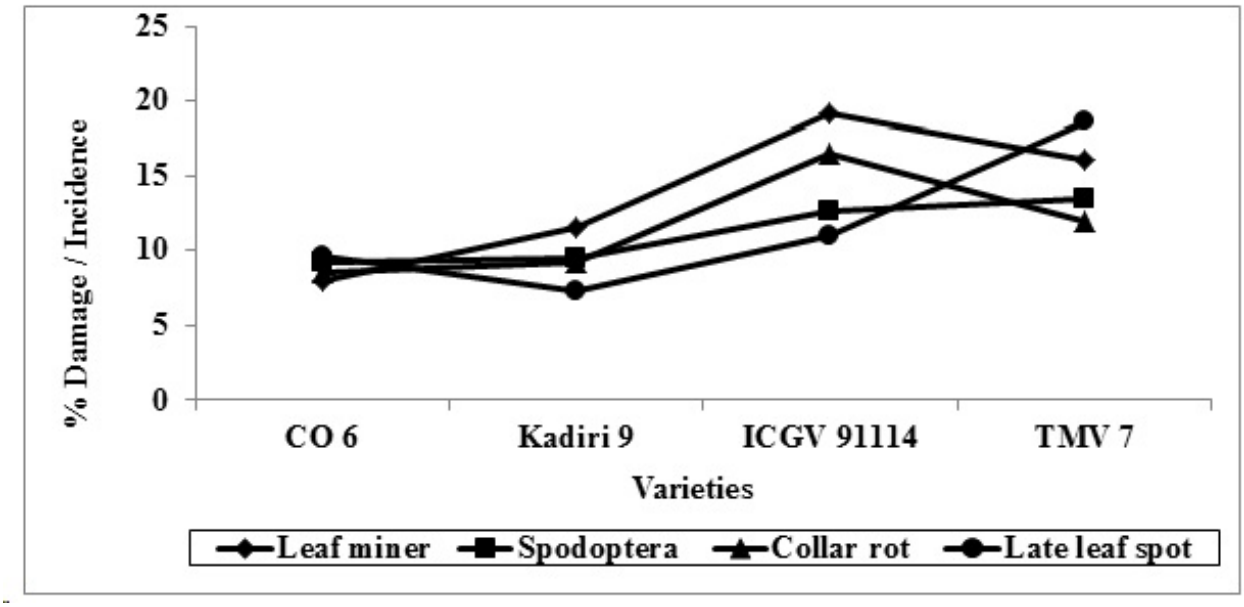

Fig. 1. Incidence major insect pests and diseases on different varieties of groundnut

The number of pods per plant and pod yield was higher in Kadiri-9 (28.8/plant and 1632 kg/ha) and lower number of pods per plant and pod yield was in TMV-7 (17.5/plant and 1244 kg/ha), respectively (Table 1). The per cent increase in pod yield over local variety i.e. TMV-7 was 31.2 per cent. The higher pod yield in variety Kadiri-9 might be due its better partitioning ability of photosynthates to the developing pods and its ability to drought tolerance. Similar findings of variation in pod yield among the varieties were reported by Zamurrad and Koukab (2013). The reasons for outstanding performance of Kadiri-9 were due to its tolerance to drought, pest, diseases and higher pod yield under rainfed conditions. Kadiri-9 accrued higher net income (₹ 26670/ha) and benefit: cost ratio (2.03) and was closely followed by CO-6. The lower net income of ₹ 14088/ha and benefit: cost ratio of 1.54 was realized in TMV-7. It might be due to the higher pod yield obtained in Kadiri-9. The findings of the present on-farm study revealed that groundnut variety Kadiri-9 was found to be the best drought tolerant, short duration, bold seeded variety with pest and disease tolerance suitable for large scale cultivation in rainfed conditions of Dharmapuri district for achieving higher productivity and income by the farmers.

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GUIDELINES TO AUTHORS

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1. **Articles on original research completed,** not exceeding 4000 words (up to 15 typed pages, including references, tables, figures, etc.) should be exclusive for the journal. They should present a connected picture of the investigation and should not be split into parts. Complete information of Ph.D thesis should preferably be given in one article.
2. **Short Communication**, not more than 1300 words (total 5 typed pages), which deal with (I) research results that are complete but do not warrant comprehensive treatment, (ii) descriptions of new material or improved techniques or equipment, with supporting data, and (iii) a part of thesis or study. Such notes require no headed sections.
3. **Critical Research Review Articles**, showing lacunae in research and suggesting possible lines of future work. These are mostly invited from eminent scientists.
4. The research article or note submitted for publication should have a direct bearing on agricultural production or open up new grounds for productive research. Articles on oilseeds research, economics, demonstrations, social sciences, extension, etc., are also considered. Basic type of articles and notes relating to investigation in a narrow specialized branch of a discipline may not form an appropriate material for this journal, nor do the articles of theoretical nature, or those of local importance, repetitive, based on old data, with no positive significance.
5. Author should note: (a) period (years) of conducting the experiment must be indicated, (b) article should preferably be submitted soon after completion of experiment, (c) articles on genetics and plant breeding and on plant crops should be based on data of minimum two years, (d) contribution involving a former or present student must clarify that it is not based/based on complete M.Sc. Thesis, or complete or a part of the Ph.D thesis, indicating its year of submission and (e) Article Certificate must be signed by all the authors and must contain subscription numbers of authors.
6. **Title** should be short, specific and information. It should be phrased to identify the content of the article and include the nature of the study and the technical approach, essential for key-word indexing and information retrieval.
7. **A Short Title** not exceeding 35 letters should also be provided for running headlines.
8. **By-line** should contain, in addition to the names and initials of the authors, the place (organization) where research was conducted. Change of address should be given as a footnote, e-mail ID and correspondence address separately.
9. **Abstract**, written in complete sentences, should not have more than 150 words. It should contain a very brief account of the materials, methods, results, discussion and conclusion, so that the reader need not refer to the article except for details. It should not have reference to literature, illustrations and tables.
10. **Introduction** part should be brief and limited to the statement of the problem or the aim and scope of the experiment. The review of recent literature should be pertinent to the problem. Key words of the article should be given in the beginning.
11. Relevant details should be given of the **Materials and Methods** including experimental design and the techniques used. Where the methods are well known, citation of the standard work in sufficient. Mean results with the relevant standard errors should be presented rather than detailed data. The statistical methods used should be clearly indicated.
12. **Results and Discussion** should be combined, to avoid repetition.
13. The results should be supported by brief but adequate tables or graphic or pictorial materials wherever necessary. Self-explanatory tables should be typed on separate sheets, with appropriate titles.
14. The tables should fit in the normal layout of the page in portrait style. All weights and measurement must be in SI (metric) unit. Tables and illustrations (up to 20% of text) should not reproduce the same data.
15. The discussion should relate to the limitations or advantages of the author's experiment in comparison with the work of others. All recent relevant literature should be discussed critically.
16. Line-drawings should be clearly drawn (7 inch or 17 cm width) in black waterproof ink on smooth, tough paper, minor points of style should be noted carefully. Photographs should be large, unmounted, glossy prints of good quality. They should be clear and relevant to the subject. Colour photographs may be sent for better identification and legibility of different parts of the object. All figures should have legends (types). Original artwork should accompany 2 copies. Repetition in graphic and tabular matter should be avoided.
17. For citing **References** a recent issue or the present journal may be referred, ensuring that all the references cited in the text are referred in the end under References section of the article. Each citation should have the name(s) of the author(s), initials (without full stops, but comma after each full name), year of publication (with full stop), full title of the article (with full stop), name of the journal (in italics with comma but without abbreviations), volume number (in bold), preferably the issue (within parentheses and colon) and complete page range (not merely the first page and full stop). Complete name of publisher and place of publication of books should be given in case of books. For proceedings or other publications complete details should be given.
18. All articles are sent to referees for scrutiny and authors should meet criticism by improving the article, indicating the modifications made (in separate sheet, 2 copies).
19. Articles should be **Typewritten** in MS Word format in Times New Roman font with 12 font size in double line spaced throughout (including byline, abstract, references and tables) on white, durable A-4 size paper with one inch margins on all sides. The hard copy of the Articles should be sent in triplicate after checking typographical errors. **It is mandatary to send soft copy of the article in neatly packed CD and/or by E-mail on: editorisor@gmail.com. Articles not sent by CD or E-mail will take longer time to consider for its publication.**
20. For **writing,** authors are requested to consult the recent issue of **Journal of Oilseeds Research**, either this issue or the immediate past issue. The language and spellings are followed as per British style, but not in American style.
21. **Proof Correction** - Author(s) should be prepared to make necessary corrections or modifications in their article in accordance with the remarks/suggestions of the referee of the article. The decision of the Referee and/or Indian Society of Oilseeds Research is final in this regard. No arguments or clarifications are entertained in any manner at any stage.
22. While submitting the article(s), please ensure that all the authors are life/annual members of the ISOR.