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Research Papers

Agrobacterium mediated *in planta* transformation in castor (*Ricinus communis* L.)

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ABSTRACT

Castor has been a recalcitrant crop for *in vitro* manipulations. To realize the potential of genetic engineering, it is essential to develop a repeatable transformation protocol. *In planta* transformation has been identified as a method of choice to obtain transgenic lines in crops that are trajectory to *in vitro* procedures. In the present investigation, we have developed an optimized protocol for realizing transgenic castor plants through *Agrobacterium* mediated *in planta* transformation. We have established procedures to ensure better survival of *Agrobacterium* treated seedlings (T_0) in transgenic green house as well as for screening T_1 progeny plants to identify putative transgenic plants. The optimized factors included : growing the Agro-treated (pricked) seedlings for two days in soilrite and then transferring to soil, treating the two day old seedlings of T_1 progeny plants in hygromycin solution @40mg/l for two hours and then transferring the normal looking plants to the soil in transgenic green house. Using the optimized protocol, we have realized 30 transgenic castor plants carrying different gene constructs.

Keywords: *Agrobacterium*, EHA105, Hygromycin, *In planta* transformation, T_1 progeny screening

Castor (*Ricinus communis* L.), a member of Euphorbiaceae family, is an important non-edible oilseed crop having more than 700 industrial uses and is recognized as a potential biofuel crop cultivated primarily in arid and semi-arid regions (Berman, 2011; Usha Kiran and Lavanya, 2016). Castor oil and its derivatives are widely employed in paints and varnishes for surface coatings, synthetic polymers, resins, lubricants for aviation engines, cosmetics, textile dyeing, insecticides, leather industry and a host of similar products (Ogunniyi, 2006; Madhu *et al.,* 2017). The crop is prone to continuous threat from several biotic and abiotic constraints affecting the productivity with 25 per cent yield loss under favourable conditions (Basappa *et al.,* 2007). Among the 150 pathogens infecting castor, the necrotrophic fungus *Botryotinia ricini,* the causal agent of grey mold disease is the major pathogen that predominantly infects the inflorescence, causing more than 80 per cent yield losses. Various approaches such as chemical, cultural and biocontrol measures adopted for control of this disease have not been successful making it the major biotic stress that reduces the productivity of this crop. And also, limited genetic variability in the germplasm of castor with respect to the resistance/tolerance against grey mold necessitates the adoption of biotechnological tools, for overcoming the huge losses inflicted by this fungus. One of the promising approaches is to develop transgenic lines with deployment of gene(s) that impart resistance against fungus. Also, the castor endosperm tissue contains two toxic proteins, ricin and RCA, that render the protein rich de-oiled meal of castor not useful as animal feed. Ricin and RCA proteins are encoded by a multi-copy gene family (Chan *et al.,* 2010) and therefore, less amenable for mutation breeding approach to develop toxin free castor. Conventional plant breeding approaches have also not been useful in developing toxin free castor.

Stable integration of foreign genes for introducing desired traits into plants represents one of the most significant developments in the field of plant biotechnology (Gasser and Fraley, 1989). Biological transformation using the naturally occurring *Agrobacterium*, physical methods using gene gun or chemical gene transfer strategies are employed to produce transformed plants with desired trairts (Christou, 1996). These methods have been successfully used to transfer agronomically important genes to many crop plants (Younis *et al.*, 2014; Todaka *et al.*, 2015). *Agrobacterium*-mediated genetic transformation with several advantages such as clean integration of transgenes in low copy number, and preferential integration into transcriptionally active regions of the genome (Li *et al.,* 2005; Wang *et al.,* 2016) is a preferred method of developing transgenic plants.

Genetic improvement of any crop species through genetic engineering techniques requires an efficient *in vitro* regeneration system that is amenable for transformation procedure. However, in case of castor, research efforts have failed to provide a reliable protocol of *in vitro* plant regeneration and thus realizing transgenic castor plants has been a daunting task. *In planta* transformation technique that targets the *Agrobacterium* to apical meristem or the

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meristems of axillary buds and allows development of transgenic shoots is considered an alternate route to obtain transgenic plants without *in vitro* regeneration protocols. So far, this protocol has been successfully standardized in buckwheat (Kojima *et al.,* 2000), mulberry (Ping *et al.,* 2003), kenaf (Kojima *et al.,* 2004), rice (Supartana *et al.,* 2005), maize (Chumakov *et al.,* 2006), wheat (Supartana *et al.,* 2006), pigeon pea (Rao *et al.,* 2008), soybean (Liu *et al.,* 2009), castor (Kumar *et al.,* 2011), ground nut (Reddy *et al.,* 2013), and sunflower (Tishchenko *et al.,* 2014). Besides being a rapid and genotype independent method, *in planta* transformation is also advantageous because it does not involve regeneration procedures and therefore, the tissue culture-induced somaclonal variations (Solanki *et al.,* 2011; Shivakumar *et al.,* 2014). It has also been reported that the transformation efficiency obtained through *in planta* transformation is much higher than conventional tissue culture based transformation procedures (Supartana *et al.,* 2006). In the present study, *in planta* transformation protocol reported for castor (Kumar *et al.,* 2011) was taken as the basic protocol and improvements were made by optimizing parameters that are known to influence *in planta* transformation efficiency. We optimized method of *Agrobacterium* culture preparation, method for establishing T_0 plants, and selection of T_1 plants using plant selection hygromycin selection marker. Using this protocol transgenic castor plants have been realized with three gene constructs. Our report will facilitate transformation of castor with many more gene constructs and thus help in improving this industrially important oilseed crop for agronomically important traits.

MATERIALS AND METHODS

Plant material and bacterial strains: *In planta* transformation was carried out in castor cv. 48-1 (Jwala). Mature seeds were soaked overnight in distilled water, followed by surface sterilization using 1% Bavistin for 10 minutes and 0.1% $HgCl_2$ for a few seconds and then the seeds were rinsed with distilled water thoroughly to eliminate traces of $HgCl_2$. Subsequently, seeds were germinated in Petri plates containing blotting paper at 30°C. Two-day-old seedlings were taken as explants for Agrobacterium infection. The disarmed *Agrobacterium tumefaciens* strain EHA105, harboring the binary vector with different gene constructs were grown in 5 ml LB medium (pH 7.0) containing 50 µg/ml kanamycin. The bacterial culture (4 mL) was later re-suspended in 50 mL of Winans' AB medium (pH 5.2) (Winans *et al.,* 1988) and grown for 18 h. For vir gene induction, filter sterilized wounded tobacco leaf (older ones) extract (2 g in 2 mL sterile water) was added to the *Agrobacterium* suspension in Winans' AB medium, 5 h before infection (Cheng *et al.,* 1996; Rohini and Rao, 2000b).

Gene cassettes used for transformation: Three gene constructs bearing the gene cassettes BIK_1 (*Botrytis* induced kinase I), ERF1 (Ethylene response factor I) and AtEBP1(Ethylene bindind protein I) developed (Durga Bhavani, Ph.D thesis and unpublished) at the Biotechnology laboratory of ICAR- Indian Institute of Oilseeds Research (formerly DOR) were used for *in planta* transformation of castor. All the gene constructs in *Agrobacterium* LBA4404 were mobilized into *Agrobacterium* strain EHA105 and further confirmed before they were used for plant transformation.

Transformation and recovery of transformants: One of the cotyledons was detached from 2 day old seedlings and the apical meristem region was pricked with a sterile needle. The seedlings were subsequently immersed in the culture of *Agrobacterium* and incubated at 28°C with gyration at 40 rpm for 1 hour. The treated seedlings were later washed in water, blot dried and transferred to soilrite mix in plastic trays for further growth and eventually transferred to soil and grown in the transgenic green house.

Screening for the selection of putative transformants: Since a large number of T_1 seeds were produced following the *in planta* transformation protocols, a high throughput viable screening protocol under hygromycin selection conditions was developed for selection of putative transformants. To decide on the effective dose of hygromycin for selecting the putative transgenic plants, two-day-old seedlings of untransformed (control) Jwala cultivar (48-1) were surface sterilized (as described earlier), treated with different concentrations of hygromycin (Invitrogen, USA) i.e. 10 to 100 mg/l for two hours, and then placed in soilrite and incubated in culture room maintained at a constant photoperiod of 16h light and 8h dark regime and 25±2°C for 7 days. Seeds untreated with hygromycin acted as control. The concentration of hygromycin that affected the normal growth of the seedlings was identified. The seeds obtained from T_0 transformants were surface sterilized and subjected to hygromycin at its effective dose (as decided in the experiment with control seedlings) for 2 h and were incubated under the controlled conditions of the lab (as described earlier) for 7 days. Plants which were phenotypically similar to untreated control were transferred to pots in the green house for acclimatization. Molecular analysis for the presence of T-DNA was carried out with these plants.

DNA extraction and PCR analysis: Total genomic DNA was isolated from young leaves of untransformed plants (Jwala variety) as well as putative transformants (T1) by CTAB method (Dellaporta *et al.*, 1983). Genomic DNA isolated from these plants was assessed for quality by subjecting it to PCR with actin gene specific primers. DNA

from PCR positive plants (for actin gene) was subjected to further PCR analysis using transgene specific primers. The PCR reaction mixture (20 µL) contained 0.2 U Taq DNA polymerase, 1 assay buffer (10 µM pH 9.0 Tris-HCl, 50 µM KCl, 1.5 µM $MgCl_2$, 0.01% gelatin), 100 µM of each dNTP, 1 µL of each forward- and reverse- primer at a final concentration of 0.2 µM and 100 ng template DNA. The DNA extracted from untransformed plants was used as a negative control, while the plasmid DNA of pCAMBIA 1300 with the gene constructs was used as a positive control and the reaction mixture. Reaction mix without DNA was used as blank. The PCR reaction profile comprised of 35 cycles, with strand separation at 94°C for 30s, annealing at 58°C for 30s, extension at 72°C for 30s-1min depending on the size of the PCR product and the final extension step at 72°C was given for 10 min PCR products were electrophoresed on a 1.2% agarose gel, stained with ethidium bromide and visualized under ultraviolet light (Sambrook and Russell, 2001).

RESULTS AND DISCUSSION

Genetic improvement of castor through transgenic technology is mainly constrained by the non-availability of a repeatable *in vitro* regeneration and transformation protocols, (Ahn *et al.,* 2007) though there have been reports of castor transformation using meristem as the target tissue (Molina and Schobert, 1995; Lakshmi and Bahadur, 1997; Sujatha and Reddy, 1998; Malathi *et al.,* 2006; Sujatha and Sailaja, 2005; Sailaja *et al.,* 2008; Sujatha *et al.,* 2009; Sousa *et al.,* 2017). *In plants* that are recalcitrant to *in vitro* procedures, *in planta* transformation methods that avoid or minimize tissue culture steps have been successful in several crops (Supartana *et al.,* 2005; Liu *et al.,* 2009; Tishchenko *et al.,* 2014) including castor (Kumar *et al.,* 2011). It is established that *in planta* transformation method basically targets the meristematic cells in the otherwise well differentiated set of tissues (in the seedlings). T_0 plants are expected to be at best chimeric and the true transformants can be obtained in the T_1 generation when the meristematic cells destined to become germ cells are transformed during the process of co-culture (Kalbande *et al.,* 2016). Therefore, the factors such as, use of efficient Agrobacterium strains, induction of *vir* genes that increase transfer efficiency of T-DNA, steps that increase accessibility of the meristematic region to Agro infection, procedures that aid in identification of transformed plants in T_1 generation, etc are considered crucial for the success of *in planta* transformation.

In the present investigation, the protocol reported by Kumar *et al.* (2011) was taken as the base procedure to try with the developed gene constructs. A few of the parameters (as reported by Kumar *et al.*, 2011) such as, use of younger seedlings for transformation, use of selection agent to screen the T_1 progeny were used in all the attempts under present investigation. Also, based on the earlier reports that *Agrobacterium* super virulent strain, EHA105 provides higher transformation efficiency of up to 62.30 % in different crops (Yasmeen *et al.*, 2009; Jagannath *et al.*, 2014; Kalabande *et al.*, 2016; Ratanasut *et al.*, 2017), all the gene constructs intended to be used in the present studies were moved into EHA 105 strain. As another support to this logic, in *Jatropha curcas*, a member of Euphorbiaceae family, *in planta* transformation efficiency has been reported to be higher with *A. tumefaciens* EHA 105 compared to LBA 4404 and EHA 101 (Jagannath *et al.*, 2014). For induction of virulence genes in *Agrobacterium* and thereby increase the efficiency of transformation, bacterial culture was grown in AB medium fortified with wounded tobacco leaf extract as reported in pigeon pea (Rao *et al.*, 2008), peanut (Rohini and Rao 2000a) and safflower (Rohini and Rao, 2000b). However, while following the procedure reported by Kumar *et al.* (2011), we faced a few bottlenecks such as accessing the shoot apical meristem for pricking, establishment of seedling after pricking, and screening of the putative transformants in T_1 generation. This led us to addressing these issues and optimizing these parameters. Results of these experiments are presented in this report. Subsequently, using the optimized protocol, putative transgenic castor plants were obtained with gene constructs carrying AtEBP, ERF1 and BIK1 genes.

Optimization of the procedure for establishment of T_0 plants: In many earlier reports (Kumar *et al.,* 2011; Rao *et al.,* 2008; Keshamma *et al.,* 2008a; Manoj Kumar *et al.,* 2009; Rohini and Sankara Rao 2001), it has been stated that two day old seedlings show better amenability for transformation. The transformation efficiency depends on the extent of meristematic cells exposed to *A. tumefaciens.* Since the meristematic cells are present inside the tissue, it is necessary that *Agrobacterium* cells reach those cells to effect transformation. Several methods have been proposed to infect the meristematic cells present deep inside the tissue. Pin pricking is one of those methods and it has been successfully used in *in planta* transformation of several crops including pigeon pea, cotton, *Notocactus scopa,* and bell pepper (Rao *et al.,* 2008; Keshamma *et al.,* 2008; Seol *et al.,* 2008; Kumar *et al.,* 2009). Earlier reports in castor (Kumar *et al.,* 2011) as well as other crops (Keshamma *et al.,* 2008) have indicated that after co-cultivation, the seedlings were transferred to jam bottles. In our initial experiments carried out with EHA105 strain carrying ERF1 gene construct, meristematic region of two day old seedlings were pin pricked and the treated seedlings were transferred to jam bottles for about 7 days. But, while transferring these seedlings into soilrite mix, for their further establishment, the roots of plants were damaged which did not allow the plants to survive. Therefore, different methods were tried for

establishing the pricked seedlings (Table 1). When seedlings were placed on media after pricking and then transferred to soil most of the plants died because of fungal contamination. As a third option, seedlings were directly transferred to soil to reduce transplantation shock, but the survival rate was quite low (10%). In the next set of experiments seedlings after pricking were placed in autoclaved soilrite in plastic trays which provided enough space for root growth and offered least disturbance during the transfer to soil. This method was followed for all the subsequent transformation experiments.

Table 1 Methods tried for establishment of pricked seedlings

Method of establishment of pricked seedlings	No. of explants tried	No. of plants that survived in transgenic glasshouse	Remarks
In jam bottles with autoclaved soilrite mix	500	10	Roots were damaged while transferring to soil
Transferred to soil directly	100	10	Plants did not survive due to transplantation shock
Media	400	None	Persistent fungal contaminations
Plastic trays with autoclaved soilrite mix	100	40-50	Each plant had enough space to grow, less damage during transfer and hence better survived

About 250 two day old, pricked seedlings were transferred to soil in pots in transgenic green house of which 175 plants survived and produced seeds. T_1 progeny plants (8750) were raised in the transgenic greenhouse. To identify the putative transgenic plants in the T_1 generation, genomic DNA, isolated from pooled leaf samples of ten seedlings each was subjected to PCR analysis with actin gene specific primers initially to know the integrity of DNA and subsequently with ERF1 gene specific primers. Only one pool (#19) showed presence of ERF1 gene. Further analysis with the DNA from individual plants that constituted the pool (#19) indicated that only one plant (#2) carried the transgene (ERF1). However, when primers for the whole gene construct of ERF1 were tried for PCR analysis, it indicated that plant # 2 carried only the coding sequence but not the entire gene cassette. In summary, out of 8750 T_1 plants analyzed with PCR only one plant showed presence of gene.

Owing to the lower frequency of transformation observed in the previous experiments, next set of experiments was carried out using a reporter gene (*gus*) construct which facilitated monitoring of the transformation process in the initial few days after pricking. With the understanding that the pin pricks done in seedlings with intact endosperm may not have reached the meristematic region, to increase the access of *Agrobacterium* to apical meristematic region of the seedlings, the endosperm portion was removed with the scalpel prior to pricking and the meristematic region was pricked with the needle, and subsequently dunked in the *Agrobacterium* culture. Three hundred and fifty two-day old seedlings were infected with *Agrobacterium* strain EHA105:pCAMBIA1305.2 (this binary vector carries gus gene under 35S promoter). *GUS* histochemical analysis done after 3 days, indicated that out of 20 explants tested (in each of the three independent replications) on an average, (data not shown) 10 seedlings showed *GUS* expression. A representative picture of GUS expression of seedlings after 72 h of pricking is shown in Fig.1. This indicated that two day old seedlings with the endosperm tissue removed could be a better option for *Agrobacterium* treatment. Two day old seedlings have been used for *in planta* transformation in other crops like sunflower (Tishchenko *et al.,* 2014), ground nut (Reddy *et al.,* 2013) and pigeon pea (Rao *et al.,* 2008).

Of the 250 seedlings (transformed with *gus* construct) grown in plastic trays, 100 plants survived after their transfer to pots in the green house and selfed seeds of the putative T0 transgenic plants were collected and raised in the green house. For PCR analysis, DNA was isolated from pooled leaf samples of ~10 T_1 seedlings each and subjected to PCR initially with actin gene specific primers to assess the integrity of DNA and subsequently with *gus* gene-specific primers. From among 20 pooled samples analyzed, only one pool showed the presence of gene cassette and again within that pool only one individual plant showed the expected PCR product (Fig. 2) indicating extremely low transformation frequency but none the less a positive result.

Screening of putative transformants: As stated earlier, T_0 plants are expected to be at best chimeric and the true transformants can be obtained in the T_1 generation if the meristematic cells destined to become germ cells were transformed during the process of co-culture with *Agrobacterium* (Kalbande *et al.,* 2016). To increase the probability of success, there is a need to subject a large number of seedlings to *Agrobacterium* treatment, self such T_0 plants to obtain a large number of T_1 seeds to increase the probability of getting a true transgenic plant. Since the T_0 plants are not subjected to selection for their chimeric nature, it requires a stringent evaluation of the T_1 generation plants, on the same lines as in any *in vitro* transformation protocol, for identifying the plants carrying transgene (Keshamma *et al.,* 2012; Jan *et al.,* 2016). This can be achieved by screening the resultant T_1 seeds on selection medium containing either the antibiotic or herbicide depending on the gene construct used for transformation. Such a screening based on selectable marker has been used for identifying

putative transgenic T_1 seedlings obtained through *in planta* transformation procedures in several crops: screening of putative transformants has been done with hygromycin as the selectable marker in MS media (Supartana *et al.,* 2005, 2006; Ratanasut *et al.,* 2017), and with kanamycin in MS media (Khesamma *et al.,* 2008; Kumar *et al.,* 2011). Zhao *et al.* (2008) optimized that kanamycin @ 200 mg/L was ideal for screening of transgenic mustard (*Brassica juncea*) seeds while in buck wheat, screening T_1 generation seeds for 5 days on geneticin at 20 µg m/L was found optimum (Kajla *et al.,* 2017).

In the present investigation, different methods were tried to screen T_1 progeny plants (Table 2). In initial experiments, screening was done by adopting PCRs of pooled DNA samples but later, as the number of T_1 to be analysed ran into thousands, there was a need to develop alternate methods based on selection agent hygromycin (as the binary vectors used in our study contained *hpt* gene as selectable marker) to identify putative transgenic plants. Considering the ease, we did the initial screening with excised embryo from T_1 seed. Excised embryos from untransformed seeds showed stunted growth on MS medium with 20 mg/L hygromycin compared to the growth on control (without selection agent) medium (Fig.3). Excised embryos from T_1 seedlings that showed growth similar to that of embryos from untransformed control seeds on control medium, were considered to be putative transformants. Even though, putative transgenic plants could be identified through this method, after 15 days of transferring them to soil the plant growth was not proper and they could not survive the transfer. Thus, even though this method apparently looked very amenable, the recovery of plants in the green house was very low. In spite of screening the T_1 seeds derived from about 250 T_0 plants, not even a single plant could be recovered as a transgenic plant. So this method was not used for further selections. As an alternate to *in vitro* screening method, Davis *et al.,* 2009 have reported a protocol to screen T_1 seeds on chromatography grade sand, with continuous supply of antibiotic solution. Therefore, we tried the same with white sand and soilrite which was supplemented with hygromycin @ 100-2000 mg/L, but there was no kill observed even in untransformed control seedlings at 2000 mg/L. Subsequently, as another alternate method, T_1 seeds were soaked directly in water supplemented with different concentrations of hygromycin (@ 100-2000 mg/L) for 2 hours and then sown in the soil to see the effect of hygromycin on germination and establishment of the seedlings. There was no difference in this method also even at high concentrations (2000 mg/L) of hygromycin. Testing another method, two day old seedlings of untransformed Jwala variety were soaked in hygromycin solution at different concentrations i.e 10 to 100 mg/L for two hours, then transferred to soilrite, and observed for the effect of hygromycin on seedling growth after 7 days. At hygromycin concentration of 40 mg/L, all the treated untransformed control plants died and therefore this concentration was taken as effective dose for selection of putative T_1 transformants. T_1 progeny seedlings subjected to hygromycin treatment that showed similar growth to untransformed seedlings (Fig. 4) were considered putative transgenics and were transferred to soil mix in the transgenic green house. This method of screening has an advantage of not using aseptic conditions during screening and also uses less antibiotic solution for screening a large quantity of T_1 seeds. This method was used for screening T_1 seeds in subsequent experiments. A summary of the results obtained with different methods adopted for screening T_1 progeny plants is given in Table 2. In the next *in planta* experiment, all the optimized conditions were followed. Six hundred and fifty, 2-day old seedlings were subjected to *Agrobacterium* infection with EHA105: pCAMBIA1300- AtEBP1 culture that was induced using tobacco leaf extracts, seedlings were transferred to soilrite for 15 days and 450 seedlings that had grown better in the trays were transferred to soil mix. Two hundred and fifty plants survived and produced T_1 seeds. Two day old T_1 seedlings were subjected to selection pressure of hygromycin @40 mg/L and seedlings that survived this pressure were transferred to green house. Seedlings that survived selection pressure were subjected to PCR analyses first with actin specific primers and then with *hpt* gene specific primers. Subsequently the plants that were positive for *hpt* were analysed for the presence of AtEBP1 using AtEBP1 specific primers (Fig. 5A). Out of 7500 seedlings subjected to treatment with hygromycin selection, 300 seedlings survived the pressure and they were transferred to the soil in transgenic glass house. Of this 112 seedlings survived and they were subjected to PCR analysis using *hpt* specific primers and 36 plants were positive (Fig. 5B). These 36 plants were subjected to PCR with AtEBP1 specific primers and 30 plants were positive indicating clearly that there were putative transgenics obtained with AtEBP1 transgene. A representative gel picture is shown in Fig. 5A.

Subsequently, using the optimized protocol, transgenic castor plants positive for two genes were obtained (AtEBP1 and BIK1) when a concoction of three *Agrobacterium* cultures (EHA105: EBP, EHA105:AtERF1, EHA105:BIK1) was used for infecting the seedlings (Fig. 6). All the positive transgenic plants are being maintained for further studies.

In conclusion, fine tuning of the procedure for castor *in planta* transformation was taken up. Transferring the seedlings subjected to *in planta* transformation procedure to soilrite for two days and then to the soil mix was identified as a crucial step for survival of the *Agrobacerium* treated seedlings. A hygromycin based method to screen a large number of T_1 progeny plants to identify transgenic plants was established. With the developed protocol (as schematically represented in the Fig. 7), in total 30 transgenic plants were realized.

Control

Pricked castor seedling after 72 hr

Fig.1. GUS histochemical analysis after 3 days of co-cultivation

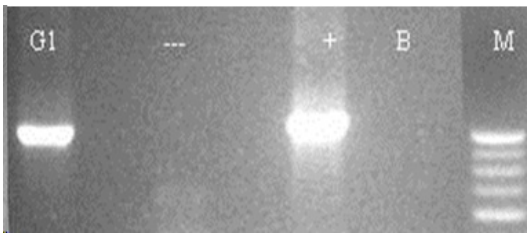

Fig.2. PCR analysis with the putative T_1 plant using gus gene specific primers
G1- pooled sample, - untransformed plant, + plasmid DNA, B - blank and M; Molecular marker

Table 2 Different methods followed to screen putative transgenics

Material used for screening	Transferred to	Concentration of hygromycin checked	Interpretation
Pooled DNA (~ 10 samples)	Grown directly in pots	Without selection pressure	Difficult to analyze as there were more samples
Seeds	Soilrite	100- 2000 mg/L	No kill observed
Seeds soaked	White sand	100- 400 mg/L	No kill observed
Excised embryo axis	Media	20 mg/L	Could not survive after 20 days
2 day old seedling soaked for 2 hr in hygromycin solution	Soilrite	40 mg/L	Clear difference between treated and un treated, plants could survive after transfer to green house

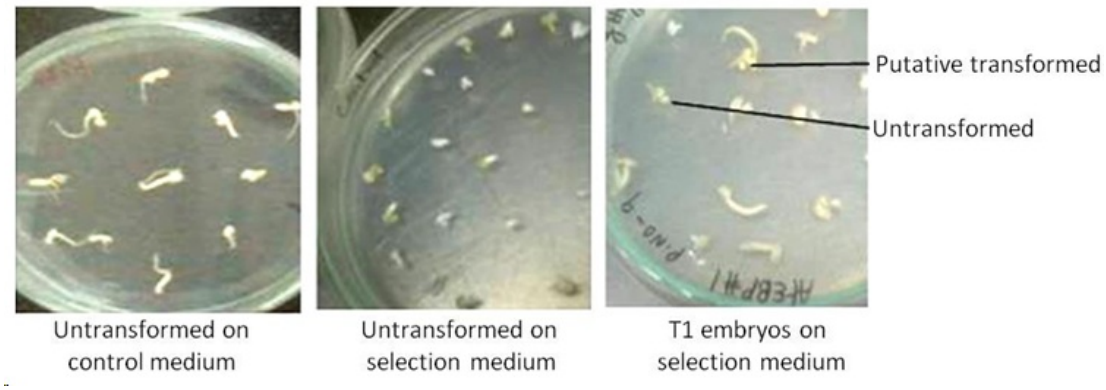

Fig. 3. Screening of excised embryo from putative transformants at 20 mg/lt on media

Fig. 4. Screening of two day old seedlings from putative transformants at 40 mg/lt-2hr

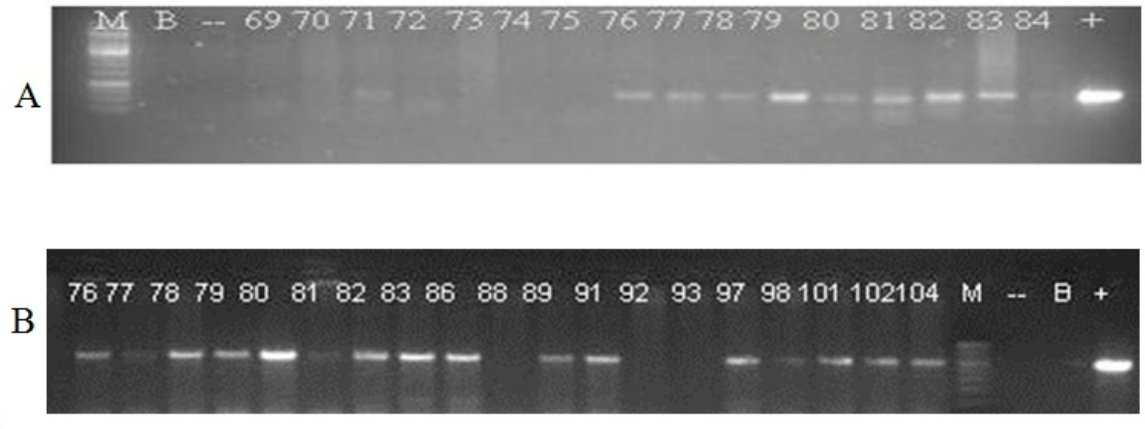

Fig. 5. Molecular analysis of putative T_1 transgenic plants

Panel A: with Hygromycin FP/RP(450 bp); Panel B: with AtEBP FP/RP (750 bp)

Lanes M-100 bp DNA ladder; lane + pCAMBIA1300-ACS7-AtEBP plasmid as a positive control; lane - untransformed genomic DNA as a negative control; lanes 77-6-104 putative transformed plants of castor plants with AtEBP gene. Lane B as a blank with out DNA.

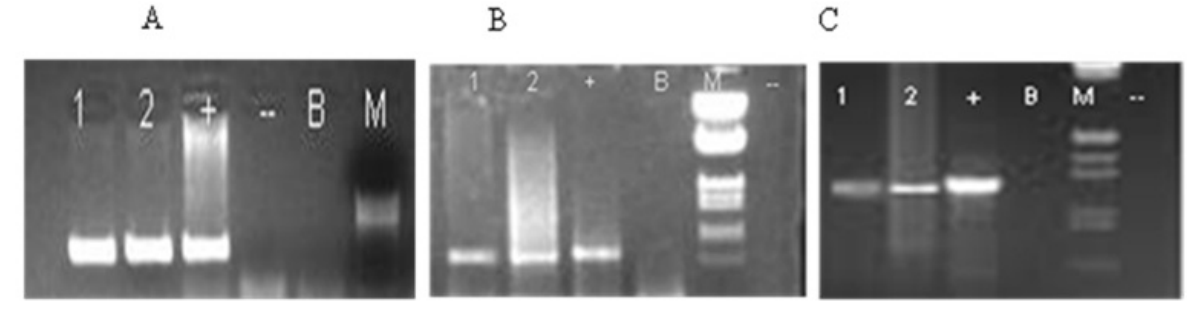

Fig 6. PCR analysis of the T1 plants obtained with concoction of AtEBP1and BIK1

Panel A: with Actin specific primers; Panel B: AtEBP specific primers; Panel C: BIK1 specific primers

Lanes 1, 2 putative transformed plants of castor plants with AtEBP and BIK 1genes; Lanes M-100 bp DNA ladder/ Lambda HindIII-EcoRI double digest; lane + pCAMBIA1300-ACS7-AtEBP/ pCAMBIA1300-ACS4-BIK1 plasmid as a positive control; lane - untransformed genomic DNA as a negative control;. Lane B as a blank with out DNA. M- DNA ladder; Lane +: PCR positive, Lane -: PCR of untransformed castor gDNA and Lane B : PCR Blank

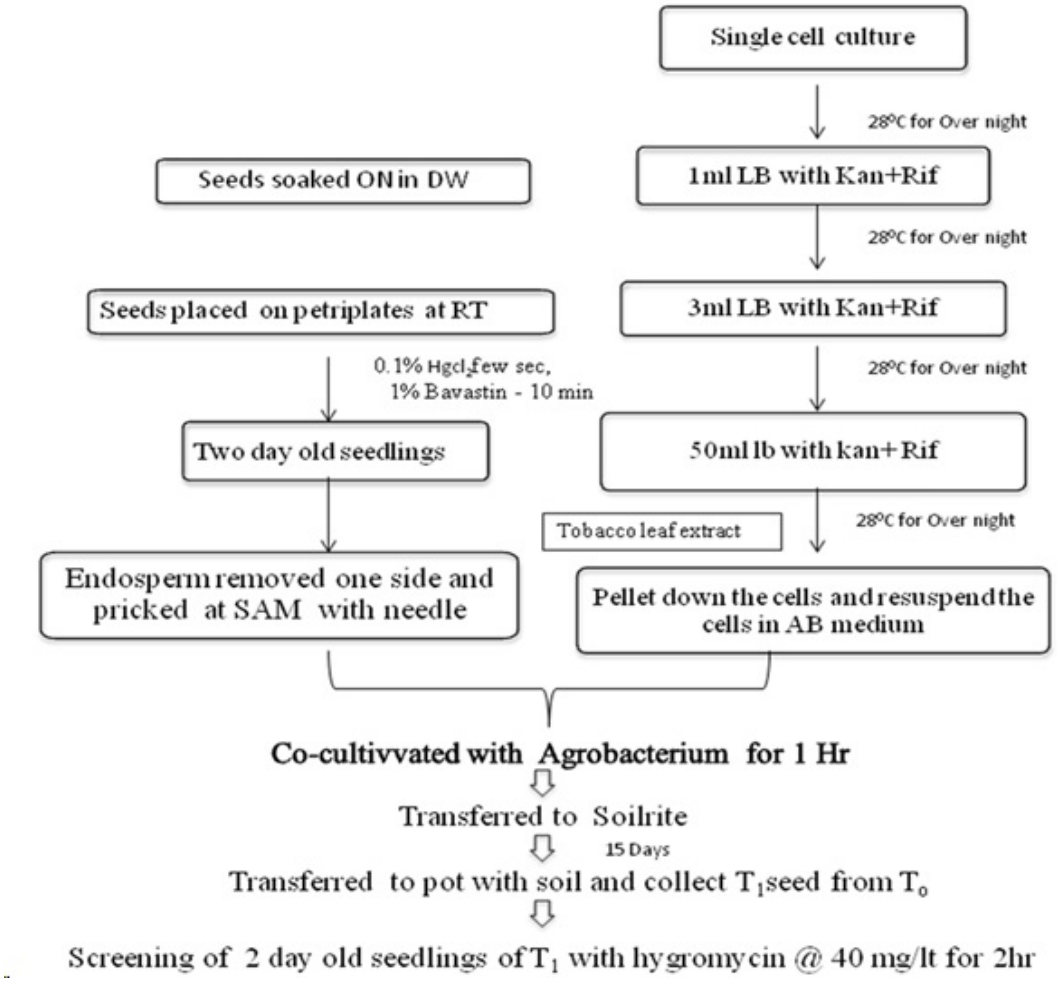

Fig. 7. Flow chart of the modified *in planta* transformation protocol in castor

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Identification of fertility restorer and sterility maintainer lines for diversified CMS lines in sunflower (*Helianthus annuus* L.)

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ABSTRACT

Six diversified CMS lines ARG-6-3-1-4, PKUZ, ARG-3, ARG-2-1-2, PRUN-29 and MUT2-8-3-2 were crossed with ninety six inbred lines in a line x tester fashion to study their sterility maintenance or fertility restoration reaction. Out of 96 inbreds tested, 48 inbreds restored fertility in the diversified CMS lines *viz.,* ARG-6-3-1-4, PKUZ, ARG-3, ARG-2-1-2, while 47 and 45 inbreds restored fertility in MUT2-8-3-2 and PRUN-29, respectively. On the other hand, 39, 46, 45, 43, 44 and 46 inbreds maintained sterility in the diversified CMS lines ARG-6-3-1-4, MUT-2-8-2, PUKZ, ARG-3, PRUN-29 and ARG-2-1-2, respectively. Among 96 inbreds, as many as 38 inbreds were identified as common maintainers for all the six diverse CMS lines. Similarly, 39 inbreds were identified as common restorers for all the six diverse CMS lines. Effective restorer lines identified for alternate sources of cytoplasm could be exploited in developing hybrids with better heterosis and it can pave way for broadening the CMS sources used in commercial hybrid development. Identified promising maintainer lines could be used in development of new CMS lines through conversion.

Keywords: CMS lines, Inbred lines, Fertility restoration, Sterility maintenance, Sunflower

Sunflower (*Helianthus annuus* L.) is an important oilseed crop of all seasons and belongs to family Asteraceae, tribe Heliantheae, subtribe Helianthinae. It is extensively grown in Argentina, France, Spain, USA, China, Ukraine and India. It is primarily grown for edible oil which is considered as healthy oil due to the presence of high concentration of polyunsaturated fatty acids (PUFAs).

In sunflower, hybrids are superior over open-pollinated cultivars in terms of yield, self fertility and resistance to diseases (Miller, 1987). The first cytoplasmic male sterile source was *Helianthus petiolaris* (PET-1), discovered by Leclercq (1969) in the progeny of cross between *Helianthus petiolaris* Nutt and cultivated sunflower (cv. Armavirskii 9345) and subsequent identification of genes for fertility restoration by Kinman (1970); Enns *et al.* (1970), Leclercq (1971) and Vranceanu and Stoenescu (1971) resulted in the development of several sunflower hybrids. In India the first ever CMS based sunflower hybrid BSH-1 was released from the University of Agricultural Sciences, Bangalore (Seetharam *et al.,* 1980) which provided the required fillip to expand sunflower cultivation in the country. From 1972 onwards, many hybrids were developed and released for commercial cultivation but all of them invariably possessed the PET-1 cytoplasm (Friedt, 1992; Reddy, 1999). Large-scale cultivation of hybrids having single CMS source might pose a threat if it becomes susceptible to pests and diseases as was recorded in other crops like corn and pearl millet.

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In order to diversify the cytoplasmic base, attempts have been made and several new cytoplasmic sources have been identified. Since the report of the first CMS in sunflower in 1969, as many as 72 CMS sources have been identified (Serieys, 2005). The lack of new CMS and fertility restoration (Rf) genes for use in commercial hybrid production is partly due to the limited number of stable CMS cytoplasm and their corresponding Rf genes, as well as the time-consuming effort of converting lines to CMS and the incorporation of Rf genes into adapted cultivated lines. Hence, it is necessary to study the role of new cytoplasmic male sterility sources on the standard heterosis for seed yield and oil content and also the possibility of converting new inbred lines into A and R lines. Such lines may be more diverse for both cytoplasmic as well as genetic content for realizing higher standard heterosis and resistance to major diseases like Alternaria, necrosis and powdery mildew. In view of this, an attempt was made at the AICRP on Sunflower, UAS, GKVK, Bengaluru to identify effective fertility restorers and sterility maintainers for diverse CMS sources in sunflower.

MATERIALS AND METHODS

Material consisted of six diverse cytoplasmic male sterile lines, 96 inbred lines, which included 49 restorer (37 Multi head and 12 Mono head) and 47 maintainer lines. Diverse CMS lines were obtained from the ICAR-Indian Institute of Oilseeds Research (formerly Directorate of Oilseeds Research), Hyderabad and Department of Oilseeds, TNAU,

Coimbatore. 96 inbred lines were obtained from the AICRP on sunflower, UAS, GKVK, Bangalore. The list of 96 inbred lines is presented in Table 1. While, the list of six diversified CMS lines is furnished below.

Diversified CMS Lines

CMS designation	Origin
ARG-2-1-2	*H. argophyllus*
ARG-6-3-1-4	*H. argophyllus*
MUT2-8-3-2	*H. annuus*
ARG 3	*H. argophyllus*
PKUZ	*H. annuus*
PRUN-29	*H. praecox* spp. *runyonii*

During *kharif* 2011, all the six diverse CMS lines and 96 inbred lines were sown in the field to effect crossing in line × tester fashion. Resultant 576 crosses were evaluated to identify fertility restorer and sterility maintainer lines for diversified CMS lines.

For investigation on sterility maintenance or fertility restoration reaction of inbreds, hybrids were evaluated with two replications. Each hybrid was sown in a single row of three meter length with a row spacing of 60 cm and 30 cm between plants within a row. All the recommended practices were followed for raising successful crop under protective irrigated condition.

Investigation on sterility maintenance or fertility restoration reaction of inbreds: All the plants in the F_1 progenies at flowering were visually counted for male fertility or sterility reaction (to know the fertility restoration or sterility maintenance behaviour of inbred lines used as males in the crossing) based on the presence or absence of pollen, anther dehiscence and pollen shedding in all the plants.

Based on the extent of fertility restored and sterility maintained by the respective inbreds in the crosses, inbreds used in the study were classified as maintainers, if all the plants in F_1 were sterile; restorers, if all the F_1 plants were fertile and as partial restorers, if some plants showed normal fertility and some plants normal sterility reaction in the F_1 progenies. Based on this, F_1 was grouped as male sterile or male fertile or partially fertile. Further each inbred line was classified as sterility maintainer or fertility restorer or partial restorer type for the respective CMS lines.

Pollen fertility: During flowering in each of 10 randomly selected plants, 10-12 disc florets were collected in the morning hours. These were examined for pollen fertility by preparing anther smears in one per cent acetocarmine stain. Deeply stained and well filled pollen grains with good exine were considered as fertile. While, poorly stained and shrivelled pollen grains were taken as sterile.

Statistical analysis: Frequencies of sterility maintainer/ fertility restorer lines were worked out for six diverse CMS lines and expressed as percentage. Percentage of sterility and fertility were worked out for each of the hybrids by counting the number of sterile or fertile plants in each cross.

RESULTS AND DISCUSSION

Based on the extent of fertility restored and sterility maintained by the respective inbreds in the crosses, inbreds used in the study were classified as maintainer, restorers and as partial restorers. Fertility restoration and sterility maintenance reaction of all six diversified CMS lines with 96 inbred lines are presented in Table 2. The fertility of identified fertile lines was again confirmed through acetocarmine staining technique.1% acetocarmine stain was used to stain the pollen, if all the pollen grains stained completely, then it was considered as 100% fertile hybrid and the corresponding male line of that hybrid was considered as fertility restorer. Differential staining of pollen showing fertile/sterile reaction is represented in Fig. 1 to 3. Out of 96 inbred lines evaluated for their fertility restoration and sterility maintenance behaviour (Table 2), 48 inbreds comprising 42 RHA lines and six maintainer lines *viz.,* CMS-336B, CMS-343B, CMS-109B, CMS-339B, CMS-850B and CMS-125B restored fertility and 39 inbreds involving 35 maintainer lines and four mono head restorer lines *viz.,* RHA-114, RHA-102, RHA-116 and DS-2 maintained sterility in the F_1s involving CMS ARG6-3-1-4 as female.

Analysis with the F_1s involving CMS line MUT2-8-3-2 indicated that 47 inbred lines comprising of 41 RHA lines and six maintainer lines *viz.,* CMS-336B, CMS-343B, CMS-109B, CMS-339B, CMS-850B and CMS-125B restored fertility while 46 inbreds consisting of 42 maintainer lines and 4 mono head restorers of PET-1 source *viz.,* RHA-114, RHA-102, RHA-116 and DS-2 maintained the sterility In CMS line PKUZ, 48 inbreds involving 42 RHA lines and 6 mono head maintainer lines *viz.,* CMS-336B, CMS-343B, CMS-109B, CMS-339B, CMS-850B, CMS-125B restored fertility and 45 inbreds comprising of 41 maintainer lines and 4 mono head restorers of PET-1 source *viz.,* RHA-114, RHA-102, RHA-116 and DS-2 maintained sterility in F_1.

In the F_1 crosses involving CMA line ARG 3, among the 96 inbred lines used as male parent, 48 lines including 42 RHA lines and 4 mono head maintainer lines *viz.,* CMS-336B, CMS-343B, CMS-109B, CMS-339B, CMS-850B and CMS-125B behaved as restorers and 43 inbreds involving 39 maintainer and 4 mono head RHA lines *viz.,* RHA-114, RHA-102, RHA-116 and DS-2 behaved as maintainers. In CMS source PRUN-29, 45 inbreds comprising of 39 RHA lines and 6 maintainer lines of PET-1 source *viz.,* CMS-336B, CMS-343, CMS-109B, CMS-339B,

CMS-850B and CMS-125B restored fertility and 44 inbreds involving 40 maintainer lines and 4 mono head RHA lines of PET-1 source *viz.,* RHA-114, RHA-102, RHA-116 and DS-2 behaved as maintainers.

With respect to CMS line ARG 2-1-2, among the inbreds tried as male parents 48 lines comprising 42 RHA lines and 6 mono head maintainer lines *viz.,* CMS-336B, CMS-343B, CMS-109B, CMS-339B, CMS-850B and CMS-125B behaved as restorers while 46 inbreds including of 42 maintainer lines and 4 mono head RHA lines *viz.,* RHA-114, RHA-102, RHA-116 and DS-2 behaved as maintainers.

Among 96 inbred lines evaluated with six diversified CMS lines, forty eight inbred lines were identified as fertility restores for the diversified CMS lines *viz.,* ARG-6-3-1-4, PKUZ, ARG 3 and ARG-2-1-2, while 47 and 45 inbreds restored fertility in the CMS background of MUT2-8-3-2 and PRUN-29 respectively. On the other hand, 39, 46, 45, 43, 44 and 46 inbreds maintained sterility in the CMS background of ARG-6-3-1-4, MUT2-8-3-2, PKUZ, ARG-3, PRUN-29 and ARG2-1-2, respectively. Virupakshappa and Jayarame Gowda (1996), Reddy *et al.* (2002), Reddy *et al.* (2008), Sujatha (2008), Suresh (2008), Venkanna *et al.* (2008), and Channamma (2009) have also reported identification of restorers and maintainers for diverse cytoplasm in sunflower. The fertility restorer behaviour of inbreds for one CMS source behaved as sterility maintainers in another CMS source and sterility maintainer for one CMS source behaved as fertility restorer in another CMS source confirming the diversity among the six CMS lines. Similar results were also reported by Virupakshappa and Jayarame Gowda (1996), Reddy *et al.* (2002), Reddy *et al.* (2008), Sujatha (2008), Suresh (2008) and Channamna (2009). The differential behavior of the inbred lines for fertility/sterility reaction may be attributed to the genetic architecture especially with respect to the number of genes controlling fertility restoration and their interaction with the cytoplasmic genome. It is also evident from the present investigation that some inbreds behaved differentially with different cytoplasmic backgrounds in respect of sterility maintenance and fertility restoration suggesting the presence of modifying genes influencing the fertility restoration, resulting in partial fertility. However, stability of restoration in different seasons and environments for same cytoplasmic background needs to be carried out.

Table 1 Inbred lines used for studying fertility restoration and sterility maintenance behaviour

	Inbreds		Inbreds		Inbreds
	RHA Lines	34	RHA-89	67	CMS-597B
1	R83R6 (Mono head)	35	DS-2 (Mono head)	68	CMS-62B
2	RHA-114(Mono head)	36	LTRR83-273	69	CMS-107B
3	RHA-102(Mono head)	37	RHA-6D-1	70	CMS-112B
4	GKVK-3	38	RCR-60P	71	CMS-131B
5	RHA-95-C-2	39	RHA-88	72	CMS-243B
6	RHA-278	40	RHA-23	73	CMS-108B
7	RHA-95-C-1	41	X-15-NB-10 (Mono head)	74	CMS-110B
8	RHA-272-II	42	GKVK-1	75	CMS-234B
9	RHA-348	43	RHA-6D-5-3-5(Mono head)	76	CMS-101B
10	LTRR-822	44	RHA-93	77	CMS-138B
11	REC-431(Mono head)	45	RHA 6D-5-3-9	78	CMS-55B
12	RHA-94	46	RHA-GK	79	CMS-135B
13	RHA-284	47	RHA-86	80	CMS-89B
14	RHA-297	48	R SEL MASTER	81	CMS-134B
15	RHA-859	49	RHA-207	82	CMS-148B
16	REC-428(Mono head)		**Maintainer Lines**	83	CMS-7-1B
17	REC-441(Mono head)	50	CMS-335B	84	CMS-300B
18	SOF-138-2(Mono head)	51	CMS-59B	85	CMS-438B
19	REC-443(Mono head)	52	CMS-852B	86	CMS-607B
20	RHA-91	53	CMS-275B	87	CMS-850B
21	RHA-92	54	CMS-336B	88	CMS-122B
22	RHA-275	55	CMS-56B	89	CMS-125B
23	M17-R	56	CMS-207B	90	CMS-127B
24	RHA-116(Mono head)	57	CMS-343B	91	NDCMS-4B
25	RHA-90	58	CMS-17B	92	CMS-851B
26	MR-1	59	CMS-109B	93	CMS-10B
27	RHA-273	60	CMS-102B	94	CMS-47B
28	RHA-378	61	CMS-103B	95	CMS-84B
29	RHA-589	62	CMS-111B	96	CMS-338B
30	GKVK-2	63	CMS-339B		
31	RHA-272-I	64	CMS-54B		
32	RHA-857	65	CMS-58B		
33	RHA-183	66	CMS-60B		

Table 2 Fertility Restoration or sterility maintenance reaction of 96 inbred lines with six diverse CMS lines in sunflower

Inbreds	ARG-6-3-1-4	MUT2-8-3-2	PKUZ	ARG3	PRUN-29	ARG-2-1-2
I.RHA lines						
R83R6	R	R	R	R	PR	R
RHA-114	M	M	M	M	M	M
RHA-102	M	M	M	M	M	M
GKVK-3	R	R	R	R	R	R
RHA-95-C-2	R	R	R	R	R	R
RHA-278	R	R	R	R	R	R
RHA-95-C-1	R	R	R	R	R	R
RHA-272-II	R	R	R	R	R	R
RHA-348	R	R	R	R	R	R
LTRR-822	R	R	R	R	R	R
REC-431	R	R	M	M	PR	M
RHA-94	R	R	R	R	R	R
RHA-284	R	R	R	R	R	R
RHA-297	R	R	R	R	R	R
RHA-859	R	R	R	R	R	R
REC-428	PR	M	PR	M	PR	M
REC-441	PR	PR	R	R	R	R
SOF-138-2	R	R	PR	R	PR	R
REC-443	R	M	R	R	R	R
RHA-91	R	R	R	R	R	R
RHA-92	R	R	R	R	R	R
RHA-275	R	M	R	R	R	R
M17-R	R	R	R	R	R	R
RHA-116	M	M	M	M	M	M
RHA-90	R	R	R	R	R	R
MR-1	R	R	R	R	R	R
RHA-273	R	R	R	R	R	R
RHA-378	R	R	R	R	R	R
RHA-589	R	R	R	R	R	R
GKVK-2	R	R	R	R	R	R
RHA-272-I	R	R	R	R	R	R
RHA-857	PR	R	R	R	R	R
RHA-183	R	R	R	R	R	R
RHA-89	R	R	R	PR	R	PR
DS-2	M	M	M	M	M	M
LTRR83-273	R	R	R	PR	R	R
RHA-6D-1	R	R	R	R	R	R
RCR-60P	R	R	R	R	R	R
RHA-88	R	R	R	R	R	R
RHA-23	R	R	R	R	PR	R
X-15-NB-10	R	R	R	R	R	R
GKVK-1	R	R	R	R	R	R
RHA-6D-5-3-5	R	R	R	R	R	R
RHA-93	R	R	R	R	R	R
RHA 6D-5-3-9	R	R	R	R	R	R
RHA-GK	R	R	R	R	R	R
RHA-86	R	R	R	R	R	R
R SEL MASTER	PR	PR	M	R	M	M

Inbreds	ARG-6-3-1-4	MUT2-8-3-2	PKUZ	ARG3	PRUN-29	ARG-2-1-2
RHA-207	R	R	R	R	R	R
II Maintainer lines						
CMS-335B	PR	M	M	M	M	M
CMS-59B	M	M	M	M	M	M
CMS-852B	M	M	M	M	M	M
CMS-275B	M	M	M	M	M	M
CMS-336B	R	R	R	R	R	R
CMS-56B	M	M	M	M	M	M
CMS-207B	M	M	M	M	M	M
CMS-343B	R	R	R	R	R	R
CMS-17B	PR	M	M	M	M	M
CMS-109B	R	R	R	R	R	R
CMS-102B	M	M	M	M	M	M
CMS-103B	PR	M	M	PR	M	M
CMS-111B	M	M	M	M	M	M
CMS-339B	R	R	R	R	R	R
CMS-54B	R	M	M	M	M	M
CMS-58B	M	M	M	M	M	M
CMS-60B	PR	PR	PR	PR	PR	PR
CMS-597B	M	M	M	M	M	M
CMS-62B	PR	R	R	R	PR	R
CMS-107B	M	M	M	M	M	M
CMS-112B	M	M	M	M	M	M
CMS-131B	M	M	M	M	M	M
CMS-243B	M	M	M	M	M	M
CMS-108B	M	M	M	M	M	M
CMS-110B	M	M	M	M	M	M
CMS-234B	M	M	M	M	M	M
CMS-101B	M	M	M	M	M	M
CMS-138B	M	M	M	M	M	M
CMS-55B	M	M	M	M	M	M
CMS-135B	M	M	M	M	M	M
CMS-89B	M	M	M	M	M	M
CMS-134B	M	M	M	M	M	M
CMS-148B	M	M	M	M	M	M
CMS-7-1B	M	M	M	M	M	M
CMS-300B	M	M	M	M	M	M
CMS-438B	M	M	M	PR	M	M
CMS-607B	M	M	M	M	M	M
CMS-850B	R	R	R	R	R	R
CMS-122B	M	M	M	M	M	M
CMS-125B	R	R	R	R	R	R
CMS-127B	M	M	M	M	M	M
NDCMS-4B	M	M	M	M	M	M
CMS-851B	M	M	M	M	M	M
CMS-10B	M	M	M	M	M	M
CMS-47B	M	M	M	M	M	M
CMS-84B	M	M	M	M	M	M
CMS-338B	M	M	M	M	M	M

Reaction: M: Sterility maintenance; R: Fertility restorer; PR: Partial Restorer

Out of 96 inbreds used, 49 were the fertility restorers and 47 were sterility maintainers in the cytoplasmic background of PET-1. Out of 49 fertility restorer lines of PET-1 cytoplasm, 39 were observed as common restorer in diverse cytoplasmic lines. Similarly, out of 47 maintainer lines of PET-1cytoplasm, 38 behaved as common maintainers in diverse cytoplasms. This differential behaviour of 96 inbreds on petiolaris and other diversified lines used in the present study indicated the distinctness of cytoplasmic sources included in the study.

Common fertility restorers and sterility maintainers for diverse CMS lines: The common sterility maintainer and fertility restorer inbred lines identified for all the six diverse CMS lines are presented in Table 3. Among 96 inbred lines, 38 inbred lines comprising of 34 maintainer lines and four mono head restorer lines *viz.,* RHA-114, RHA-102, RHA-116 and DS-2 behaved as common sterility maintainers and 39 inbred lines comprising 33 restorer lines and six maintainer lines *viz.,* CMS-336B, CMS-343B, CMS-109B, CMS-339B, CMS-850B, CMS-125B behaved as common restorers for all the six diverse CMS lines. This indicated that, though CMS lines were different by cytoplasmic background, the fertility restoring gene could be same.

Branching (Multi head) and Non branching (Mono head) fertility restorers and sterility maintainers: Out of the identified 39 common fertility restorers, 31 inbred lines were branching RHA lines and 8 inbred lines *viz.,* 2 RHA lines and 6 CMSB lines were non branching restorers. All the 38 identified common sterility maintainers were non branching (34 CMSB lines and 4 mono head RHA lines) as indicated in Table 4. Number of branching and non branching restorer lines for the six diverse CMS lines are listed in Table 5.

The inbred lines identified as sterility maintainers for the different cytoplasmic could be used in conversion programme to convert maintainer lines into new CMS lines for their utilization in heterosis breeding programme for developing hybrids with diversified CMS source. The restorers identified will help in exploitation of new CMS sources for hybrid development with better heterosis and diversity of cytoplasm in sunflower.

Frequency of fertility restorers and sterility maintainers for diverse CMS lines: Out of the 96 pollen parents tested for fertility restoration on six diverse CMS lines, some turned out to be sterility maintainers and some acted as fertility restorers. Differential behaviour of inbred lines was observed for this on different cytoplasm. The frequency of sterility maintainer/fertility restorer behaviour (%) of inbred lines for different diverse CMS lines is given in the Table 6.

In conclusion, analysis of the F_1 plants of 576 crosses identified new restorers that could be utilized in heterosis breeding programme to develop superior hybrids with diversified CMS base. Also, the identified sterility maintainers could be converted in to new CMS lines with diversified CMS backgrounds.

Table 3 Common sterility maintainer and fertility restorer inbred lines for all six diverse CMS lines in sunflower

	Inbred lines	Total
Common Restorers	I RHA Lines GKVK-3, RHA-95-C-2, RHA-278, RHA-95-C-1, RHA-272-II, RHA-348, LTRR-822, RHA-94, RHA-284, RHA-297, RHA-859, RHA-91, RHA-92, M17-R, RHA-90, MR-1, RHA-273, RHA-378, RHA-589, GKVK-2, RHA-272-I, RHA-183, RHA-6D-1, RCR-60P, RHA-88, X-15-NB-10, GKVK-1, RHA-6D-5-3-5, RHA-93, RHA 6D-5-3-9, RHA-GK, RHA-86 and RHA-207	33
	II Maintainer lines CMS-336B, CMS-343B, CMS-109B, CMS-339B, CMS-850B and CMS-125B.	6
	Total	39
Common Maintainers	I Maintainer lines CMS-59B, CMS-852B, CMS-275B, CMS-56B, CMS-207B, CMS-102B, CMS-111B, CMS-58B, CMS-597B, CMS-107B, CMS-112B, CMS-131B, CMS-243B, CMS-108B, CMS-110B, CMS-234B, CMS-101B, CMS-138B, CMS-55B, CMS-135B, CMS-89B, CMS-134B, CMS-148B, CMS-7-1B, CMS-300B, CMS-607B, CMS-122B, CMS-127B, NDCMS-4B, CMS-851B, CMS-10B, CMS-47B, CMSB-84B and CMS-338B	34
	II RHA lines (Mono head) RHA-114, RHA-102, RHA-116 and DS-2	4
	Total	38

Table 4 Branching and Non-branching Common sterility maintainers and fertility restorers for six diverse CMS lines in sunflower

Common fertility restorer inbred lines	Common sterility maintainer inbred lines
RHA lines	Maintainer lines (CMS B)
Branching (Multi head) - 31 GKVK-3, RHA-95-C-2, RHA-278, RHA-95-C-1, RHA-272-II, RHA-348, LTRR-822, RHA-94, RHA-284, RHA-297, RHA-859, RHA-91, RHA-92, M17-R, RHA-90, MR-1, RHA-273, RHA-378, RHA-589, GKVK-2, RHA-272-I, RHA-183, RHA-6D-1, RCR-60P, RHA-88, GKVK-1, RHA-93, RHA 6D-5-3-9, RHA-GK, RHA-86, RHA-207 Non branching (Mono head) - 2 X-15-NB-10, RHA-6D-5-3-5	Non branching (Mono head) - 34 CMS-59B, CMS-852B, CMS-275B, CMS-56B, CMS-207B, CMS-102B, CMS-111B, CMS-58B, CMS-597B, CMS-107B, CMS-112B, CMS-131B, CMS-243B, CMS-108B, CMS-110B, CMS-234B, CMS-101B, CMS-138B, CMS-55B, CMS-135B, CMS-89B, CMS-134B, CMS-148B, CMS-7-1B, CMS-300B, CMS-607B, CMS-122B, CMS-127B, NDCMS-4B, CMS-851B, CMS-10B, CMS-47B, CMS84B, CMS-338B. Branching (Multi head) - 0-
II CMS B lines	RHA lines
Non branching (Mono head) - 6 CMS-343B, CMS-109B, CMS-339B CMS-343B, CMS-850B and CMS-125B. Branching (Multi head) - 0	Non branching (Mono head) - 4 RHA-114, RHA-102, RHA-116, andDS-2 Branching (Multi head) - 0
Total : 39	Total : 38

Table 5 Number of branching and non-branching fertility restorer and sterility maintainer inbred lines for each diverse CMS lines

Diverse CMS lines	Number of inbred lines	Number of maintainer inbred lines			Number of restorer inbred lines		
		Non Branching	Branching	Total	Branching	Non Branching	Total
ARG-6-3-1-4	96	39	0	39	36	12	48
MUT2-8-3-2	96	46	0	46	36	11	47
PKUZ	96	45	0	45	37	11	48
ARG3	96	43	0	43	36	12	48
PRUN-29	96	44	0	44	35	10	45
ARG-2-1-2	96	46	0	46	36	12	48

Fig. 1. Fertile reaction in F_1 hybrids

Fig. 2. Sterile reaction in F_1 hybrids

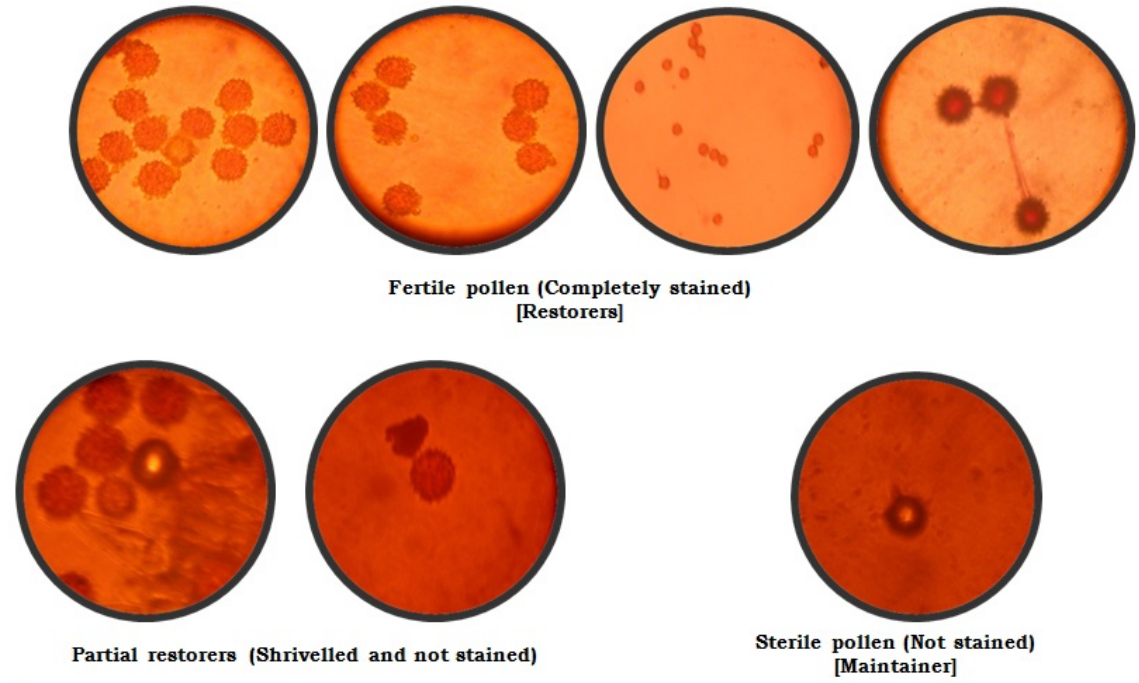

Fig. 3. Staining of pollen using acetocarmine depicting fertile and sterile pollen

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Assessment of genetic divergence and principal component analysis in oil palm (*Elaeis guineensis* Jacq.)

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ABSTRACT

Twenty-nine oil palm DxD crosses derived from 37 dura parents were evaluated to identify high yielding and dwarf palms. Yield performance of progenies of 29 oil palm DxD crosses varied significantly and it ranged from 102.53 to 191.37 kg/palm/year with an experimental mean of 145.95 kg/palm/year. The other yield related traits like sex ratio and bunch number also significantly varied. Palm height increment after five years of planting ranged from 20.40 to 31.44 cm with experimental mean of 25.93 cm. Based on cluster analysis, all 29 DxD crosses with important traits grouped into five distinct clusters. From the present study, eight genotypes (DD7, DD8, DD11, DD12, DD17, DD18, DD21, and DD22) were identified to be high yielding and with slow vertical growth habit. Among the cluster IV DxD crosses, DD7 and DD8 had a common parent 257 CD; DD17 and DD18 had a common parent 232 CD. The preferred genotypes in the present diversity studies could be utilized as desirable parent in hybridization programme which led to the improvement of dura oil palm in high yield and slow vegetative growth.

Keywords: Diversity, Dura, Dwarf, Improvement, Oil palm

Oil Palm (*Elaeis guineensis* Jacq.), a cross pollinated monoecious crop species having diploid number of chromosomes (2n=32), is a native of Africa. The oil yield of oil palm is more than five times than any major oil yielding annual crops. According to USDA (2018) reports the global palm oil production in 2018 was 73.30 Million metric tonnes with a change in production of 2.94 MMT than the previous year. The commercial cultivation of oil palm in India and other developing countries has been on rise due to its very high oil yielding capacity which can help developing economies to cater edible oil demand. Being a commercial crop, analysis of the genetic diversity of oil palm is particularly important for the protection of genetic resources, identification of oil palm populations, further exploration of plant genetic resources and development of future breeding programmes (Zhou *et al.,* 2015).

Oil palm is having three distinct types of fruit forms depending on their shell thickness *viz.,* thick shelled type (Dura), thin shelled (Tenera) and shell-less (Pisifera). The commercial planting material in oil palm is a hybrid known as Tenera. The duras are mostly used as a female parent whereas, pisiferas are male parents to produce intra-specific hybrid tenera (Corley and Tinker, 2003). The main yield components of oil palm are the number and weight of harvested bunches (Corley and Tinker, 2003). The utilization of planting material of high-yielding genetic base has been proven to be the most resourceful and sustainable means of increasing the yield output of oil palm (Arolu *et al.,* 2016; Hayati *et al.,* 2004). The evaluation of progeny plays an important role in revealing the yield performance and to know the potentiality of germplasm materials (Noh *et al.,* 2014). Due to the narrow genetic base of the existing oil palm population, there is a need to widen the genetic base of the current population through crossing programmes (Anitha *et al.,* 2013; Rajanaidu and Ainul, 2013). Understanding genetic structure and genetic diversity of oil palm collections in relation to breeding populations are guides to the introduction of new materials in the base populations of breeding programmes (Cochard *et al.,* 2009).

In the present study 29 genotypes (DxD crosses) were used for estimating genetic diversity and principal component analysis, this will help to understand the genetic relatedness of dura oil palm genotypes so as to bring together the divergent alleles to exploit the potential hybrid vigour. High bunch weight coupled with less height increment plays an important role for the selection of high yielding and dwarf oil palm genotypes, with this view the present research programme was undertaken.

MATERIALS AND METHODS

Twenty-nine oil palm genotypes (Dura x Dura crosses) were included in the present studies which were developed by crossing 37 diverse dura mother palms selected in the field gene bank maintained at ICAR-Indian Institute of Oil Palm Research, Pedavegi, Andhra Pradesh, India. These crosses were evaluated in Randomized Complete Block Design with three replications during 2016-18. The yield data were recorded regularly from fourth year of planting onwards on every harvest basis. The fresh fruit bunch weight (BW) in kg and bunch number (BN) were summarized annually. Morpho-physiological observations were recorded on number of leaves (NL), number of male inflorescences,

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number of female inflorescences and sex ratio on every quarterly basis and expressed over annual basis. The dry matter related parameters were recorded on 17th leaf once in a year following Corley (1977) and Mathur *et al.* (2018). On 17th frond observations were recorded on rachis length (RL) in cm, Leaflet length (LLL) and Leaflet width (LLW) measured in cm by collecting six longest leaflets in middle (three each from left and right hand side), number of leaflets (NLL) counted individually both (left and right) sides of the frond, petiole width (PW) and petiole depth (PD) in cm at the point of insertion of leaflet region recorded.

During 6th year, observations were also recorded on palm height (PH) measured from the ground level to the base of the 41st frond; height increment (HI) was calculated according to Breure and Powell (1987) using the formula: height increment/year = (height at year t) / (t - 2), where t is the age of the palm; and stem girth (SG) recorded as circumference of the stem above 0.5m of the ground level. The dry matter parameters were calculated according to Corley (1977) and Mathur *et al.* (2017) by using the formulae: Leaf Area (LA) in Sq cm=0.57 x NLL x LLL x LLW /100 /100; Leaf Dry Weight (LDW) in Kg = 0.1023 x (PW X PD) + 0.2062; Specific Leaf weight (SLW) in kg/sqcm = LDW /LA; Total leaf Dry weight (TLDW) in kg = LDW x Number of leaf / year; Average Bunch Weight (ABW in kg) = Bunch Weight / Number of Bunches; Bunch Dry weight (BDW in kg) = 0.5275 x Bunch weight; Vegetative Drymatter (VDM) in kg = TLDW + TrDW; Total Dry Matter (TDM) in kg = VDM + BDW; Bunch Index (BI) = BDW / TDM.

The data collected on different characters were analyzed by using Mahalanobis' D^2 analysis and variance was calculated for all the characters and test of significance was done. Analysis of covariance for the character pairs was estimated on the basis of mean values. The grouping of genotypes into different clusters was done using the Tocher's method as described by Rao (1952). Statistical analysis was done by using Windostat version 9.1. Principal component analysis (PCA) was done following 'past 'software.

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) revealed highly significant ($P \leq 0.01$) differences among the genotypes for TLDW, HI, SR, BN and BW indicating the presence of a good deal of genetic variability in the test materials for these traits (Table 1). Similar trend was also reported by Zhou *et al.* (2015). Bunch weight (BW) ranged from 102.53 to 191.37 kg/palm/year with experimental mean of 145.95 kg/palm/year. The highest BW was recorded in DD11 (191.37 kg/palm/year) followed by DD17 (184.28 kg/palm/year). The yield related traits are quantitative in nature, but the increased yield observed in the genotypes under consideration may be attributed to their exotic dura parents (Arolu *et al.,* 2017). Annual palm height increment ranged from 20.40 to 31.44 cm with experimental mean of 25.93 cm. The lowest average height increment was recorded in DD9 (20.40 cm) followed by DD15 (20.99 cm) as shown in Fig 1. Based on the above data it is confirmed that the selected DxD crosses may be used in future breeding programmes aimed at high yield and slow vertical growth.

Cluster analysis: The twenty nine DxD crosses were grouped into five distinct clusters using Tocher's method as illustrated in Table 2 and Fig. 2. The dendrogram also showed that the common parents in some D x D crosses are grouped together. Cluster III and IV were the largest clusters each consisting of eight D x D crosses followed by cluster II and V each with five D x D crosses. These results showed that the genotypes present in single cluster were genetically similar and those distributed in different clusters were diverse even though they were crossed from different parents from different sources. Matta *et al.* (2015) reported that the pattern of phenotype groups on dendrograms was influenced by genetics and environment.

The first cluster consists of three D x D crosses (DD3, DD9 and DD10) among which DD3 and DD9 having a common male parent 192 CD. The second cluster had five D x D crosses (DD2, DD6, DD19, DD20, DD24), among which DD2 having more number of leaves (25.40), a trait that is very useful in oil palm crop improvement due to its direct relation with inflorescence production thereby economic yield. Eight crosses fell in each cluster III and IV. In cluster III crosses DD4 and DD5 having a common parent 93 CD whereas, DD13, DD14 and DD28 having a common parent 42 CD that are of medium height and moderate yields. Cluster IV (DD7, DD8, DD11, DD12, DD17, DD18, DD21, DD22) were identified with higher yields and more number of bunches. In cluster IV genotypes DD7 and DD8 had a common parent 257 CD whileDD17 and DD18 had a common parent 232 CD. Cluster V having five crosses (DD15, DD16, DD23, DD26 and DD27) with less leaf area, which could be subjected to selection for high density planting breeding programme.

In cluster IV, sex ratio (0.59), BN (22.76), BW (174.61) and BI (0.34) were having higher mean values. It takes two years time period for sex differentiation and anthesis in oil palm. The 'sex ratio' (ratio of female to total inflorescences in a given group of palms) in oil palm is influenced by both genetic and environmental factors (Naveen *et al.,* 2017). Bunch index is an indication of biomass partition efficiency of oil palm towards economic yield. The BW of oil palm per unit area could be increased by utilizing genotypes with high bunch index. The higher mean values for LA (5.54), SLW (1.35) and TLDW (177.82) were seen in cluster III, higher mean values for NL (24.55) were seen in cluster II, low mean values for HI (24.67) were seen in cluster I (Table 3). The combined effect of environmental and internal signals results in annual oscillations of yield and sex ratio (Cros *et al.,* 2013).

Table 1 Analysis of variance for nine characters in 29 DxD crosses oil palm

Source of Variation	d.f.	NL	LA	SLW	TLDW	HI	SR	BN	BW	BI
Replication	2	0.85	2.33	0.0180	638.18	214.89	0.0015	4.98	89.57	0.0010
DxD crosses	28	0.67	0.71	0.0238	971.78**	25.57**	0.0215**	27.38**	1513.66**	0.0023
Error	56	0.51	0.44	0.0220	337.66	9.60	0.0013	12.74	542.53	0.0015

**Significant at 1% level; NL: Number of leaves; LA: Leaf area; SLW: Specific leaf weight; TLDW: Total leaf dry weight; HI: Height increment; SR: Sex Ratio; BN: Bunch number; BW: Bunch weight; BI: Bunch index.

Table 2 Clustering pattern of 29 genotypes of 'dura' oil palm (Tocher's method)

Clusters	No of genotypes	Genotype name
I	3	DD3, DD9, DD10
II	5	DD2, DD6, DD19, DD20, DD24
III	8	DD1, DD4, DD5, DD13, DD14, DD25, DD28, DD29
IV	8	DD7, DD8, DD11, DD12, DD17, DD18, DD21, DD22
V	5	DD15, DD16, DD23, DD26, DD27

Table 3 Cluster mean of 29 DxD crosses of oil palm

Clusters		NL	LA	SLW	TLDW	HI	SR	BN	BW	BI
I	Mean	23.80	4.93	1.17	137.88	24.67	0.39	15.23	108.96	0.27
	SE±	0.59	0.16	0.07	1.35	6.04	0.08	2.02	9.09	0.02
II	Mean	24.55	5.11	1.21	151.01	26.27	0.57	18.23	128.07	0.29
	SE±	0.49	0.28	0.05	6.23	3.42	0.07	1.77	10.26	0.03
III	Mean	23.95	5.54	1.35	177.82	26.60	0.51	17.81	145.83	0.29
	SE±	0.27	0.38	0.06	7.72	3.18	0.10	1.80	7.47	0.01
IV	Mean	24.12	5.48	1.28	166.17	25.75	0.59	22.76	174.61	0.34
	SE±	0.40	0.35	0.07	9.45	2.06	0.03	2.53	11.03	0.01
V	Mean	23.80	4.53	1.27	133.66	25.24	0.57	20.23	136.56	0.32
	SE±	0.52	0.32	0.12	5.14	2.88	0.05	1.70	12.34	0.01

NL: Number of leaves; LA: Leaf area; SLW: Specific leaf weight; TLDW: Total leaf dry weight; HI: Height increment; SR: Sex Ratio; BN: Bunch number; BW: Bunch weight; BI: Bunch index.

Table 4 Average intra (bold) and inter-cluster D^2 values for five clusters in 29 DxD crosses of dura oil palm (Tocher's method)

Clusters	I	II	III	IV	V
I	2.075				
II	3.168	2.094			
III	4.054	2.913	2.090		
IV	5.551	3.430	3.156	1.848	
V	3.685	2.651	3.792	3.392	2.070

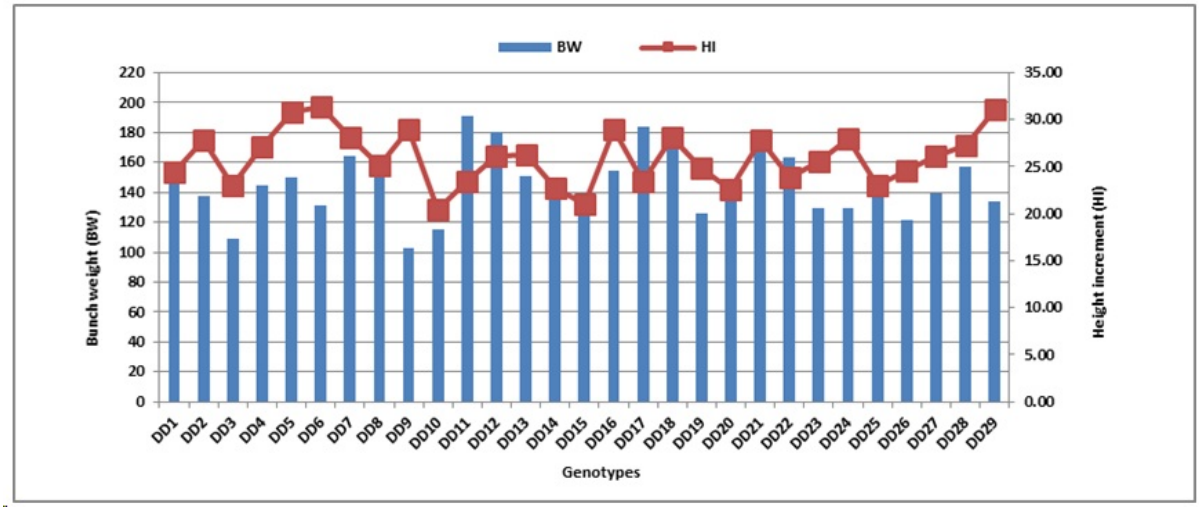

Fig .1. Mean bunch weight and height increment of 29 DxD crosses of dura oil palm

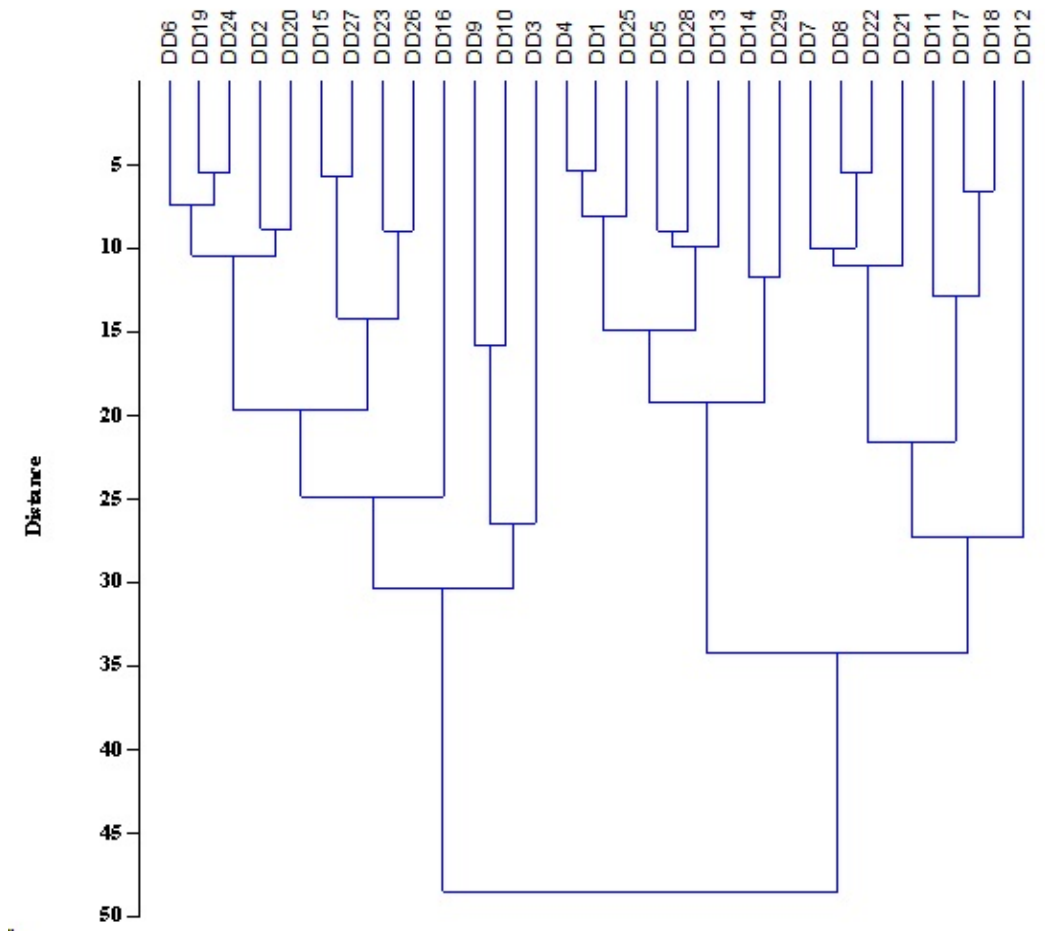

Fig. 2. Dendrogram showing relationship among different 29 DxD crosses of oil palm

Table 5 Principal components, eigen values and per cent variance for nine characters from principal component analysis

Characters	PC1	PC2	PC3	PC4
NL	0.14	-0.22	0.70	-0.19
LA	0.23	0.80	0.41	0.07
SLW	0.12	0.44	-0.65	-0.48
TLDW	0.26	0.92	0.16	-0.22
HI	-0.17	0.36	-0.20	0.78
Sex ratio	0.54	-0.35	-0.04	-0.22
Bunch No	0.90	-0.20	-0.05	0.19
BW	0.91	0.31	-0.06	0.11
BI	0.87	-0.35	-0.08	0.11
Eigenvalue	2.87	2.23	1.16	1.02
% Variance	31.90	24.85	12.97	11.42
Cumulative percentage of variability	31.90	56.75	69.72	81.14

NL: Number of leaves; LA: Leaf area; SLW: Specific leaf weight; TLDW: Total leaf dry weight; HI: Height increment; SR: Sex Ratio; BN: Bunch number; BW: Bunch weight; BI: Bunch index.

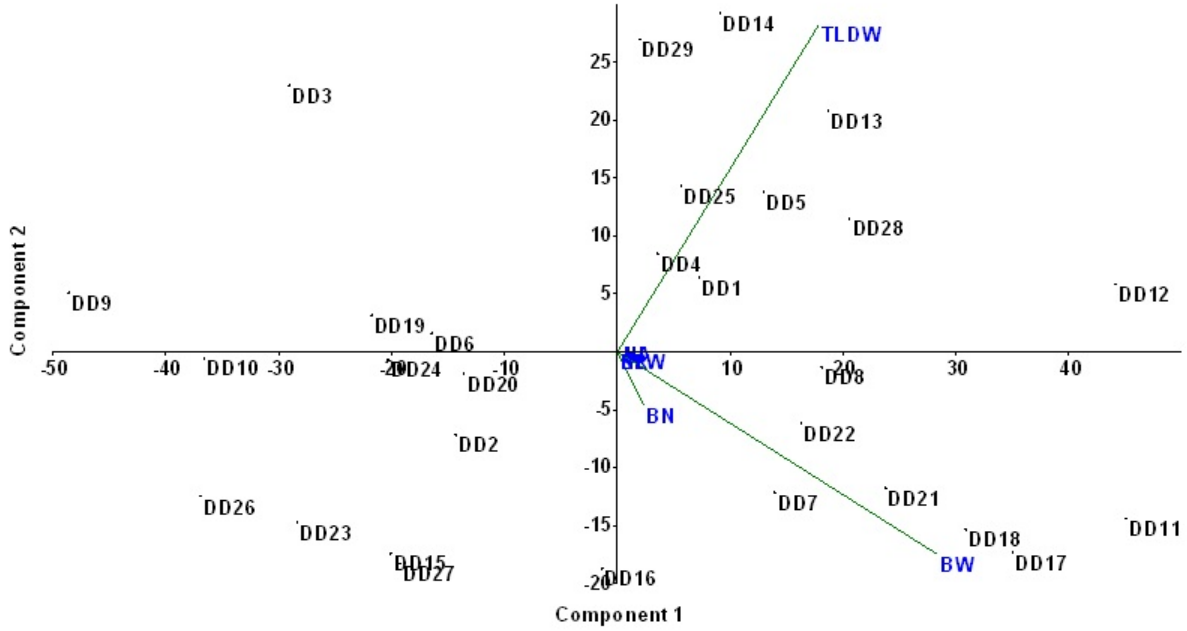

Fig. 3. Principle component analysis of 29 DxD crosses of oil palm

The average intra- and inter- cluster D^2 values are presented in Table 4 and Fig 2. The highest intra cluster distance was observed in cluster II (2.094) which indicated the presence of wide genetic diversity among the crosses in this cluster; the lowest intra cluster distance was observed in cluster IV (0.00) indicating homogeneity among the crosses with least genetic variation. The inter-cluster distance was minimum between the cluster V and II (2.651) while it was maximum between the cluster IV and I (5.551) indicating presence of substantial amount of genetic diversity in the crosses. Crosses with one common parent were observed more close/ related to each other than to crosses with different parents.

The morphological diversity in a uniform environment might be influenced by genetic character. Pandin and Matana (2015) reported that oil palms of Dura and Tenera types grown under the same environmental conditions had different characters in both vegetative and generative characters.

Under favourable conditions the vegetative growth and development are constant under favourable conditions in spite of strong seasonal deviations of reproductive growth (Legros, 2009; Corley and Tinker, 2003; Henson, 2007). It was therefore suggested that vegetative growth and development of oil palm constitute priority sinks for assimilates (Henson, 2007).

Principal component analysis: Principal component analysis (PCA) is used to explain the variances observed in the data and to understand the relationship between the different parameters (Ramli *et al.,* 2010). In addition, PCA calculates an unrelated set of variables (principal components) and gives supplementary information on utility of characters for definition of groups. When the PCA is run on correlations, one rule-of thumb is to retain those factors whose eigen values are greater than one. The eigen values are always used to decide how many factors to retain. If the eigen value is lower than one, it explains that the explanatory power of principal components is lower than the average explanatory power of the original variables. The variation among 29 dura crosses was assessed through principal component analysis based on the nine yield and height related traits. Four of the nine principal components extracted, had eigen value greater than 1 and accounted for 81.15 % of the total variation among 29 genotypes (Table 5). The first principal component accounted for 31.90% of the total variation. The variation in principal component 1 was mainly attributed to BW followed by BN, SR, and BI. The principal component 2 contributed 24.85% of the total divergence and depicted the pattern of variation mainly in TLDW, LA and SLW. The principal component 3 constituted 12.97 per cent of the total variation and was mainly attributed to NL and LA. Principal component 4 described an additional 11.42 per cent of the total variation and was dominated by HI and BN. The present results revealed that PC1 contributed maximum variability due to yield related traits. The characters with positive values indicate highest contribution and its importance in divergence, whereas negative values indicate the least contribution to the total divergence (Zhou *et al.,* 2015). The separation based on component 1 and component 2 revealed that the D x D crosses were distributed in different directions which revealed the diversity of the all crosses (Fig. 3).

Thus, the nine studied characters were able to discriminate the 29 investigated D x D crosses, with a clear separation between them. Variables that have significant positive as well as negative impact on the PCs can be said to contribute mostly to the diversity, especially those on PC1 are likely to be the source of variation and can be said to be the characters which differentiate the accessions in the oil palm germplasm (Hamza *et al.,* 2014).

Finally it is concluded that, dura crosses with high genetic diversity in terms of high yield and slow vertical growth in the present study could be a good source of new genes in the upcoming breeding programmes. The D x D crosses namely, DD11 and DD17 were identified as highest yielders and having slow vertical growth (low height increment) and hence, could be utilized in breeding programmes on development of parental/commercial planting materials for high yield and dwarfness.

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Response of integrated nutrient management on growth, seed yield and economics of sesame (*Sesamum indicum* L.) under rainfed conditions in sub montane Punjab

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ABSTRACT

Experiment was conducted during *kharif* 2014 and 2015, under rainfed conditions using sesame cv. RT 346, in sandy loam soil at Regional Research Station (Punjab Agricultural University) Ballowal Saunkhri, SBS Nagar District, Punjab. The aim of the study was to assess the effect of different levels of N, P and K on seed yield, nutrient uptake and agronomic efficiencies in sesame. The experiment was laid out in randomized block design with 6 treatments *viz.,* Control, 35:0:0 (basal dose), 35:0:0 (basal dose) + 10 ton FYM/ha, 70:0:0 (2 N splits), 70:40:0 (2 N splits), 70:40:15 (2 N splits). Among the different treatments, application of NPK as 70:40:0 with nitrogen in two splits recorded the maximum values for growth parameters *viz.,* plant height, number of branches per plant and yield attributes *viz.,* number of capsules plant per plant and number of seeds capsule per capsule and this treatment was at par with application of NPK as 70:0:0 treatment (2 N splits) and 35:0:0+10 ton FYM/ha treatment. Highest average seed yield of 852 kg/ha was recorded with treatment 70:40:0 with nitrogen in two splits which was 44 per cent higher over the control treatment. The nitrogen, phosphorus and potassium uptake was also highest in the treatment NPK 70:40:0 followed by 70:0:0 and 35:0:0 + 10t/ha FYM, which was significantly higher over the control treatment. The net return (₹ 42,545) and B:C ratio (3.34) was also highest in the treatment 70:40:0 as compared to the other treatments.

Keywords: Net return, Nutrient uptake, Nutrient management, Sesame, Yield attributes

Sesame (*Sesamum indicum* L.) commonly known as til is an antique cultivated oil-rich crop in the world (Langham *et al.,* 2001) and also called 'queen of oilseeds' by virtue of its excellent oil quality. Sesame has both nutritional and medicinal values. The oil content generally varies from 46 to 52 per cent, protein content 20 to 26 per cent, sugar 14 to 16 per cent and minerals 5 to 7 per cent (Thanvanathan *et al.,* 2001; Parameshwarappa, 2017). Sesame oil is acclaimed as an useful one for reducing stress and tension, preventing nervous disorders, relieving fatigue, relaxing properties (ease pain and muscle spasm) and promoting strength and vitality.

In India, it is cultivated in 2.5 m ha (14% of total area under oilseed crops) with a productivity of only 335 kg per hectare as against the genetic potential of around 2000 kg per hectare (Mkamilo and Bedigian, 2007). Sesame crop can be grown in wide range of environments, extending from semi-arid tropics and subtropics to temperate regions. It is mostly cultivated under rainfed conditions on marginal and sub-marginal lands with sub-optimal rate of fertilizer and poor management practices. This probably indicates a great opportunity for a higher increase in sesame productivity in India. The main reason for low productivity of sesame is use of low yielding varieties (local), poor soil fertility and imbalanced nutrition (Engoru and Bashaasha, 2001). Ssekabembe *et al.* (2002) reported that soil fertility degradation was the most limiting constraint to increase sesame production in many sesame producing areas of the world. Although the fertilizer requirement of sesame crop is low, application of organic and inorganic fertilizers showed significant increase in seed yield as compared to untreated plots (Umar *et al.*. 2012). Shehu *et al.* (2010) recommended NPK fertilizer at a rate of 75 kg N, 45 kg P_2O_5 and 22.5 kg K_2O/ha for highest net return in sesame production. The importance of split nitrogen application on different crops has been reported by many authors. Sesame is highly fertilizer responsive crop especially to nitrogen. Adequate applications of nitrogenous fertilizers not only improve the crop yield but also maintain soil N status and thus sustain productivity. The successive increase in N level up to 150 kg/ha increased the various growth parameters *viz.,* plant height, number of branches and dry matter production and yield components. Pariacha *et al.* (1988) pointed out that sesame seed production could be raised by 50 per cent by way of proper fertilization alone. In order to maximize the production and quality of oilseed crops like sesame, it has become necessary to look for other alternative strategies of production technology, mainly the adoption of proper fertilization with application of N fertilizers (Devasagayam and Jayapaul, 1997). In view of the above, the objective of the present study was to assess the efficiency and judicious use of plant nutrients to attain sustainable crop production with minimum deleterious effect on the soil health and least disturbance to plant soil environment.

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MATERIALS AND METHODS

Field experiments were conducted during *kharif* 2014 and 2015 under rainfed conditions in sandy loam soil at Regional Research Station (Punjab Agricultural University), Ballowal Saunkhri, Punjab. The site is located at 31°06.019' N, 76°23.277'E with altitude of 510 m amsl. The experiment was laid out in randomized block design with 6 treatments *viz,* Control, 35:0:0 (basal dose), 35:0:0 (basal dose) + 10 ton FYM/ha, 70:0:0 (2 N splits), 70:40:0 (2 N splits), 70:40:15 (2 N splits) replicated thrice. The soil was sandy loam, neutral in reaction (pH 7.4), low in organic carbon (0.26%), low in available nitrogen (142.4 kg/ha), medium in available phosphorus (20.25 kg/ha) and high in potassium (245 kg/ha). Sesame variety RT346 was used in the experiment. Growth parameters (plant height, number of branches per plant, number of capsules/plant and seed per capsule) were determined at the harvest of the crop.

The soil samples (0-15cm) so collected were air dried, ground with the help of wooden pestle and mortar, sieved through 2 mm sieve and analyzed for pH (Glass Electrode Method, Jackson, 1967), organic carbon (Walkley and Black rapid titration method, Walkley and Black, 1934), available nitrogen (Alkaline Permanganate Method, Subbiah and Asija, 1956), available phosphorus (Olsen *et al.,* 1954) and available potassium (AOAC, 1988). Data collected was subjected to analysis of variance (ANOVA). Duncan's Multiple Range Test (DMRT) was used for mean separation, where differences were significant, at 5% level of probability.

Table 1 Effect of different levels of NPK and FYM on growth and yield parameters of sesame

Levels of NPK (kg/ha)	Plant Height (cm)			No of Branches/plant			No of capsules/Plant			No of seed/capsule			Test weight (g)		
	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean
Control	106	167	136	2.6	3	2.8	39.4	40.4	39.9	60	66	63	2.61	2.75	2.68
35:0:0 (B)	130a	184	157a	3.5a	3.1	3.3a	61.3b	50.4b	55.8b	65 a	72	68	2.64	2.78	2.71
35:0:0(B) +10t FYM/ha	136a	184	160a	3.6a	3.2	3.4a	62.3ab	52.5ab	57.4b	66 a	73 a	69 a	2.63	2.77	2.70
70:0:0 (S)	130a	187	158a	3.5a	3.5	3.5a	58.4b	52.7ab	55.6b	67 a	74 a	70 a	2.62	2.76	2.69
70:40:0 (S)	138a	181	160a	3.6a	3.4	3.5a	74.8a	54.6ab	64.7a	68 a	76 a	72 a	2.65	2.79	2.72
70:40:15 (S)	140a	182	161a	3.7a	3.5	3.6a	57.3b	58.0a	57.7b	67 a	74 a	70 a	2.63	2.78	2.71
CD(P=0.05)	11	NS	11	0.5	NS	0.5	12.9	5.9	6.7	3	3	3	NS	NS	NS

B -Nitrogen at basal, S- Nitrogen applied in two splits (½ at sowing and ½ one month after sowing)

RESULTS AND DISCUSSION

Growth parameters and yield traits: Among growth parameters, plant height and number of branches per plant increased significantly with the application of fertilizers over the control treatment (Table 1). Akanbi *et al.* (2006) reported that increase in nitrogen level to certain limit associated with increase in crops growth and yield, including the leaf area and weight, carboxylases and chlorophyll content, photosynthetic activities of leaf and ultimately dry matter production. Similar findings were also reported by Babajide and Oyeleke (2014).

Similar to growth parameters, yield attributes i.e. number of capsules per plant and number of seed per capsules increased significantly with the application of different levels of fertilizers. Maximum number of capsules per plant was recorded with treatment 70:40:0 (S) i.e. 64.7, which was 62 per cent higher than the control treatment. Number of seed per capsule increased significantly up to nitrogen application of 70 kg/ha, however the application of phosphorus and potassium did not affect the number of seed per capsule. The weight of sesame seed did not show any significant variation with the application of fertilizers. Mitra and Pal (1999) reported the significant increase in drymatter, number of capsules/plant, seed/capsule and seed yield of sesame up to 100 kg N/ha. Further increase in nitrogen depressed the seed yield and yield attributes. The application of 90 kg N/ha resulted in the highest number of capsules per plant, seeds per capsule, 1000 seed weight, seed yield, straw yield and harvest index (Om Prakash *et al.,* 2001).

Yield and economics: The seed and straw yield of sesame increased significantly with the application of fertilizers over the control treatment. The maximum seed yield (607 kg/ha) was recorded with treatment 70:40:0 (S) which was statistically at par with treatments 70:0:0 (S), 70:40:15 (S) and treatment 35:0:0 (B) +10t /FYM/ ha, respectively (Table 2). This suggested that plant responded to nitrogen application more in comparison to P and K application. The growth characters such as number of branches and number of leaves provided better opportunity for higher sunlight interception. Weiss (1983) also observed that in addition to nitrogen, phosphorus was a major factor for limiting crop production in large areas of Africa, even where there is no deficiency of phosphorus. Kene *et al.* (1991) reported that seed yield of sesame increased significantly with application of 40 and 75 kg P_2O_5/ha, respectively. However, Olowe and Busari (2000) reported the non-significant increase in seed

yield of sesame up to 60 kg P_2O_5/ha. The treatment 70:40:0 (S) also gave the maximum net return (₹ 42,545 /ha) and a B:C ratio of 3.34 followed by treatment 70:0:0 (S), 70:40:15 (S) and minimum net return (₹ 15,407 /ha) and B:C ratio (1.76) was recorded with control treatment.

Soil properties: The significant increase in organic carbon content in soil was recorded with the treatment 35:0:0(B) + 10t/FYM/ ha over all other treatments. The soils amended with organic fertilizers improved the organic matter content in soil (Zhao *et al.,* 2009). Benbi *et al.* (1998) found that farm yard manure in combination with NPK chemical fertilizers resulted in higher soil organic carbon concentration, enhanced crop growth along with higher root biomass production. The soil pH and electrical conductivity of soil did not show any variation with the application of different levels of fertilizers. A non-significant increase in the available nitrogen, available phosphorus and available potassium content in soil has been observed with the application of different levels of fertilizers over the control (Table 3).

Table 2 Effect of different levels of NPK and FYM on yield (kg/ha) and economics of sesame

Levels of NPK (kg/ha)	2014		2015		Average		Net return (₹/ha)	B:C ratio
	Grain	Straw	Grain	Straw	Grain	Straw		
Control	315c	1410d	396c	1687b	356c	1548d	15,407	1.76
35:0:0 (B)	473b	1831c	513b	1975ab	493b	1903c	31,155	2.72
35:0:0(B) +10t /FYM/ha	541ab	1971bc	567ab	2174ab	554ab	2072bc	37,265	3.05
70:0:0 (S)	569a	2197ab	629a	2423a	599a	2310ab	41,745	3.30
70:40:0 (S)	589a	2403a	624a	2485a	607a	2444a	42,545	3.34
70:40:15 (S)	567a	2510a	612ab	2498a	590a	2504a	40,845	3.25
CD (P=0.05)	84	398	107	549	64	317		

B -Nitrogen at basal, S- Nitrogen applied in two splits (½ at sowing and ½ one month after sowing)

Table 3 Effect of different levels of NPK and FYM on soil properties after sesame crop

Levels of NPK (kg/ha)	Soil pH	EC (dS/cm)	OC (%)	Available nitrogen (kg/ha)	Available phosphorus (kg/ha)	Available potassium (kg/ha)
Control	7.9	0.25	0.27	185.6	17.9	158.5
35:0:0 (B)	8.0	0.29	0.28c	210.2	24.5	161.8
35:0:0(B) +10t /FYM/ ha	7.9	0.27	0.42a	236.6	28.5	198.7
70:0:0 (S)	7.9	0.28	0.35b	195.9	23.5	169.3
70:40:0 (S)	8.0	0.27	0.32bc	210.3	25.2	173.9
70:40:15 (S)	8.0	0.27	0.34bc	220.8	23.3	168.5
CD(P=0.05)	NS	NS	0.06	NS	NS	NS

B -Nitrogen at basal, S- Nitrogen applied in two splits ((½ at sowing and ½ one month after sowing)

Nutrient uptake: The average total nitrogen, phosphorus and potassium uptake in sesame plant varied from 12.07 to 22.70, 5.67 to 10.26 and 17.31 to 31.52 kg/ha respectively with the application of different levels of fertilizers. The maximum total uptake for nitrogen, phosphorus and potassium was recorded with treatment 70:40:15 (S) i.e. 22.70, 10.26 and 31.52 kg/ha which was 88, 80 and 82 per cent higher over the control treatment (Table 4). Akintoye *et al.* (1998) reported that increasing levels of nitrogen application significantly increased nitrogen use efficiency (NUE), crop performance and nutrient uptakes but, these reduced significantly when nitrogen application became excessive. Nitrogen promotes Phosphorus uptake by increasing tap root growth, increasing plant metabolism and increasing P solubility by decreasing soil pH. Havlin *et al.* (2005) reported that phosphorus fertilization enhanced phosphorus uptake by 32 per cent at 22.5 kg P_2O_5/ha over control.

Sesame is highly fertilizer responsive crop especially to nitrogen. Generally, farmers grow sesame on marginal land and seldom apply inorganic fertilizers. The application of different fertilizers in sesame crop resulted in significant increase in growth, yield parameters and seed yield. Among different treatments, application of NPK as 70:40:0 (nitrogen two splits) gave highest seed yield, net return, B:C ratio and maximum values for growth parameters and yield attributes.

Table 4 Effect of different levels of NPK and FYM on the nutrient uptake by sesame crop

Levels of NPK (kg/ha)	Nitrogen uptake (kg/ha)			Phosphorus uptake (kg/ha)			Potassium uptake (kg/ha)		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
Control	4.27	7.80	12.07	1.24	4.43	5.67	1.81	15.50	17.31
35:0:0 (B)	6.71c	10.36b	17.07	1.80b	5.85b	7.65	2.86b	22.06	24.92
35:0:0(B)+10t /FYM/ha	7.38bc	10.81b	18.19	2.23a	6.96ab	9.19	3.27a	24.47a	27.74
70:0:0 (S)	8.53a	12.87a	21.40	2.30a	7.41a	9.71	3.50a	27.24a	30.74
70:40:0 (S)	8.67a	13.74a	22.41	2.30a	7.71a	10.01	3.43a	27.72a	31.15
70:40:15 (S)	8.44ab	14.26a	22.70	2.26a	8.00a	10.26	3.32a	28.20a	31.52
CD(P=0.05)	1.12	1.99		0.31	1.17		0.45	3.92	

B -Nitrogen at basal, S- Nitrogen applied in two splits (½ at sowing and ½ one month after sowing)

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Effect of drip fertigation on productivity and profitability of castor (*Ricinus communis* L.)

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ABSTRACT

A field experiment was conducted at the Main Oilseeds Research Station, Junagadh Agricultural University, Junagadh (Gujarat) during *kharif* for three consecutive seasons of the year 2013-14, 2014-15 and 2015-16. The experiment was laid out in randomized block design, with four replications. The soil was medium black in texture. The seven treatments comprised of two levels of drip irrigation [at 0.6 and 0.8 Pan Evaporation Fraction (PEF)] with combination of three levels of nitrogen (50 %, 75 % and 100 % of recommended dose through fertigation) and check basin method of irrigation 0.6 IW/CPE ratio with IW of 50 mm. Drip system (4 LPH) was operated after every third day for 2 hours during October and for 1 hour and 45 minutes during November to January. The pooled analysis of results revealed that drip fertigation at 0.8 PEF in conjunction with nitrogen fertigation @ 90 kg/ha in the form of urea (20 kg as basal and 70kg in five equal split doses at 12 days interval) resulted in the highest seed yield (3541 kg/ha), net returns (Rs. 90712/ha) and B:C ratio (3.25). Drip fertigation also recorded saving of 25% nitrogen fertilizer and better water use efficiency. The highest water use efficiency of 12.26 kg/ha mm was obtained under drip fertigation at 0.6 PEF +100% RDN (T3).

Keywords: Castor, Drip fertigation, Economics, Yield

Castor (*Ricinus communis* L.) is one of the most important non-edible oilseed crops widely cultivated in the arid and semi-arid regions of the world. It is cultivated to an extent of 8.3 lakh ha in India with an average productivity of 1713 kg/ha (Anonymous, 2018). Water, a scarce commodity in drylands is a key natural resource for stable agricultural production. In arid and semi-arid areas it is considered as liquid gold for sustainable crop production. Major part of India including Gujarat state falls under semi-arid conditions where crop production generally depends on vagaries of monsoons, which is quite irregular, erratic and inadequate (Lakshmamma *et al.,* 2016). The application of water and fertilizer are essential for the higher production per unit and time. Irrigation and fertilizer are the costliest inputs in the crop production, the saving and efficient use is very much essential in general and production of castor in particular. The drip fertigation method of irrigation was found more efficient resulting in higher water use efficiency, fertilizer use efficiency and water saving (Patel *et al.,* 2004). Present investigation was therefore proposed to evaluate the drip fertigation method of irrigation with different Pan Evaporation Fraction (PEF) and doses of nitrogen fertilizer.

MATERIALS AND METHODS

The field experiment was conducted at the Main Oilseeds Research Station, Junagadh Agricultural University, Junagadh (Gujarat) during *kharif* 2013-14 to 2015-16 for three consecutive seasons. The experiment was laid out in randomized block design, replicated four times. The soil was medium black in texture having 0.60 % organic carbon, 165 kg/ha available N, 21.9 kg/ha available P_2O_5 and 321 kg/ha available K_2O with a pH of 7.79. The seven treatments comprised of T_1:Drip Fertigation at 0.6 Pan Evaporation Fraction (PEF) +50% RDN (recommended dose of nitrogen), T_2:Drip Fertigation at 0.6 PEF +75% RDN, T_3:Drip Fertigation at 0.6 PEF +100% RDN, T_4:Drip Fertigation at 0.8 PEF +50% RDN, T_5:Drip Fertigation at 0.8 PEF +75% RDN, T_6:Drip Fertigation at 0.8 PEF+100% RDN and T_7:Check basin method of irrigation at 0.6 IW/CPE ratio with IW of 50 mm and 100% RDF. Full dose of phosphorus (50 kg/ha) was applied as basal in the form of single super phosphate and in fertigation 10, 20 and 30 kg/ha nitrogen as a basal dose in 50%, 75% and 100% RDN and remaining nitrogen was applied in five equal splits, each at a twelve day interval (RDF: Recommended dose of fertilizer 120 kg N + 50 kg P_2O_5/ha). Gross plot size of 6.0 x 5.4 m and net plot size of 4.8 x 3.6 m was maintained. The crop (GCH-7) was sown with 5 kg seed rate at 120cm x 60cm spacing. Other cultural practices and plant protection measures were followed as per recommendations. Drip system was laid out in such a way that the main pipe was connected with head unit. The line was divided into sub main having separate controlling valves with different drip irrigation levels as listed above (T_1-T_7). Lateral lines connected with sub main were laid out at a distance of 120 cm. The drippers were placed on lateral lines at a distance of 60 cm. The crop was sown in first fort night of August. Drip irrigation was given

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after cessation of rainfall through drip. The drip irrigation treatments were given at every 3rd day, based on fraction of pan evaporation of two days. Daily pan evaporation measured with the help of USDA Class-A pan evaporimeter. Drippers were operated at 1.2 bar pressure for required period as per treatment to deliver water at flow rate of 4 liter per hour (LPH). The water meters were used to measure the volume of water applications. In surface method of irrigation, irrigation depth of 5.0cm was applied at 0.6 IW/CPE. The oil content of seed was determined using Nuclear Magnetic Resonance Spectro Photometer. The cost of cultivation excluding cost of irrigation included cost of various inputs like cost towards land preparation, seeds, seed treatment, fertilizer, sowing, agro chemicals, weeding, inter culturing, harvesting, threshing, cleaning and packing etc. The cost of seeds, fertilizer and agro chemicals were taken following the recommended package of agronomic practices. The cost of drip irrigation (Ci) includes the cost of labor, electricity and maintenance required for the irrigation application. It was assumed that the drip irrigation system could be useful for 2 seasons per year for 10 years. The following expressions were used for assessing the economics (Rank, 2007).

$$C_t = C_c + C_i, \quad C_j = \frac{P \times i \times (1+i)^n}{2\{(1+i)^n - 1\}}$$

Where,

Ct = Total cost of cultivation (₹/season/ha); Cc = Cost of cultivation (₹/ha/season); Ci = Cost of drip irrigation (₹/ha/season); P = Cost of drip irrigation system, ₹/ha; n = Life of the drip irrigation system, years; i = Prevailing rate of interest.

RESULTS AND DISCUSSION

Growth and yield attributes: The pooled analysis of results revealed that irrigation treatments significantly influenced plant height, number of spikes, number of branches; capsules per spike and length of spike (Table 2 and 3). The drip fertigation at 0.8 PEF +75% RDN (T_5) and drip fertigation at 0.8 PEF +100% RDN (T_6) recorded significantly highest plant height, number of spikes per plant, number of branches, capsules per spike and length of spike. Number of internodes, 100 seed weight and oil per cent was not influenced significantly due to different drip irrigation treatments. The increase in growth and yield attributes under drip fertigation might be due to application of fertilizers at different crop growth stages as per crop demand and enhanced availability and uptake of nutrients leading to enhanced photosynthesis, expansion of leaves and translocation of nutrients to reproductive parts compared to conventional method irrigation along with soil application of nutrients. Bhoi and More (2005) also reported that the general losses due to leaching, volatilization, de-nitrification etc. are avoided under controlled application of water through micro irrigation. Similar results were also reported in castor by Patel *et al.* (2006), Reddy *et al.* (2006) and Patel *et al.* (2010).

Seed yield: The results indicated that (Table 1) drip fertigation at 0.8 PEF +75% RDN (T_5) resulted in significantly higher seed yield of 3625, 3843 and 3541 kg/ha during 2013-14 to 2015-16 years and pooled results, respectively, which remained at par with drip fertigation at 0.8 PEF +100% RDN (T_6) and drip fertigation at 0.6 PEF +100% RDN (T_3) Significantly higher seed yield (3526 kg/ha) was recorded under drip fertigation at 0.8 PEF +100% RDN (T_6) during the year 2014-15, which was at par with treatments of drip fertigation at 0.8 PEF +75% RDN (T_5) and drip fertigation at 0.6 PEF +100% RDN (T_3). The lowest seed yield of 1595, 2233, 2473 and 2100 kg/ha was recorded by drip fertigation at 0.6 PEF + 50% RDN (T_1) during 2013-14, 2014-15, 2015-16 and in pooled results, receptively. The magnitude of per cent seed yield increase under I_5 treatment of drip irrigation over check basin method of irrigation (T_7) was to the tune of 17.36 per cent in pooled results. The increase in seed yield under drip irrigation T_5 was due to maintenance of favourable soil moisture status in the root zone, which in turn helped plants to maintain better turgor pressure, thus utilized moisture as well as nutrients more efficiently from wetted area and ultimately enhanced vegetative as well as reproductive growth of the crop. Similar results were also reported by Reddy *et al.* (2006), Patel *et al.* (2010) and Singh *et al.* (2012).

Water use efficiency: The results further revealed that the highest water use efficiency (Table 3) of 12.26 kg/ha mm was recorded under drip fertigation at 0.6 PEF +100% RDN (T_3) followed by drip fertigation at 0.6 PEF +75% RDN (10.32 kg/ha mm, T_1) check basin method of irrigation (10.07 kg/ha mm, T_7) and drip fertigation at 0.8 Epan +75% RDN (9.98 kg/ha mm, T_4). Higher WUE at T_3 and T_1 levels was due to better utilization of water at lower fractions, whereas at higher levels of water application, the rate of water losses through evapotranspiration and percolation were high and relative increase in yield was not proportionate to the increasing rate of water application. Similar results were reported by Patel *et al.* (2006) and Singh *et al.* (2012).

Economics: Raising castor through drip fertigation at 0.8 PEF +75% RDN (T_5) resulted in highest gross returns (₹ 131027 /ha), net returns (₹ 90712/ha) and B:C ratio (3.25) with saving of 25% nitrogen fertilizer. Similar results were also confirmed by Singh *et al.* (2012).

From these results, it could be concluded that on medium black calcareous soils of Saurashtra region of Gujarat, drip fertigation at 0.8 PEF+75%RDN in the form of urea (20 kg/ha as basal and 70 kg/ha in five equal splits) at 12 days interval resulted in higher seed yield of *kharif* castor leading to higher profitability.

Table 1 Influence of different drip irrigation treatments on growth, yield attributes and yield of castor (pooled data of three years)

	Treatments	Plant height (cm)	No. of spike/ Plant	No. of branches/ Plant	No. of internodes/ plant	Capsules /spike	Seed yield (kg/ha)			
							2013-14	2014-15	2015-16	Pooled yield
T_1	Drip Fertigation at 0.6 PEF +50% RDN	74.15	5.40	5.57	16.41	50.24	1595	2233	2473	2100
T_2	Drip Fertigation at 0.6 PEF +75% RDN	82.71	6.76	6.56	16.30	65.21	2365	2680	3082	2709
T_3	Drip Fertigation at 0.6 PEF +100% RDN	88.48	7.17	6.86	16.59	70.89	3325	3132	3293	3250
T_4	Drip Fertigation at 0.8 PEF +50% RDN	81.19	7.16	6.55	16.41	58.77	2056	2989	3411	2819
T_5	Drip Fertigation at 0.8 PEF +75% RDN	92.04	8.55	6.88	16.92	73.30	3625	3156	3843	3541
T_6	Drip Fertigation at 0.8 PEF +100% RDN	95.88	7.72	7.10	16.78	74.80	3396	3526	3567	3496
T_7	Check basin method of irrigation	88.30	7.46	6.63	16.37	65.64	2931	2974	3145	3016
	S.Em±	1.95	0.37	0.27	0.32	2.80	168	215	196	170
	C.D. at 5%	5.60	1.05	0.79	NS	8.03	519	662	605	523
	C.V.%	6.79	15.33	12.46	5.78	12.80	10.58	12.59	10.43	11.25
	Y : C.D. at 5 %	4.64	0.43	0.23	0.45	4.81	-	-	-	226
	YxT : C.D. at 5 %	NS	NS	NS	NS	NS	-	-	-	557

Table 2 Influence of different drip irrigation treatments on yield attributes, quality and economics of castor (pooled data of three years)

	Treatments	Length of spike (cm)	100 seed wt (g)	Oil (%)	Total quantity of water applied (mm)	Water Use Efficiency (kg/ha-mm)	Total cost of irrigation ₹/ha	Gross returns (₹/ha)	Cost of cultivation (₹/ha)	Net returns (₹/ha)	B:C ratio
T_1	Drip Fertigation at 0.6 PEF +50% RDN	41.50	32.23	48.64	267	7.92	11725	77699	39675	38024	1.96
T_2	Drip Fertigation at 0.6 PEF +75% RDN	46.52	32.68	48.67	267	10.22	11725	100226	40015	60211	2.50
T_3	Drip Fertigation at 0.6 PEF +100% RDN	48.70	33.55	48.92	267	12.26	11725	120251	40350	79901	2.98
T_4	Drip Fertigation at 0.8 PEF +50% RDN	46.34	32.60	48.42	355	7.94	12025	104286	39975	64311	2.61
T_5	Drip Fertigation at 0.8 PEF +75% RDN	51.62	32.62	48.91	355	9.98	12025	131027	40315	90712	3.25
T_6	Drip Fertigation at 0.8 PEF +100% RDN	51.80	33.55	49.65	355	9.85	12025	129361	40650	88711	3.18
T_7	Check basin method of irrigation	49.93	32.90	48.74	300	10.07	4975	111821	35625	76196	3.14
	S.Em±	1.38	0.45	0.33							
	C.D. at 5%	3.97	NS	NS							
	C.V.%	8.63	2.57	2.03							
	Y : C.D. at 5 %	2.90	0.57	0.31							
	YxT : C.D. at 5 %	NS	1.40	NS							

Market price: Castor seed: ₹ 37/kg, Cost of inputs (₹/kg) DAP-: ₹ 25.20, Urea -₹ 6.50

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Screening of *Arachis* ssp. against *Aspergillus flavus* with *in vitro* seed colonization, EST-SSRs and generic primers and efficacy of different fungicidal control measures

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ABSTRACT

Aflatoxin produced in groundnut due to the infection by the fungus *Aspergillus flavus* is a major issue with respect to human health as well as export potential. Genetic resistance against this fungus is an important trait needed to counter the issue of Aflatoxin. In the present investigation, 50 *Arachis* subspecies genotypes including five different *Arachis* botanical types *viz.,* spanish bunch, virginia bunch and valencia (cultivated) as well as two wild species *viz., A. peruviana* and *A. aequatoriana* were tested for their resistance to *A. flavus.* Compared to the reported resistant variety ICG1326 (J11), only three genotypes *viz.,* ICG10933, ICG12625, TG26 showed resistance to fungal infection. Specific EST-SSR marker shown to be associated with resistance to *A. flavus* as well as generic molecular markers known to be associated with fungal resistance was tested in the selected genotypes. But, no strong association between markers and fungal resistance could be established. Also, among different fungicides tested for their ability to control *A. flavus,* carbendazim + thiram was found to be effective.

Keywords: Aflatoxin, *Aspergillus flavus,* Fungicides, Groundnut, Molecular markers

Groundnut is an important oilseed crop consumed world over not only for its edible oil but also for myriad uses such as in confectioneries, peanut butter and also for its nutritive fodder and cake (Basha, 2016). *Aspergillus flavus* and *Aspergillus parasiticus* are two important seed borne pathogens of groundnut which produces aflatoxin and cause yellow mold disease. Aflatoxins are carcinogens causing many diseases in human as well as animals. This fungus is capable of invading groundnut seeds before harvest, during post-harvest drying and storage as well. Different categories of aflatoxins *viz.,* B1, B2, G1 and G2 have been reported. As a result of infection, accumulation of toxin occurs in the kernels and infected kernels look discoloured and shriveled. Aflatoxin production in the field is favored by high seed moisture, temperature in the range of 25-30°C and relative humidity of 85 per cent.

Integrated management involving genetic resistance and identifying the suitable resistant genotypes against the fungus appears to be the best possible solution in reducing this mycotoxin problem. Hence, evaluation of groundnut genetic resources to identify potential germplasm having resistance/tolerance to aflatoxin contamination is very essential. There are molecular markers identified that could be used to screen the genotypes for the resistance trait (Guo *et al.,* 2011). Also, there are possibilities of using fungicides to control the infection as well as proliferation of the fungus. In the present study, the germplasm lines belonging to different *Arachis* ssp. were screened to identify aflatoxin resistant/tolerant genotypes through *in vitro* seed colonization procedure.

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MATERIALS AND METHODS

The experimental material comprised of 50 *Arachis* subspecies genotypes. It included five different *Arachis* botanical types *viz.,* spanish bunch, virginia bunch and valencia (cultivated) as well as two wild species *viz., A. peruviana* and *A. aequatoriana.*

Biological material of *Aspergillus flavus*: Pure culture of *A. flavus* strain (ID No. 8569.11) was used in the study. This strain was isolated from groundnut seeds and identified for its authenticity by Indian Type Culture Collection, Division of Plant Pathology, IARI, New Delhi.

Maintenance of the fungus culture: The pure culture of the fungus, *A. flavus* was sub cultured on the Potato Dextrose Agar (PDA) slants and allowed to grow at 25±1°C temperature. The culture obtained was stored in refrigerator at 4°C for further use. The sub culturing was done regularly at one-month interval.

Preparation of inoculums: *A. flavus* was grown on PDA Petri plates. The culture was incubated at room temperature for 7 days to achieve maximum sporulation. The Petri plates having thick/heavy sporulation were poured with 5 ml of distilled sterile water and the conidia were harvested into suspension by gentle brushing with inoculation loop without

disturbing the agar. This suspension was added to a test tube containing 5 ml of distilled sterile water to make up 10 ml of spore suspension. To this, about one or two drops of Tween-80 was added for uniform dispersal of conidia in the suspension. Serial dilution and pour plate method was used for enumeration of spores or conidia per ml of spore suspension. Accordingly, the original spore suspension was diluted using distilled sterile water to get final concentration of 10^6 CFU/ml and was used for inoculation of groundnut seeds.

Inoculation of groundnut seeds: Twenty healthy seeds of each genotype were selected for inoculation with *A. flavus in vitro*. Seeds were soaked in distilled sterile water for 3-5 min. They were surface sterilized with 1% sodium hypochlorite for 1 min. and subsequently washed three times using distilled sterile water to remove any traces of sodium hypochlorite. Each seed was uniformly wounded by pricking with a sterile needle to facilitate the invasion by *A. flavus* spores. Seeds were dipped in *A. flavus* spore suspension (10^6CFU/ml) for 1-2 min under aseptic conditions. They were then placed in sterilized Petri plates (9 cm diameter) containing moist blotting paper. The experiment was conducted in two replications with 10 seeds per replication.

Incubation: The Petri dishes were placed at high humidity (>95% RH) in semi-rigid plastic boxes lined with cotton wool and moist blotting paper with closely fitting lids and incubated at 25±1°C in dark for 7-10 days.

Score for recording colonization severity: Individual seeds were scored for surface colonization by *A. flavus* and for colonization severity following rating scale given by Thakur *et al.* (2000).

Scale	Description
Scale 1	< 5% seed surface colonized with mycelia growth and scanty sporulation
Scale 2	5-25 % seed surface colonized with good mycelia growth and scanty sporulation
Scale 3	26-50 % seed surface colonized with good mycelia growth and good sporulation
Scale 4	>50 % seed surface colonized with heavy sporulation

Screening of different *Arachis* ssp. using EST-SSR and generic primers specific to *A. flavus* tolerance: Three generic (BURP, Lipoxygenase and Trypsin inhibitor) and one SSR primer (BURP-1) were synthesized from gene sequence reported for resistance in groundnut as studied by Guo *et al.* (2011). ESTs which are available in public databases were studied and peanut EST sequences down-loaded from dbEST database (NCBI, http://www.ncbi.nlm.nih.gov) were used for synthesizing the primers. These primers were used for screening of genotypes to evaluate their resistance behavior. The BURP domain containing proteins are a large family of evolutionarily conserved proteins only found in plants. Members of the family had been reported to be involved in the reproductive development and stress resistance of plants. The lipoxygenase has shown anti-fungal activities in peanut, corn, and soybean (Burow *et al.,* 1997; Calvo *et al.,* 1999; Wilson *et al.,* 2001; Burow *et al.,* 2002). The trypsin protein inhibitor was demonstrated to impart resistance to *A. flavus* infection in corn (Banks *et al.,* 2002; Chen *et al.,* 1999a; Chen *et al.,* 1999b; Guo *et al.,* 1998).

Table 1 List of generic and EST-SSR Primers with their sequences

Marker	Type of primer	F/R	Primer sequences	Tm
BURP	Generic	F	CGT AGC CAA ACT TCT AGA ACA C	58.4
		R	GTA AGT AAT GCC CTC CTT ATG A	56.5
Trypsin	EST-SSR	F	GGA CTC ATT CAG GTT CTT CAT	55.9
		R	GGT CAC TCC AAT TTC TCA CAT A	56.5
BURP-1	EST-SSR	F	ACT GCC GAT CTT GTG TTT CC	57.3
		R	GAA GCT GAG TCC AAC CGA AG	59.4
Lipoxygenase	Generic	F	CAC GGT AGT GTG GGG AAA GT	59.4
		R	CCA GCA CAT GAA GGA GTT GA	57.3
Trypsin inhibitor	Generic	F	AAC TTT CCC CGA GAC GCT AT	57.3
		R	CAC TGC TCC CTC CCA ATA TAA G	60.3

***In vitro* testing of fungicides (inhibition zone technique):** Fungal suspension of *A. flavus* was prepared by adding 10 ml of sterile water to 10 day old culture tubes. One ml of suspension was poured and spread uniformly over the hardened surface of PDA medium. The groundnut seeds treated with respective test fungicides @ 2g/kg of seed was kept in the center of the Petri plate and incubated at room temperature. Two replicates were maintained for each treatment. A suitable control was also maintained. Inhibition zone developed around the treated seed in each plate was measured (in cm) after 72 h as followed by Reddy *et al.* (1991). The following five fungicides were tested:

1. Carbendazim (Methyl-1H-benzimidazole-2-yl carbamate)
2. Copper-oxychloride
3. Mancozeb (Manganese ethylenebis-dithiocarbamate + Zinc)
4. Thiram (Tetramethylthiuram disulphide)
5. Carbendazim+Thiram

RESULTS AND DISCUSSION

Screening of *Arachis* ssp. against seed colonization by *A. flavus in vitro*: The results (Table 2) revealed that *A. flavus* seed colonization severity ranged from 1.0 to 4.0 with a mean performance of 3.10. Genotype ICG 1326 (J-11) recorded lowest seed colonization severity (1.0), and showed highest tolerance against the fungus.

The study revealed that maximum number of genotypes (15) *viz.,* J68, J71, J73, JB1109, JB1137, JB1142, JB1176, JB1184, AG2240, AG2245, ICG3267, ICG4750, ICG12697, ICG9619, ICGV00310 belonged to the highly susceptible class having a disease score of 3.5-4.0 (Fig. 1). However, it was observed that four genotypes *viz.,* ICG10933, ICG12625, ICG1326, TG26 were found to fall in the resistant class having the lowest disease score i.e., 1-1.5. Only ICG7412 grouped in the moderately resistant class of 1.6-2.0. The rest of the genotypes fell in the intermediate disease reaction groups of 2.1-2.5, 2.6-3.0 and 3.0 to 3.5.

Screening using EST-SSR and generic primers specific to *A. flavus* tolerance: Screening of different *Arachis* spp. was carried out using three generic primers *viz.,* BURP, lipoxygenase, trypsin inhibitor that are known to impart resistance against fungi and one EST- SSR primer i.e. BURP-1 specific to *A. flavus* tolerance. Multiple alleles were seen with the markers tested (Table 5) and frequency distribution of different alleles for the four primer sets was worked out (Fig. 2). As J-11 is considered to be a resistant genotype, the banding patterns, with the tested markers, seen in different genotypes were compared with that seen in J-11 and the results are summarized in Table 3. It was observed that the genotype ICGV00308 appeared to share the common band length with the resistant genotype J11, when three primers out of four, *viz.,* BURP-1, Lipoxygenase and Trypsin inhibitor were used for screening but with BURP generic primer, similar bands with respect to J-11 was not seen. The two genotypes *viz.,* ICG 10933 and ICG -12625 showed a banding pattern similar to J-11 with lipoxygenase and trypsin inhibitor. These two genotypes exhibited moderately resistant behavior having disease score 1.5.

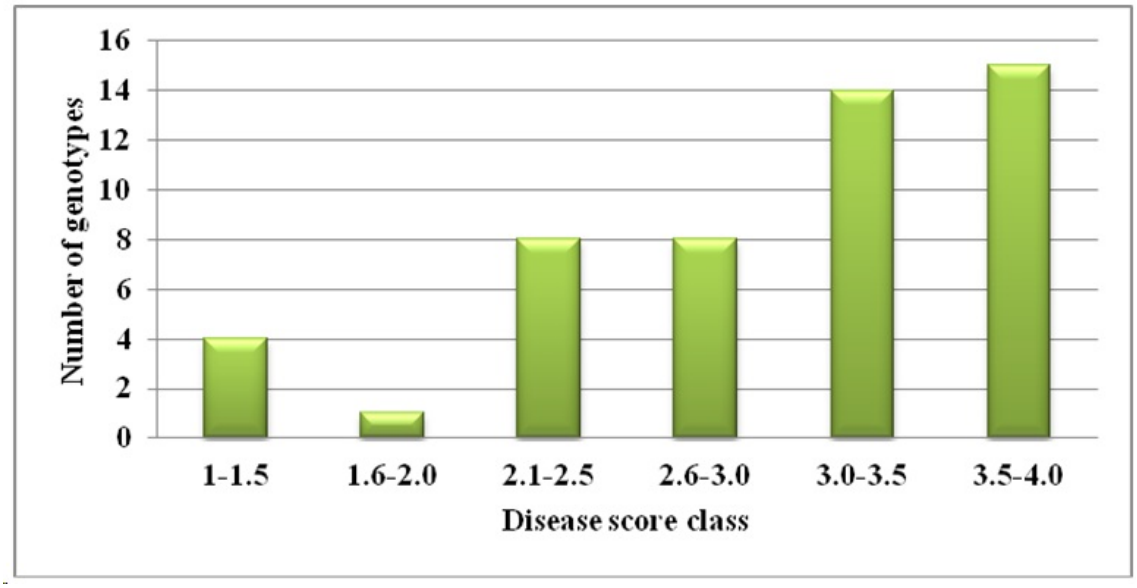

Fig. 1. Number of genotypes belonging to different disease score

Table 2 Mean infestation score of *A. flavusin* seeds of different *Arachis* genotypes after 8 days of incubation

Treatment	Genotype	Infection score
G1	J68	4.0
G2	J71	4.0
G3	J73	4.0
G4	JB1109	3.9
G5	JB1137	3.6
G6	JB1142	3.7
G7	JB1144	3.1
G8	JB1145	3.0
G9	JB1168	3.3
G10	JB1176	4.0
G11	JB1180	3.3
G12	JB1184	3.5
G13	AG2240	4.0
G14	AG2245	4.0
G15	AG1	3.0
G16	GG2	3.3
G17	GG5	2.9
G18	GG6	3.1
G19	GG7	2.5
G20	TG26	1.5
G21	TAG24	3.7
G22	TPG41	3.6
G23	ICG1122	3.0
G24	ICG1173	3.5
G25	ICG1323	3.5
G26	ICG1326 (J-11)	1.0
G27	ICG1994	3.4
G28	ICG3267	3.5
G29	ICG4750	3.9
G30	ICG12697	4.0
G31	ICG9619	4.0
G32	ICGV00308	3.0
G33	ICGV00309	3.2
G34	ICGV00310	3.5
G35	ICGV00321	2.5
G36	ICGV00380	3.0
G37	ICGV00387	2.6
G38	ICGV00429	2.5
G39	ICGV00440	3.0
G40	ICGV00441	3.3
G41	ICGV95070	3.2
G42	ICGV99083	2.5
G43	ICGV99213	2.4
G44	GG20	3.3
G45	ICG12370	2.5
G46	ICG14482	2.5
G47	ICG6813	2.5
G48	ICG7412	2.0
G49	ICG10933	1.5
G50	ICG12625	1.5
	Mean	3.10
	S.Em.	0.13
	CD (p=0.05)	0.37
	CV%	5.91

However during screening study, the genotype ICG00308 showed a disease score of 3.0 and thus could not be considered as resistant. It may be possible that some other genes could be involved in imparting resistance to this cultivar. The two genotypes *viz.,* ICG 10933 and ICG 12625 showed a banding pattern similar to J-11 with lipoxygenase and trypsin inhibitor. These two genotypes exhibited moderately resistant behavior. It was reported that resistance to Aflatoxin in maize kernels is a multi-genic quantitative trait with a large genotype x environment interaction (Paul *et al.,* 2003).

A simple correlation analysis was carried out for establishing association between amplified bands (with four different primers) and disease score (Table 4). But the correlations were very low and therefore, no inferences could be drawn. This needs to be tested with a large number of genotypes with varying yellow mold resistance trait. However, going by the magnitude and direction, in case of three primers *viz.,* BURP, lipoxygenase and trypsin inhibitor, the molecular weight was negatively correlated with disease score. While in case of one primer, i.e. BURP-1 (0.10983), molecular weight was positively correlated with disease score.

In vitro testing of fungicides (inhibition zone technique) to control *Aspergillus* infection: In vitro testing of fungicides was done by inhibition zone technique. Among the genotypes maximum and minimum inhibition zone was observed in ICG 1326 (3.08) and GG20 (1.84), respectively. Among the fungicides, carbendazim + thiram showed highest (3.46) and the fungicide copper-oxychloride (1.68) showed lowest inhibition zone development. There was significant interaction effect between genotypes and fungicide treatments on inhibition zone development. Among all combinations ICG10933 (*A. peruviana*) with carbendazim + thiram (4.50) recorded the highest inhibition zone development. In the present study, a combination of carbendazim + thiram (systemic fungicide + non-systemic fungicide) was found to be most effective than the other fungicides in controlling *A. flavus* infection. It was also inferred that the botanical type *A. peruviana* in combination with the best fungicidal treatment of carbendazim + thiram gave the best results for controlling Aspergillus infection. This indicated that the ssp. peruviana can be explored for inducing aflatoxin resistance in cultivated groundnut.

In conclusion, as compared to the reported resistant variety ICG1326 (J11), only three genotypes *viz.,* ICG10933, ICG12625, TG26 showed similar disease score. Even though there were associations between the tested (four) molecular markers with resistance, correlation coefficients were low and this precluded establishing clear associations between alleles and the trait. Experimental results also established that *Aspergillus* infection can be effectively controlled by exploring alternate resistance sources such as botanical type *A. peruviana* and fungicidal treatments like carbendazim + thiram.

Table 3 Genotypes having same bands as in ICG1326 (J11) amplified by different generic and EST-SSR primers

Primers	Band length in ICG1326 (J11)	Genotypes having same bands along with disease score
BURP	154 bp	JB1145 (3.0), JB1168 (3.3), JB1176 (4.0), AG1 (3.0), ICG1173 (3.5) and ICGV00309 (3.2)
BURP-1	187 bp	JB1137 (3.6), JB1144 (3.1), JB1145 (3.0), JB1168 (3.3), JB1176 (4.0), ICG9619 (4.0) and ICGV00308(3.0)
Lipoxygenase	273 bp	ICG12697 (4.0),ICGV00308 (3.0), ICGV00310 (3.5), ICGV00321 (2.5), ICGV00441 (3.3), ICGV95070 (3.2), ICGV99083 (2.5), ICG12370 (2.5), ICG14482 (2.5), ICG6813 (2.5), ICG10933 (1.5) and ICG12625 (1.5)
Trypsin inhibitor	148 bp	ICGV00308(3.0), ICGV00309 (3.2), ICGV00321 (2.5), ICGV00380 (3.0), ICGV00387 (2.6), ICGV99083 (2.5), ICGV99213 (2.4), ICG12370 (2.5), ICG14482 (2.5), ICG6813 (2.5), ICG7412 (2.0), ICG10933 (1.5) and ICG12625 (1.5)

Table 4 Correlation of disease score with molecular weight of bands amplified by different generic and EST derived primers

Primers	Avg. mol. wt. of amplified bands	Correlation with disease score
BURP	160.57	-0.12518
BURP-1	186.43	0.10983*
Lipoxygenase	270.29	-0.26939*
Trypsin Inhibitor	147.00	-0.33061*

*significant at 0.05 % level of probability

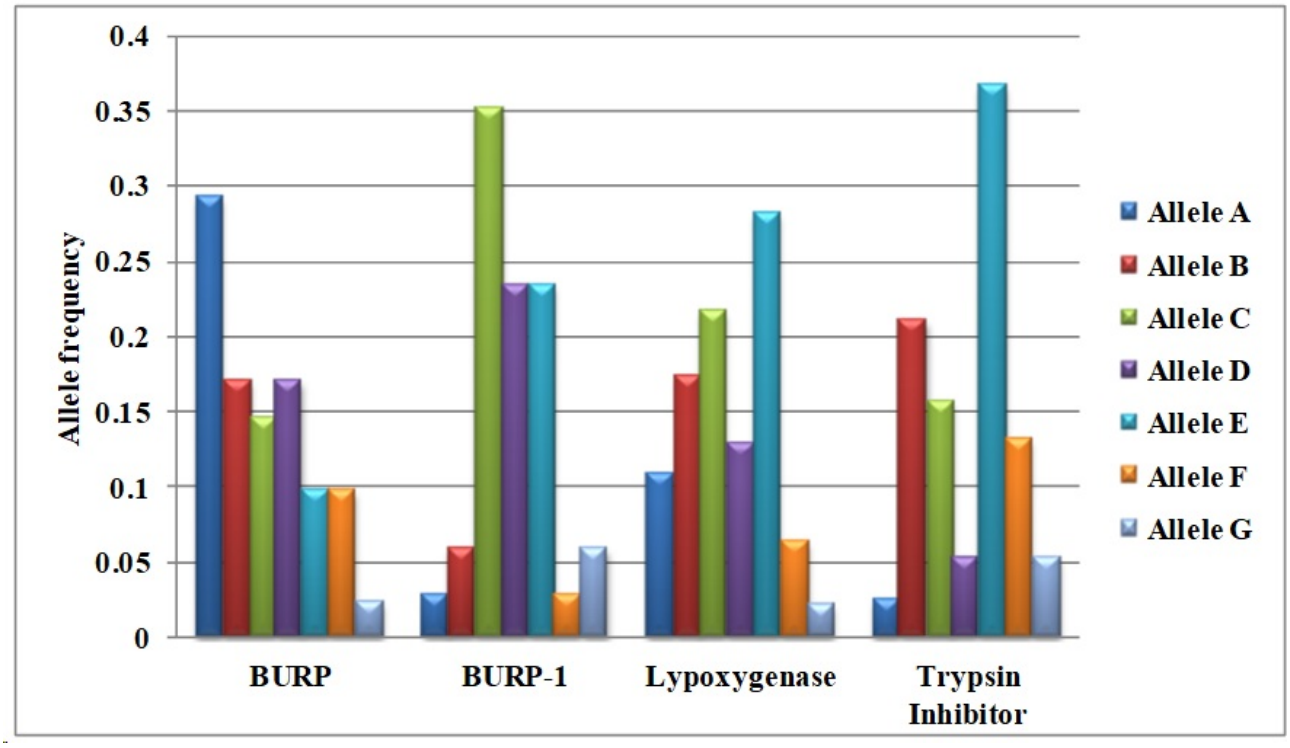

Fig. 2. Graph showing the frequency of alleles amplified by generic and EST-SSR primers

Table 5 Allele description of EST derived SSR primer

Allele designation	Allele length (bp)	No. of bands	Allele frequency
Allele description of BURP (product size varied between 150 and 175 bp)			
A	150	12	0.293
B	154	7	0.171
C	156	6	0.146
D	159	7	0.171
E	163	4	0.098
F	167	4	0.098
G	175	1	0.024
Allele description of BURP-1 (product size varied between 171 and 200 bp)			
A	171	1	0.029
B	179	2	0.059
C	183	12	0.353
D	187	8	0.235
E	190	8	0.235
F	195	1	0.029
G	200	2	0.059
Allele description of Lipoxygenase (product size varied between 260 and 280 bp)			
A	260	5	0.109
B	265	8	0.174
C	267	10	0.217
D	271	6	0.130
E	273	13	0.283
F	276	3	0.065
G	280	1	0.022
Allele description of Trypsin inhibitor (product size varied between 138-158 bp)			
A	138	1	0.026
B	142	8	0.211
C	144	6	0.158
D	146	1	0.053
E	148	14	0.368
F	153	5	0.132
G	158	2	0.053

Table 6 Mean value of inhibition zone developed during *in vitro* testing of fungicides in different *Arachis* subspecies

Treatment	Genotype	Inhibition zone (in cm) after 72 hr. of inoculation
G1	J68	1.91
G2	J71	2.05
G3	J73	2.02
G4	JB1109	1.90
G5	JB1137	2.35
G6	JB1142	2.64
G7	JB1144	2.40
G8	JB1145	2.56
G9	JB1168	2.34
G10	JB1176	2.14
G11	JB1180	2.68
G12	JB1184	2.27
G13	AG2240	2.78
G14	AG2245	2.52
G15	AG1	2.40
G16	GG2	2.04
G17	GG5	2.73
G18	GG6	2.36
G19	GG7	2.18
G20	TG26	2.26
G21	TAG24	2.16
G22	TPG41	2.20
G23	ICG1122	2.08
G24	ICG1173	2.64
G25	ICG1323	2.73
G26	ICG1326	3.08
G27	ICG1994	2.42
G28	ICG3267	2.56
G29	ICG4750	2.44
G30	ICG12697	2.26
G31	ICG9619	2.72
G32	ICGV00308	2.46
G33	ICGV00309	2.80
G34	ICGV00310	2.50
G35	ICGV00321	2.40
G36	ICGV00380	2.60
G37	ICGV00387	2.68
G38	ICGV00429	2.58
G39	ICGV00440	2.54
G40	ICGV00441	2.50
G41	ICGV95070	2.70
G42	ICGV99083	2.49
G43	ICGV99213	2.59
G44	GG20	1.84
G45	ICG12370	2.30
G46	ICG14482	2.78
G47	ICG6813	2.78
G48	ICG7412	2.86
G49	ICG10933	2.86
G50	ICG12625	2.90
	S.Em.	0.072
	CD (p=0.05)	0.200
	Fungicide	
F1	Carbendazim	2.59
F2	Copper-oxychloride	1.68
F3	Mancozeb	2.17
F4	Thiram	2.38
F5	Carbendazim+Thiram	3.46
	S.Em.	0.023
	CD(p=0.05)	0.063
	GXF	significant
	CV%	9.28

Table 7 Interaction effects of genotypes and fungicidal treatment on inhibition zone development

	Genotype	F1	F2	F3	F4	F5
G1	J68	2.00	1.00	1.70	1.90	2.95
G2	J71	2.20	1.20	1.80	2.00	3.05
G3	J73	2.10	1.30	1.70	2.00	3.00
G4	JB1109	2.00	1.20	1.50	1.80	3.00
G5	JB1137	2.50	1.60	2.00	2.30	3.35
G6	JB1142	2.90	1.80	2.40	2.70	3.40
G7	JB1144	2.60	1.90	2.10	2.30	3.10
G8	JB1145	2.80	2.00	2.30	2.50	3.20
G9	JB1168	2.30	1.80	2.00	2.10	3.50
G10	JB1176	2.10	1.50	1.80	2.00	3.30
G11	JB1180	2.70	2.00	2.20	2.50	4.00
G12	JB1184	2.40	1.40	1.90	2.10	3.55
G13	AG2240	2.80	2.00	2.50	2.70	3.90
G14	AG2245	2.90	2.00	2.40	2.60	2.70
G15	AG1	2.50	1.60	2.00	2.30	3.60
G16	GG2	2.10	1.60	1.80	2.00	2.70
G17	GG5	2.90	2.30	2.60	2.70	3.15
G18	GG6	2.50	1.70	2.00	2.20	3.40
G19	GG7	2.30	1.50	1.90	2.00	3.20
G20	TG26	2.70	1.50	2.10	2.40	2.60
G21	TAG24	2.50	1.60	2.20	2.20	2.30
G22	TPG41	2.40	1.50	2.00	2.20	2.90
G23	ICG1122	2.20	1.30	1.70	2.00	3.20
G24	ICG1173	2.80	2.00	2.40	2.60	3.40
G25	ICG1323	2.90	2.00	2.30	2.60	3.85
G26	ICG1326	3.20	2.10	2.80	3.00	4.30
G27	ICG1994	2.60	1.50	2.10	2.30	3.60
G28	ICG3267	2.80	1.50	2.10	2.40	4.00
G29	ICG4750	2.50	2.00	2.20	2.40	3.10
G30	ICG12697	2.30	1.60	2.00	2.10	3.30
G31	ICG9619	2.80	2.00	2.50	2.70	3.60
G32	ICGV00308	2.60	2.00	2.00	2.30	3.40
G33	ICGV00309	2.90	1.90	2.30	2.60	4.30
G34	ICGV00310	2.50	1.60	2.00	2.30	4.10
G35	ICGV00321	2.50	1.40	2.00	2.20	3.90
G36	ICGV00380	2.80	2.00	2.40	2.60	3.20
G37	ICGV00387	2.90	2.10	2.60	2.70	3.10
G38	ICGV00429	2.80	2.10	2.50	2.70	2.80
G39	ICGV00440	2.50	2.00	2.20	2.40	3.60
G40	ICGV00441	2.60	1.60	2.10	2.40	3.80
G41	ICGV95070	2.90	1.30	2.60	2.80	3.90
G42	ICGV99083	2.70	1.40	2.30	2.50	3.55
G43	ICGV99213	2.50	1.90	2.30	2.40	3.85
G44	GG20	2.10	1.00	1.80	2.00	2.30
G45	ICG12370	2.30	1.20	2.00	2.20	3.80
G46	ICG14482	2.90	1.70	2.40	2.60	4.30
G47	ICG6813	2.80	1.80	2.50	2.70	4.10
G48	ICG7412	2.80	1.90	2.60	2.70	4.30
G49	ICG10933	2.90	1.50	2.60	2.80	4.50
G50	ICG12625	2.10	1.60	2.70	2.90	4.20
S.Em.			0.16			
CD(p=0.05)			0.44			
CV%			9.28			

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In vitro evaluation of fungicides, botanicals and biocontrol agents against *Macrophomina phaseolina* (Tassi.) Goid. - The causal organism of root rot of sesame

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ABSTRACT

The efficacy of six fungicides was evaluated *in vitro* by poisoned food technique which revealed that all the fungicides were effective in inhibiting mycelial growth of *Macrophomina phaseolina* to varying degrees. Complete inhibition (100%) of growth of pathogen over control was observed in Carboxin 37.5% + Thiram 37.5% WP followed by Mancozeb 63% WP + Carbendazim 12% WP with mycelial growth inhibition percentage of 98.79%. Among the commercially available botanicals, fungal and bacterial biocontrol agents Neem oil, *Trichoderma viride* (Tv1) and *Pseudomonas fluorescens* (Pf1) were effective with mycelial growth inhibition percentage of 27.05, 71.05, 40.58 per cent, respectively.

Keywords: *Bacillus subtilis*, *Macrophomina phaseolina, P. fluorescens,* Root rot, *Trichoderma harzianum, T. viride*

Since sesame seed and oil are in high demand for export due to the presence of high amounts of unsaturated fatty acid as well as high methionine content, of late focus has been to produce sesame with no residual effect of chemicals such as fungicides/insecticides by using non-chemical alternatives such as botanicals or bio-control agents. Also, there is a perceived less demand for fungicides because of their non-ecofriendly and pollutive nature. Moreover, residual toxicities of chemical fungicides could cause diseases in human and farm animals (Brindha *et al.*, 2009). The increasing consciousness of fungicide related risks has stressed the need for embracing biological methods, that are also eco-friendly, as alternative disease control methods (Khare *et al.*, 2010; Kishore Varma *et al.*, 2107). Biological control appears to be the best solution for long term sustainability and effective management of soil borne diseases which can considerably minimize the disease (Howell, 2003). Root rot/stem rot caused by *Macrophomina phaseolina* (Tassi.) Goid (= *Rhizoctonia bataticola*) is one of the most important diseases of sesame in India (Chattopadhyay and Sastry, 1998). Benefit of management approaches to this disease can be well realized when we adopt integrated disease management (IDM) practices wherein bio-control agents and botanicals are combined with minimal quantity of most effective fungicide. In this perspective, the present investigation was carried out in Plant Pathology laboratory of PJTSAU, Hyderabad to study the effect of fungicides, botanicals and bio-control agents against *M. phaseolina in vitro*.

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MATERIALS AND METHODS

In vitro evaluation of fungicides, botanicals and bio-control agents:

***In vitro* screening of fungicides against *M. phaseolina*:** Fungicides mentioned in Table 1 were evaluated against *M. phaseolina* under *in vitro* conditions by poisoned food technique (Vincent, 1927) at two concentrations i.e. recommended and half the recommended dose. For each treatment, 100 ml of potato dextrose agar was taken in 250 ml conical flask and sterilized in an autoclave. Fungicide was added to the sterilized medium at lukewarm temperature under aseptic conditions and mixed thoroughly by shaking to obtain the above-mentioned concentrations. The poisoned medium was equally distributed in the Petri plates and allowed to solidify.

Three replications were maintained for each treatment. Discs of 5mm diameter of the actively growing test fungal cultures were cut with sterilized cork borer separately and transferred to the centre of the poisoned medium in each of the Petri plates. Similarly, control was maintained by placing 5 mm discs of test fungal culture in centre of the plates containing the medium without fungicide. All the Petri plates were incubated at 28±1ºC in BOD incubator. The diameter of fungal colony was measured in each of the treatment when the pathogen growth in control plate was full. The colony diameter inhibited in fungicide treated plates as compared to control was taken as a measure of fungitoxicity. Per cent inhibition over control was calculated by following the equation (Vincent, 1927):

$$I = [(C-T)/C]x100$$

Where,
I = Per cent inhibition over control
C = Radial growth of pathogen in control (mm)
T = Radial growth of pathogen in treatment (mm)

In vitro* screening of commercial botanicals against *M. phaseolina: Four commercial botanicals *viz*., neem cake powder, neem oil, neem powder and karanja oil were evaluated against the test pathogen at two concentrations *viz*., 5% and 10 % under *in vitro* conditions by poisoned food technique (Vincent, 1927). The details of commercial botanicals are mentioned in Table 2.

***In vitro* screening of bio-control agents against *M. phaseolina*:** The bio-agents *viz, Trichoderma* sp., *Pseudomonas fluorescens* and *Bacillus subtilis* were tested for their efficacy against *M. phaseolina* by dual culture plate technique (Dennis and Webster, 1971). The pathogen as well as bioagents were inoculated at equidistance on PDA medium aseptically and incubated at 28±1°C. The experiment was executed in a completely randomized block design (CRD) with three replications. The details of fungal and bacterial biocontrol agents are mentioned in Table 3 and Table 4, respectively.

The bacterial bio-control agent was streaked at one end of the Petri plate on PDA media by means of a sterilized inoculation loop. A five mm PDA culture disc of the test pathogen was cut with a sterilized cork borer from the edge and placed at the opposite end. Control was maintained by placing only the pathogen on culture medium. Each treatment was triplicated. The plates were incubated at room temperature (28±1°C) till mycelial growth in the control plates covered the entire plate. Petri plates were observed daily for recording antagonistic interactions between the pathogen and biocontrol agent. Radial growth of the pathogen was measured after the growth in control plates reached full growth (90 mm diameter) and the per cent inhibition over control was calculated using the formula given below.

$$I = [(C-T)/C]x100$$

Where,
I = Per cent inhibition over control
C = Radial growth of pathogen in control (mm)
T = Radial growth of pathogen in treatment (mm)

RESULTS AND DISCUSSION

***In vitro* evaluation of fungicides, botanicals and bio-control agents**: The efficacy of six fungicides was tested *in vitro* by poisoned food technique and the results are presented in Table 5 and Fig. 1. All the fungicides were effective in inhibiting radial growth of *M. phaseolina* to varying degrees. Significant difference was observed among the fungicides except two fungicides Vitavax power and Toptoo which were found to be on par with each other in inhibiting the mycelial growth of the pathogen. Complete inhibition (100%) of growth of pathogen over control was observed in Vitavax power treatment at 2000ppm (Table 5). This was followed by Toptoo (98.79%),

Similar results were obtained by Deepthi *et al.* (2014) who reported that Vitavax power and Penflufen gave 100% inhibition of mycelial growth of *M. phaseolina* and the field evaluation of different fungicides indicated that Vitavax power, when used for seed treatment, gave highest sesame seed germination (85.10%) and less pre and post emergence mortality (14.88% and 27.66%), and yield loss (32.09%) against *M. phaseolina*.

The results of *in vitro* screening of botanicals against *M. phaseolina* are presented in Table 6 and Fig. 5 which indicated that neem oil was highly effective in inhibition of mycelial growth (27.05%) followed by karanja oil (14.70%), while neem cake powder was least effective with no inhibition at its half-recommended dosage (5%), against *M. phaseolina.*

These results are in line with the findings of Dubey *et al.* (2009) who found neem oil to be most toxic followed by cake, leaf and bark extracts. Effect of neem extract on sclerotial survival of *M. phaseolina* was found inhibitory after 2 and 4 days of incubation. *Sclerotia* treated with neem oil did not germinate, hence resulted in 100% inhibition.

Mallaiah and Krishna Rao (2016) also observed that neem oil (Starneem) to be more effective in inhibiting the growth of the pathogen by 87.1 per cent at 600 ppm than neem gold with (75.1%) inhibition. Similar results were reported on antifungal activity properties of commercial neem product, neem oil against *R. solani* which were found to be effective in reducing the growth of the pathogen to the extent of 80-100 per cent in vitro by Dhanapal *et al.* (1993).

***In vitro* screening of biocontrol agents against M. phaseolina:** The results of antagonistic activity of fungal bioagents as presented in Table 7 and Fig. 2, indicated that *T. viride* (Tv1) was highly effective (71.05%) followed by *T. harzianum* (Th1) (66.35%) in inhibiting the mycelial growth of *M. phaseolina* and least inhibition (58.82%) was exhibited by *T. harzianum* (Th2) isolate (Fig. 2)

The present investigation is in agreement with the findings of Meena and Pandey (2015) who reported that *T. viride* exhibited the greatest reduction in mycelial growth of *M. phaseolina* and *R. solani,* followed by *T. harzianum, T. virens* and *P. fluorescens* as compared to control. The bio-control agent *T. viride* showed maximum growth inhibition of *M. phaseolina* (Chirame and Padule, 2005;

Khan, *et al.,* 2012). Thilagavathi *et al.* (2007) tested the antagonistic effect of *T. viride* (strains Tv1 and Tv13), *Pseudomonas fluorescens* (Pf1 and Pf15) and *Bacillus subtilis* (Bs16) individually and in combination against *M. phaseolina* causing root rot in greengram. Among all individual bio-control agents, *T. viride* (strains Tv1 and Tv13) individually showed maximum growth inhibition of the pathogen.

Reduction in pathogen growth may be due to antibiotics produced by the biocontrol agents, as reported by many workers (Ramamoorthy and Samiyappan, 2001; Viswanathan and Samiyappan, 2001). Difference in the inhibitory ability between isolates has often been attributed to factors such as antibiosis, myco-parasitism, competition for space and nutrients and over growth (Ghaffar *et al.,* 1964; Karunanithi *et al.,* 2000; Naik *et al.,* 2009; Manjunatha and Naik, 2011).

The evaluation of bacterial bioagents against *M. phaseolina* revealed that significant inhibition was observed among the isolates regarding their antagonistic potential (Table 8 and Fig. 4). *Pseudomonas fluorescens* (Pf1) was found to be highly effective (40.58%) followed by Pf 6 (32.5%) in inhibiting the mycelial growth of *M. phaseolina*.

These findings are similar to those reported by Manjunatha *et al.* (2013) who observed significant variation in the ability of the different *P. fluorescens* isolates to reduce mycelial growth of *M. phaseolina,* and the isolate *P. fluorescens* (Pf4) was found to be significantly more effective than the other isolates. Anand *et al.* (2010) also observed differences in the ability of various species of *Pseudomonas* and between isolates within each species in inhibiting the growth of *Rhizoctonia solani* associated with root rot of cotton under laboratory conditions. These differences are attributed to the production of antimicrobial compounds such as phenazines and hydrogen cyanide.

The suppression of mycelial growth of the pathogen by the bio-control agents may be due to antibiotics produced, as has been reported by many workers (Ramamoorthy and Samiyappan, 2001; Viswanathan and Samiyappan, 2001). There exist different forms of antagonism i.e., competition, antibiosis, parasitism and the growth inhibition of *M. phaseolina* might be attributed mainly due to antibiosis or hyper parasitism (Baker and cook, 1974).

In conclusion, *in vitro* evaluation of fungicides, botanicals, fungal and bacterial bio-control agents, Vitavax power, neem oil, *T. viride* (Tv1) and *P. fluorescens* (Pf1) were found to be most effective against *M. phaseolina.* Further, these can be tested under field conditions to develop best IDM module for management of root rot of sesame.

Table 1 Details of the fungicides used in bioassay studies under *in vitro* conditions against *M. phaseolina*

Common name	Trade name	Treatment number	Dosage (ppm)
Tebuconazole + Trifloxystrobin 75 WG	Nativo	T_1	2000
		T_2	1000
Hexaconazole 5% + Captan 70% WP	Taqat	T_3	2000
		T_4	1000
Carboxin 37.5% + Thiram 37.5% WP	Vitavax power	T_5	2000
		T_6	1000
Iprovalicarb 5.5% + Propineb 61.25%WP	Melody duo	T_7	2000
		T_8	1000
Carbendazim 50WP	Hycarb	T_9	2000
		T_{10}	1000
Mancozeb 63% W.P. + Carbendazim 12% WP	Top too	T_{11}	2000
		T_{12}	1000

Table 2 Details of the commercially available botanicals used in bioassay studies under *in vitro* conditions against *M. phaseolina*

Common name	Trade name	Treatment number	Concentrations %
Neem cake powder	ThiryO'neem	T_1	5
		T_2	10
Neem oil	SGK products, Neem Seed Oil	T_5	5
		T_6	10
Neem powder	NIRD Neem powder	T_3	5
		T_4	10
Karanja oil	SGK products, Pongamia Seed Oil	T_7	5
		T_8	10

Table 3 Details of the fungal biocontrol agents used in bioassay studies under *in vitro* conditions against *M. phaseolina*

Fungal Bio control agent	Isolate code	Source
Trichoderma harzianum	Th 1	IIOR, Rajendranagar, Hyderabad
Trichoderma asperellum	Ta 1	IIOR, Rajendranagar, Hyderabad
Trichoderma harzianum	Th 2	NIPHM, Rajendranagar, Hyderabad
Trichoderma harzianum	Th 3	Varsha Bioscience and Technology India Private Limited, Hyderabad
Trichoderma viride	Tv 1	Varsha Bioscience and Technology India Private Limited, Hyderabad

IIOR: Indian Institute of Oilseeds Research; NIPHM: National Institute of Plant Health Management.

Table 4 Details of the bacterial biocontrol agents used in bioassay studies under *in vitro* conditions against *M. phaseolina*

Bacterial Bio control agent	Isolate code	Source/ Isolated from
Pseudomonas fluorescens	Pf 1	Varsha Bioscience and Technology India Private Limited, Hyderabad
Pseudomonas fluorescens	Pf 2	NIPHM, Rajendranagar, Hyderabad
Pseudomonas fluorescens	Pf 3	Rice Research centre, Rajendranagar
Pseudomonas fluorescens	Pf 4	ARI, Rajendranagar
Pseudomonas fluorescens	Pf 5	College farm CA, Rajendranagar
Pseudomonas fluorescens	Pf 6	IIRR, Rajendranagar
Pseudomonas fluorescens	Pf 7	IIOR, Rajendranagar
Pseudomonas fluorescens	Pf 8	Student farm CA, Rajendranagar
Bacillus subtilis	Bs 1	Rice Research centre; ARI, Rajendranagar
Bacillus subtilis	Bs 2	IIOR, Rajendranagar
Bacillus subtilis	Bs 3	IIRR, Rajendranagar
Bacillus subtilis	Bs 4	College farm CA, Rajendranagar
Bacillus subtilis	Bs 5	ARI, Rajendranagar
Bacillus subtilis	Bs 6	Student farm CA, Rajendranagar

ARI- Agriculture Research Institute; IIRR- Indian Institute of Rice Research; CA- College of Agriculture; IIOR- Indian Institute of Oilseeds Research

Table 5 Effect of fungicides on the mycelial growth of *Macrophomina phaseolina* under *in vitro* conditions

Fungicide	Recommended concentration (ppm)	Treatment number	Linear mycelial (mm) growth	Inhibition of *Macrophomina phaseolina* over control (%)	Half the Recommended concentration (ppm)	Treatment number	Linear mycelial growth (mm)	Inhibition of *M. phaseolina* over control (%)
Tebuconazole + Trifloxystrobin 75 WG	2000	T_1	5.19 *	94.23	1000	T_2	6.05 a	93.27
Hexaconazole 5% + Captan 70% WP	2000	T_3	30.25	66.38	1000	T_4	34.14	62.06
Carboxin 37.5% + Thiram 37.5%	2000	T_5	0.00	100	1000	T_6	1.09	98.79
Iprovalicarb 5.5% + Propineb 61.25%WP	2000	T_7	64.39	28.45	1000	T_8	73.36	18.48
Carbendazim 50WP	2000	T_9	2.17	97.59	1000	T_{10}	5.51	93.87
Mancozeb 63% W.P. + Carbendazim 12% WP	2000	T_{11}	1.09	98.79	1000	T_{12}	2.17	97.59
Control	-----		90.00				90.00	
CD (p = 0.05)			1.23				1.33	1.79
SE(m) ±			0.40				0.43	0.58
CV (%)			2.51				2.47	1.29

*Average of three replications.

Table 6 Effect of botanicals on the mycelial growth of *M.. phaseolina* under *in vitro* conditions

Botonical	Treatment number	Recommended concentration (%)	Linear mycelial growth (mm)	Inhibition over control (%)	Treatment number	Half the Recommended concentration (%)	Linear mycelial growth (mm)	Inhibition over control (%)
Neem cake powder	T_2	10	87.14*	3.17	T_1	5	90.00 *	0.0
Neem oil	T_6	10	65.65	27.05	T_5	5	81.54	9.4
Neem powder	T_4	10	82.59	8.23	T_3	5	88.94	1.17
Karanja oil	T_8	10	76.77	14.70	T_7	5	77.86	13.48
Control		-	90.00	-		-	90.00	-
CD (p = 0.05)			4.24				4.24	
SE(m) ±			1.33				1.33	
CV (%)			2.86				2.68	

*Average of three replications.

Table 7 Effect of fungal biocontrol agents on the mycelial growth of *M. phaseolina* under *in vitro* conditions

Treatment	Isolate Code	Linear mycelial growth (mm)	Inhibition of *M. phaseolinaover* control (%)
Trichoderma harzianum	Th 1	30.28 *	66.35
Trichoderma asperellum	Ta 1	33.88	62.35
Trichoderma harzianum	Th 2	37.06	58.82
Trichoderma harzianum	Th 3	31.03	65.52
Trichoderma viride	Tv 1	26.05	71.05
Control	-	90.00	-
CD (p = 0.05)		2.16	
SE(m) ±		0.69	
CV (%)		2.9	

*Average of three replications.

Table 8 Effect of bacterial biocontrol agents on the mycelial growth of *M. phaseolina* under *in vitro* conditions

Treatment	Isolate Code	Linear mycelial growth (mm)	Inhibition of *M. phaseolina* over control (%)
Pseudomonas fluorescens	Pf 1	53.47 *	40.58
Pseudomonas fluorescens	Pf 2	71.57	20.47
Pseudomonas fluorescens	Pf 3	62.47	30.58
Pseudomonas fluorescens	Pf 4	74.12	17.64
Pseudomonas fluorescens	Pf 5	60.88	32.35
Pseudomonas fluorescens	Pf 6	61.87	31.25
Pseudomonas fluorescens	Pf 7	64.17	28.70
Pseudomonas fluorescens	Pf 8	76.77	14.70
Bacillus subtilis	Bs 1	63.53	29.41
Bacillus subtilis	Bs 2	64.59	28.23
Bacillus subtilis	Bs 3	61.41	31.76
Bacillus subtilis	Bs 4	62.47	30.58
Bacillus subtilis	Bs 5	62.47	29.80
Bacillus subtilis	Bs 6	63.53	29.41
Control	-	90.00	-
CD (p = 0.05)		2.79	
SE(m) ±		0.96	
CV (%)		2.52	

*Average of three replications.

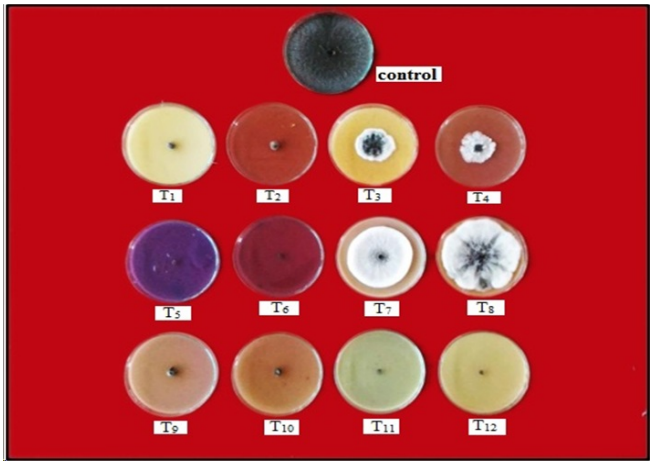

Fig. 1. *In vitro* evaluation of fungicides against *M. phaseolina*

Fig. 2. *In vitro* evaluation of fungal biocontrol agents against *M. phaseolina*

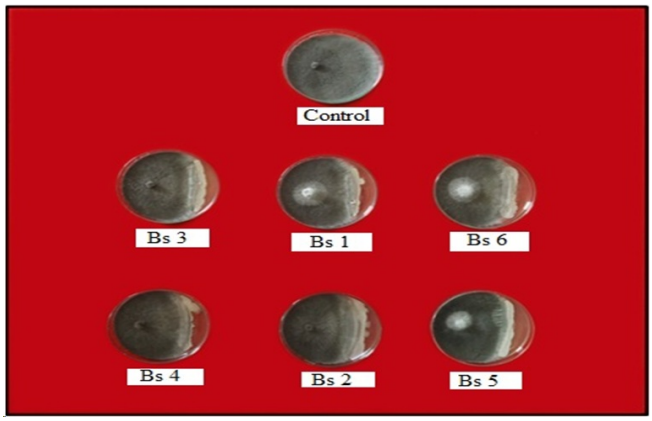

Fig.3. *In vitro* evaluation of different isolates of *Bacillus subtilis* against *M. phaseolina*

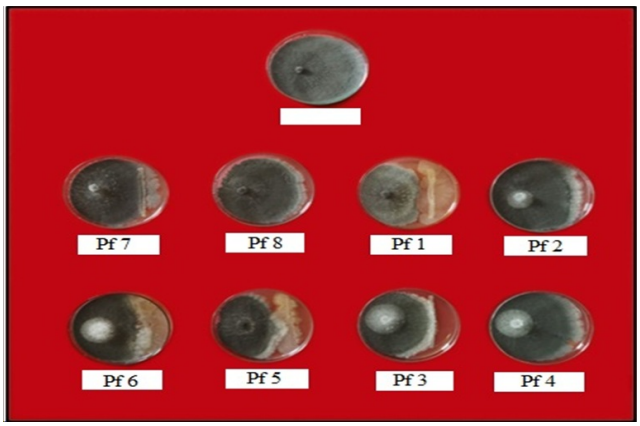

Fig. 4. *In vitro* evaluation of different isolates of *Pseudomonas fluorescens* against *M. phaseolina*

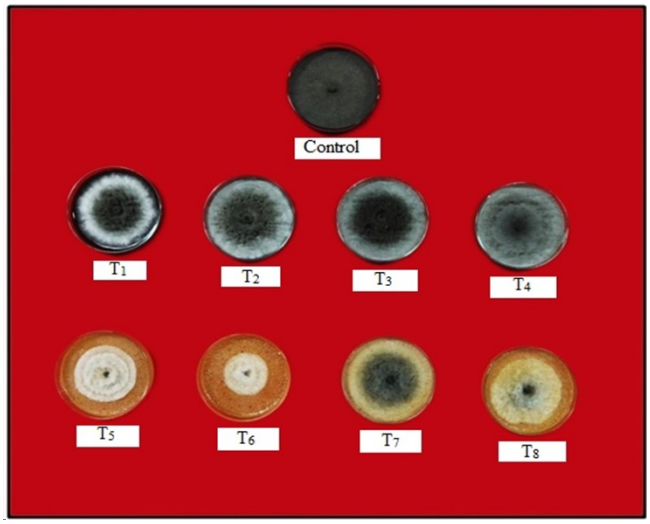

Fig. 5. *In vitro* evaluation of different commercially available botanicals against *M. phaseolina*

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Field efficacy and economics of newer insecticides against defoliators infesting castor (*Ricinus communis* L.)

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ABSTRACT

Field experiments were conducted during *kharif* season of 2014-15 and 2015-16 to evaluate the field efficacy of newer insecticides emamectin benzoate 5WG @ 0.5 g/l, lufenuron 5EC @ 1 ml /l, flubendiamide 39.35 EC @ 0.2 ml/l, chlorantraniliprole 18.5SC@ 0.3 ml/l, lambda cyhalothrin @ 1 ml/l along with conventional insecticides like profenophos 50EC @ 2 ml/l, indoxacarb 14.5SC @ 1 ml/l, thiodicarb 75 WP @ 1 g/l against castor semilooper, tobacco caterpillar and hairy caterpillars in castor. The experiments were conducted in a randomized block design with eight treatments along with an untreated control and replicated thrice. The results revealed that the maximum percentage of larval reduction was in chlorantraniliprole 18.5 SC@ 0.3 ml/l followed by flubendiamide 38EC @ 0.2 ml/1. Highest seed yield of 1543 kg/ha was obtained from chlorantraniliprole treated plots, followed by that obtained with flubendiamide (1410 kg/ha) and profenophos (1375 kg/ha) treated plots with 93.5 and 88.7 per cent increase over control respectively as against minimum yield of 729 kg/ha in the untreated control. The favourable incremental cost-benefit ratio of 1: 6.25 was obtained with profenophos 50 EC @ 2 ml/l.

Keywords: Castor, Bioefficacy, Defoliators, Economics, Management, Newer Insecticides

Castor (*Ricinus communis* L.) is an industrially important non-edible oilseed crop of the world. Among the biological constraints in castor production, insect pests dominate the scenario. In India, several insect pests infecting castor have been recorded (Rai, 1976; Duraimurugan and Lakshminarayana, 2015). The most important ones are the defoliators including semilooper (*Achaea janata*), tobacco caterpillar (*Spodoptera litura*), hairy caterpillars (*Euproctis* spp. and *Ergolis merione*). The castor semilooper are common and regular pests in Tamil Nadu and its outbreaks occurred during August-September. The economic threshold level for the semilooper is 4 larvae/plant on 30 days old crop. The tobacco caterpillar is another major pest on castor and the pest appears during August and October causing heavy defoliation. The hairy caterpillars like *Euproctis* sp. and *Ergolis merione* reported to cause damage to castor particularly during October to December months. The young instars feed gregariously and confined to certain portion of the field. The congregating habit continues even in the mature larvae, on contact with larvae causing urticarial or nettle rash in human beings. The seed yield loss due to semilooper and *S. litura* is to the tune of 31.0-40.8 per cent followed by hairy caterpillars 19.0 per cent (Anonymous, 2006). Management of defoliators and capsule borer relies heavily on insecticides when other management strategies of pest control do not give satisfactory control under high pest infestation level. A number of insecticides have been found reported to be effective for controlling castor defoliators and capsule borer (Duraimurugan and Lakshminarayana, 2014). Exploring new insecticides with lesser residues and lower environmental threat has become imperative. In recent years, newer compounds with novel modes of action are being evolved to check infestation by this pest. The present study is aimed at evaluating the efficacy of certain new insecticides against the defoliators in castor.

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MATERIALS AND METHODS

To evaluate the field efficacy of different newer insecticides against castor defoliators, field experiments was conducted at Tapioca and Castor Research Station, Yethapur (Tamil Nadu) during *kharif* seasons 2014-15 and 2015-16 on the castor hybrid DCH 519 was sown in plots of 5.4 m x 6.0 m with the spacing of 90 cm x 90 cm. The experiment was conducted in a randomized block design with nine treatments and three replications. The treatments were imposed by using knapsack sprayer with 500 liters of spray solution per hectare. The crop received two sprays at 15 days intervals when the pest crossed the economic threshold level. Nine treatments *viz.,* T_1 - Emamectin 5WG @ 0.5g/l, T_2 - Lufenuron 5EC @ 1ml/l, T_3 - Flubendiamide 39.35SC @ 0.2 ml/l, T_4 - Chlorantraniliprole 18.5SC @ 0.3 ml/l, T_5 - Lambda cyhalothrin @ 1ml/l, T_6 - Profenophos 50EC @ 2 ml/l, T_7 - Indoxacarb14.5 SC @ 1 ml/l, T_8 - Thiodicarb 75WP @ 1g/l, and T_9 - Untreated control was imposed. Soil type in the experimental plot was red soil. Straight fertilizers

of NPK were applied @ 60 kg N, 30 kg P_20_5 and 30 kg K_2O in the form of urea, single superphosphate and muriate of potash, respectively. The entire dose of phosphate and potash and half the dose of nitrogen were applied before sowing by broadcasting and the remaining half of nitrogen at 30 days after sowing and proper plant stand was maintained. Insecticidal treatments were given when about 25% defoliation due to defoliators was observed during vegetative and flowering stages. Larval population per plant at 1, 3, 7 and 14 days before and after the application of insecticides on ten plants was observed and the average was worked out. The per cent reduction of pests over untreated control was worked out by using the formula given by Henderson and Tilton (1955). The monetary returns and incremental cost-benefit ratios of treatment were also worked out for selecting economical treatment against the pests. All the above data were subjected to RBD analysis using AGRES package (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Efficacy of different newer insecticides against semilooper: The results of the first year experiment conducted during *kharif* season of 2014-15 revealed that the population of semilooper was almost homogenously distributed throughout the experimental field and varied between 3.80 to 5.70 semilooper/plant in different treatments (Table 1). After two rounds of spraying, data revealed that chlorantraniliprole 18.5SC @ 0.3ml/l was most effective in reducing the semilooper population. It was reduced from 5.10 to 0.74 larvae/plant followed by flubendiamide 39.35 EC @ 0.2ml/l which was found to reduce population from 4.50 to 0.77 semilooper/plant in their mean population of 2 sprays observed at 1, 3, 7 and 14 days after spraying as compared to standard check of thiodicarb 75WP @ 1 g/l in which reduction observed from 4.75 to 1.53 larvae/plant. The mean population of semilooper per plant was highest in untreated control (6.52 larvae/plant). Per cent reduction over control indicated that chlorantraniliprole 18.5SC @ 0.3ml/l reduces the semilooper population upto 87.3 per cent closely followed by flubendiamide 39.35 EC @ 0.2 ml/l registered 85.1 per cent, whereas thiodicarb 75WP @ 1 g/l, profenophos 50EC @ 2ml/l, emamectin benzoate 5 WG @ 0.5 g/lit, lamdacyhalothrin 5 EC @ 1ml/l, indoxacarb 14.5 SC @1ml/l and lufenuron 5 EC @ 0.1 ml/l recorded 71.85, 70.36, 68.40, 67.87, 62.13 and 58.58 per cent reduction of semilooper over control respectively.

Table 1 Bioefficacy of newer insecticides against castor semilooper (*Achaea janata*)

Treatments	Dose	2014-15					2015-16				
		Mean population of *Achaea janata* (Number per plant)*					Mean population of *Achaea janata* (Number per plant)*				
		PTC	1st spray	2nd spray	Pooled	PRC	PTC	1st spray	2nd spray	Pooled	PRC
Emamectin benzoate 5 WG	0.5g/l	4.15 (2.01)	1.70 (1.24)	1.30 (1.10)	1.50 (1.17)	68.40	1.90 (1.31)	0.53 (0.69)	0.93 (0.95)	0.73 (0.82)	56.30
Lufenuron 5 EC	1 ml/l	3.80 (2.01)	2.10 (1.39)	1.50 (1.21)	1.80 (1.30)	58.58	1.43 (1.12)	0.58 (0.75)	0.87 (0.88)	0.73 (0.81)	42.00
Flubendiamide 39.35 EC	0.2 ml/l	4.50 (2.10)	0.75 (0.84)	0.80 (0.87)	0.77 (0.85)	85.05	2.53 (1.57)	0.81 (0.85)	1.36 (0.94)	0.83 (0.90)	62.70
Clorantraniliprole 18.5 SC	0.3 ml/l	5.10 (2.25)	0.82 (0.88)	0.67 (0.80)	0.74 (0.84)	87.32	2.17 (1.43)	0.47 (0.67)	0.95 (0.93)	0.71 (0.80)	62.80
Lamdacyhalothrin 5 EC	1 ml/l	5.25 (2.28)	2.02 (1.39)	1.85 (1.34)	1.93 (1.37)	67.87	1.80 (1.28)	0.49 (0.66)	1.05 (0.97)	0.77 (0.81)	51.30
Profenophos 50 EC	2 ml/l	4.10 (2.01)	1.47 (1.18)	1.32 (1.13)	1.39 (1.16)	70.36	1.90 (1.34)	0.43 (0.64)	0.88 (0.88)	0.65 (0.76)	61.10
Indoxacarb 14.5 SC	1 ml/l	4.20 (2.03)	2.02 (1.40)	1.62 (1.29)	1.82 (1.35)	62.13	1.60 (1.25)	0.41 (0.59)	1.03 (0.94)	0.72 (0.77)	48.75
Thiodicarb 75WP	1 g/l	4.75 (2.16)	1.65 (1.23)	1.42 (1.21)	1.53 (1.22)	71.85	2.22 (1.41)	0.57 (0.72)	0.95 (0.96)	0.76 (0.84)	61.10
Untreated control	-	5.70 (2.37)	5.97 (2.43)	7.07 (2.60)	6.52 (2.52)	-	1.23 (1.07)	0.73 (0.85)	0.93 (1.07)	1.08 (0.96)	-
CD (p=5%)	-	0.15	0.11	0.06	0.08	-	0.35	0.17	0.34	0.34	-
SED±	-	0.071	0.05	0.02	0.04	-	0.16	0.08	0.16	0.16	-
CV(%)	-	4.00	5.07	2.81	3.94	-	17.34	14.65	13.43	13.43	-

*Mean of three replications; PTC - Pre treatment count ; PRC -Percentage Reduction Over Control; Figures in parentheses are square root n+1 transformed values

The results of the second year experiment conducted during *kharif* season of 2015- 16 revealed that after two rounds of spraying, data revealed that chlorantraniliprole 18.5 SC @ 0.3ml/lit was most effective in reducing the semilooper population. It was reduced from 2.17 to 0.71 larvae/plant followed by flubendiamide 39.35 EC @ 0.2 ml/l which was found to reduce semilooper population from 2.53 to 0.83 semilooper/plant in their mean population of 2 sprays observed at 1, 3, 7 and 14 days after spraying as compared to standard check of thiodicarb 75 WP @ 1 g/l in which reduction observed from 2.22 to 0.76 larvae/plant (Table 1).The mean population of semilooper per plant was highest in untreated control (1.08 larvae/plant). Per cent reduction over control indicated that chlorantraniliprole 18.5 SC @ 0.3ml/l reduces the semilooper population up to 62.8 per cent closely followed by flubendiamide 39.35 SC @ 0.2 ml/l registered 62.7 per cent, whereas thiodicarb 75 WP @ 1 g/l, profenophos 50 EC @ 2ml/l, emamectin benzoate 5WG @ 0.5 g/l, lamdacyhalothrin 5 EC @ 1ml/l, indoxacarb 14.5 SC @1ml/l and lufenuron 5 EC @ 1 ml/l recorded 61.10, 61.10, 56.30, 51.30, 48.75 and 42.00 per cent reduction of semilooper over control, respectively.

Efficacy of different newer insecticides against tobacco caterpillar: The results of the first year experiment conducted during *kharif* season of 2014-15 revealed that mean population of tobacco caterpillar one day before first spraying in experimental field ranged from 3.00 to 5.40 larvae/plant (Table 2). The post spray data showed that chlorantraniliprole 18.5 SC @ 0.3 ml/l was most superior to reduce the population of tobacco caterpillar from 3.45 to 0.74 larvae/plant (mean population of 2 sprays) observed at 1, 3, 7 and 10 days after spraying followed by flubendiamide 39.35 SC @ 0.2 ml/l which was found to reduce tobacco caterpillar from 3.35 to 0.93larvae/plant as compared to standard check thiodicarb 75WP @ 1 g/l , which reduction in population of tobacco caterpillar was from 5.40 to 1.68 larvae/plant. Per cent reduction over control indicated that chlorantraniliprole 18.5 SC reduces the tobacco caterpillar population up to 83.4 per cent closely followed by flubendiamide 39.35 SC which registered 78.5 per cent, whereas thiodicarb 75 WP @ 1 g/l, profenophos 50EC @ 2ml/l, emamectin benzoate 5 WG @ 0.5 g/l, lamdacyhalothrin 5 EC @ 1ml/l, indoxacarb 14.5 SC @1ml/l and lufenuron 5 EC @ 1 ml/l recorded 75.6, 75.5, 70.8, 58.2, 56.9 and 52.1 per cent reduction of tobacco caterpillar over control, respectively.

The results of the second year experiment conducted during *kharif* season of 2015-16 revealed that chlorantraniliprole 18.5 SC @ 0.3ml/l was most superior to reduce the population of tobacco caterpillar from 3.33 to 0.40 larvae/plant (mean population of 2 sprays) observed at 1, 3, 7 and 10 days after spraying followed by flubendiamide 39.35 SC @ 0.2 ml/l which was found to reduce tobacco caterpillar from 3.08 to 0.78 larvae/plant as compared to standard check thiodicarb 75 WP @ 1 g/l , which reduction in population of tobacco caterpillar was from 3.73 to 1.34 larvae/plant (Table 2). Percent reduction over control indicated that chlorantraniliprole 18.5 SC reduces the tobacco caterpillar population up to 85.3 per cent followed by flubendiamide 39.35 SC which registered 65.0 per cent, whereas thiodicarb 75WP @ 1 g/l, profenophos 50EC @ 2ml/l, emamectin benzoate 5 WG @ 0.5 g/l, lamdacyhalothrin 5EC @ 1ml/l, indoxacarb 14.5 SC @1ml/l and lufenuron 5EC @ 0.1 ml/l recorded 55.90, 53.90, 48.50, 38.70, 26.10 and 16.00 per cent reduction of tobacco caterpillar over control, respectively.

The present findings are closely associated with Tohinishi *et al.* (2005) and Ameta and Ajay Kumar (2008) who reported that application of flubendiamide was significantly superior and highly effective in reduction of population of *H. armigera* and *S. litura.* Chowdary *et al*. (2010) also reported that chlorantraniliprole 20SC @ 30 and 20 g a.i./ha were superior in recording less larval population, lowest fruit damage and higher fruit yield against okra fruit and shoot borer.

Efficacy of different newer insecticides against hairy caterpillar: The results of the first year experiment conducted during *kharif* season of 2014-15 revealed that, the pre treatment population ranged from 2.80 to 4.40 larvae/plant in different treatments (Table 3). After two rounds of spraying, the mean population of hairy caterpillars per plant was highest in untreated control (4.40 larvae/plant). chlorantraniliprole 18.5 SC recorded lowest population hairy caterpillar from 3.35 to1.42 larvae/plant followed by flubendiamide 39.35 EC @ 0.2 ml/l which was found to reduce hairy caterpillar from 4.25 to 1.21 larvae/plant as compared to standard check thiodicarb 75 WP @ 1 g/l, which reduction in population of hairy caterpillar was from 4.40 to 1.69 larvae/plant. Per cent reduction over control indicated that chlorantraniliprole 18.5 SC reduces hairy caterpillar larval population up to 75.6 per cent, cent closely followed by flubendiamide 39.35SC which registered 71.80 per cent, whereas thiodicarb 75WP @ 1 g/l, profenophos 50EC @ 2ml/l, emamectin benzoate 5 WG @ 0.5 g/l, lamdacyhalothrin 5 EC @ 1ml/l, indoxacarb 14.5 SC @1ml/l and lufenuron 5 EC @ 1 ml/l recorded whereas, profenophos 50EC, lufenuron 5EC, emamectin benzoate 5WG and lamdacyhalothrin 5EC recorded 67.7, 62.0, 61.3, 58.0, 50.8 and 48.9 per cent reduction of larvae of hairy caterpillar over control.

Table 2 Bioefficacy of newer insecticides against tobacco caterpillar, (*Spodoptera litura*)

Treatments	Dose	2014-15					2015-16				
		Mean population of *S. litura* (Number per plant)*					Mean population of *S. litura* (Number per plant)*				
		PTC	1st spray	2nd spray	Pooled	PRC	PTC	1st spray	2nd spray	Pooled	PRC
Emamectin benzoate 5 WG	0.5 g/l	4.55 (2.10)	2.00 (1.39)	1.45 (1.17)	1.72 (1.28)	70.76	1.43 (0.99)	0.75 (0.83)	0.44 0.78	0.60 (0.81)	48.50
Lufenuron 5 EC	1 ml/l	3.00 (1.72)	1.92 (1.36)	1.80 (1.32)	1.86 (1.34)	52.06	0.92 (0.92)	0.88 (0.91)	0.38 0.57	0.63 (0.74)	16.00
Flubendiamide 39.35 EC	0.2 ml/l	3.35 (2.10)	1.02 (0.97)	0.85 (0.90)	0.93 (0.93)	78.54	3.08 (1.75)	0.98 (0.93)	0.78 0.85	0.88 (0.89)	65.00
Clorantraniliprole 18.5 SC	0.3 ml/l	3.45 (1.83)	0.82 (0.88)	0.67 (0.80)	0.74 (0.84)	83.42	3.33 (1.80)	0.58 (0.69)	0.23 0.49	0.40 (0.59)	85.30
Lamdacyhalothrin 5 EC	1 ml/l	3.90 (1.96)	2.42 (1.53)	1.80 (1.32)	2.11 (1.42)	58.17	1.50 (1.01)	0.54 (0.70)	0.96 0.97	0.75 (0.83)	38.70
Profenophos 50 EC	2 ml/l	4.55 (2.12)	1.32 (1.10)	1.57 (1.23)	1.44 (1.17)	75.53	2.13 (1.30)	0.43 (0.64)	1.17 1.01	0.80 (0.83)	53.90
Indoxacarb 14.5 SC	1 ml/l	3.75 (1.91)	2.52 (1.55)	1.67 (1.27)	2.09 (1.41)	56.91	1.78 (1.09)	1.09 (0.92)	0.26 0.47	0.68 (0.69)	26.10
Thiodicarb 75WP	1 g/l	5.40 (2.30)	2.00 (1.37)	1.37 (1.14)	1.68 (1.25)	75.95	3.73 (1.55)	2.42 (1.34)	0.26 0.48	1.34 (0.91)	55.90
Untreated control	-	4.40 (2.09)	6.57 (2.56)	4.82 (2.18)	5.69 (2.37)	-	1.13 (0.89)	1.37 (1.03)	0.48 0.75	0.92 (0.89)	-
CD(p=5%)	-	0.18	0.15	0.08	0.11	-	0.29	0.20	0.17	0.18	-
SED±	-	0.08	0.22	0.03	0.13	-	0.13	0.09	0.08	0.09	-
CV(%)	-	5.19	6.22	3.80	5.01	-	13.99	13.30	13.96	13.63	-

*Mean of three replications; PTC - Pre treatment count; PRC -Percentage Reduction Over Control; Figures in parentheses are square root n+1 transformed values

Table 3 Bioefficacy of newer insecticides against hairy caterpillars

Treatments	Dose	2014 - 15					2015 - 16				
		Mean population of hairy caterpillars (Number per plant)*					Mean population of hairy caterpillars (Number per plant)*				
		PTC	1st spray	2nd spray	Pooled	PRC	PTC	1st spray	2nd spray	Pooled	PRC
Emamectin benzoate 5 WG	0.5 g/l	3.40 (1.83)	1.42 (1.16)	1.25 (1.08)	1.33 (1.12)	61.25	1.83 (0.89)	0.93 (0.94)	0.71 (0.84)	0.82 (0.89)	81.20
Lufenuron 5 EC	0.1 ml/l	3.80 (1.94)	3.02 (1.40)	1.90 (1.36)	1.96 (1.38)	48.90	3.17 (1.09)	1.45 (1.19)	1.23 (0.98)	1.34 (1.09)	78.60
Flubendiamide 39.35 EC	0.2 ml/l	4.25 (2.05)	1.25 (1.06)	1.17 (1.03)	1.21 (1.04)	71.80	2.50 (0.75)	0.75 (0.82)	0.73 (0.68)	0.74 (0.75)	84.90
Clorantraniliprole 18.5 SC	0.3 ml/l	3.90 (1.96)	1.02 (0.96)	0.90 (0.91)	0.96 (0.93)	75.61	2.63 (0.90)	1.03 (0.98)	0.98 (0.82)	1.00 (0.90)	86.90
Lamdacyhalothrin 5 EC	1 ml/l	3.35 (1.81)	1.67 (1.33)	1.17 (1.06)	1.42 (1.20)	58.00	2.57 (0.99)	1.35 (1.14)	0.93 (0.84)	1.14 (0.99)	80.30
Profenophos 50 EC	2 ml/l	4.40 (2.09)	1.72 (1.29)	1.67 (1.26)	1.69 (1.27)	62.00	2.55 (0.81)	0.83 (0.87)	0.91 (0.75)	0.87 (0.81)	83.10
Indoxacarb 14.5 SC	1 ml/l	2.80 (1.66)	1.37 (1.14)	1.42 (1.17)	1.39 (1.16)	50.82	2.67 (0.91)	1.10 (1.02)	1.13 (0.80)	1.12 (0.91)	80.10
Thiodicarb 75WP	1 g/l	3.25 (1.79)	1.15 (1.03)	0.97 (0.98)	1.06 (1.01)	67.69	2.93 (1.09)	1.60 (1.24)	1.22 (0.93)	1.41 (1.09)	81.40
Untreated control	-	3.25 (1.79)	3.15 (1.77)	3.42 (1.84)	3.28 (1.80)	-	2.42 (2.30)	7.80 (2.77)	3.08 (1.82)	5.44 (2.30)	-
CD(p=5%)	-	0.24	0.16	0.16	0.16	-	0.50	0.30	0.43	0.36	-
SED±	-	0.11	0.07	0.07	0.078	-	0.23	0.14	0.20	0.17	-
CV(%)	-	7.52	7.90	8.07	7.98	-	13.92	14.44	16.76	15.60	-

*Mean of three replications ; PTC - Pre treatment count ; PRC -Percentage Reduction Over Control; Figures in parentheses are square root n+1 transformed values

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

Treatments	Dose	Yield (kg/ha)	Increase in yield over control (kg)	Increase in yield over control (%)	Cost of increased (`) (A)	Plant protection cost * (`) (B)	Net profit (`) A-B	ICBR
Emamectin benzoate 5WG	0.5 g/l	1252	523	71.9	20940	6200	15440	1:2.49
Lufenuron 5 EC	0.1 ml/l	1066	337	46.3	13500	5100	8220	1:1.61
Flubendiamide 39.35 EC	0.2 ml/l	1410	681	93.5	27260	5505	21015	1:3.81
Clorantraniliprole 18.5SC	0.3 ml/l	1542	814	111.9	32560	6565	26155	1:3.98
Lamdacyhalothrin 5EC	1 ml/l	950	222	30.5	8880	2720	6320	1:2.32
Profenophos 50EC	2ml/l	1374	646	88.7	25840	3430	21450	1:6.25
Indoxacarb 14.5SC	1 ml/l	974	245	33.7	9820	6000	4360	1:0.72
Thiodicarb 75WP	1 g/l	1045	316	43.4	12660	5125	7595	1:1.48
Untreated control	-	728	-	-	-	-	-	-
CD(p=5%)	-	266	-	-	-	-	-	-
SED±	-	123	-	-	-	-	-	-
CV(%)	-	13	-	-	-	-	-	-

Market price of castor: `40/kg; Standard spray volume: 500lit/ha; * Labour charges included ; ICBR = Net profit/Plant protection cost

The results of the second year experiment conducted during *kharif* season of 2015-16 revealed that, chlorantraniliprole 18.5SC recorded lowest population hairy caterpillar from 2.63 to1.00 larvae/plant followed by flubendiamide 39.35 EC @ 0.2 ml/l which was found to reduce hairy caterpillar from 2.50 to 0.74 larvae/plant as compared to standard check thiodicarb 75WP @ 1 g/l, which reduction in population of hairy caterpillar was from 2.93 to 1.41 larvae/plant. Per cent reduction over control indicated that chlorantraniliprole 18.5 SC reduces hairy caterpillar larval population up to 86.90 per cent, closely followed by flubendiamide 39.35 EC which registered 84.90 per cent, whereas profenophos 50 EC @ 2ml/l, thiodicarb 75 WP @ 1 g/l, emamectin benzoate 5 WG @ 0.5 g/l, lamdacyhalothrin 5EC @ 1ml/l, indoxacarb 14.5 SC @1ml/l and lufenuron 5EC @ 1 ml/l recorded 83.1, 81.4, 81.2, 80.3, 80.1 and 78.6 per cent reduction of larvae of hairy caterpillar over control.

Effect on yield and economics: Data on yield over years revealed that there was significant impact of insecticidal treatments on seed yield of castor (Table 4). Pooled data revealed that highest seed yield was recorded in chlorantraniliprole 18.5 SC @ 0.2ml/l treated plots (1543 kg/ha) with 111.9 per cent increase over control, followed by flubendiamide (1410 kg/ha) and profenophos (1375 kg/ha) with 93.5 and 88.7 per cent increase over control respectively as against minimum yield of 728.5 kg/ha in the untreated control. The cost effectiveness of profenophos 50EC @ 2 ml/l was high with very favourable incremental cost-benefit ratio of 1: 6.25 followed by chlorantraniliprole 18.5SC @ 0.2ml/l and flubendiamide 39.35EC @ 0.2 ml/l with ICBR of 1:3.98 and 1:3.81, respectively. Suganthy (2012) and Anonymous (2006) reported that profenophos 0.05% was effective in controlling capsule borer and castor defoliators.

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Farmers' income from oilseeds production in India: Trends and prospects

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ABSTRACT

Oilseeds are of pivotal significance in the agricultural economy of India supporting income of millions of farmers practicing mainly rainfed cultivation. Profitability of oilseeds is an important concern for enhancing domestic production in order to reduce import dependence for edible oils. The present study attempts to analyze the trends in real income from oilseed crops in selected states and discuss some of the underlying factors using secondary data from the cost of cultivation surveys for selected states during the period 2000-01 to 2014-15. Farm income from oilseeds has increased in the states with higher proportionate rise in price realized and or yield of the crop as compared to the change in cost of inputs. Profitability of oilseeds has declined in the states with higher proportionate increase in cost of inputs as compared to the yield or decline in the real price received. The factors which affected change in income from oilseeds included change in yield realized, farmers' price and change in cost of inputs. There exists a large yield gap for oilseeds across states on account of poor adoption of production technologies and lower application of productive and protective inputs. The yield gap can be narrowed down through ensuring quality input supply at affordable prices, increase adoption of production technology and price support with effective procurement. Efforts are to be enhanced to improve water use efficiency through protective irrigation, effectiveness of extension services to enhance productivity and profitability, and in turn farmers' income.

Keywords: Cost and profitability, Farmers' income, Oilseeds, Prospects, Trends

The oilseed sector has been an area of concern for policy makers and research managers, as the country is import dependent to fulfil its growing edible oil requirement. This sector occupies an important position in the agricultural economy of the country as oilseeds accounts for about 13 per cent of gross cropped area and contributes to about 10 per cent of total value of output from agricultural crops and 6.0 per cent of value of output from agriculture and allied sector (Sharma, 2016c; Teja *et al.,* 2017). Rising income levels and changing food habits of the growing population in India is leading to faster increase in the demand of edible oils as compared to the production growth, as the demand for edible oils is highly income and price-elastic (Srinivasan, 2005). The demand for edible oils skyrocketed in the recent years and the import of edible oils has reached to nearly 70% of the total requirement in the country. The mismatch between demand and supply is continually widening as the production growth is not matching up with the growth (6%) in demand (Jha *et al.,* 2012; IIOR, 2015). A portion of this ever growing demand can be met by enhanced domestic production provided the increase in the level of productivity is achieved by bridging the yield gap.

Productivity of major edible oilseed crops in India is one third of global average. Majority of oilseeds are cultivated in rainfed ecosystem on marginalised land (Jha *et al.,* 2012) predominantly with low and erratic rainfall and under input starved conditions coupled with poor crop management (IIOR, 2015) resulting in low yield realisation and thus, income from oilseeds. The area under oilseeds in general is not increasing due to their low and uncertain profitability at the prevailing yield levels and marketing situations. Large scale inter regional and inter district productivity differences for oilseeds do exist (Sharma, 2014) due to various technological, weather related and other factors. There exists a realisable yield gap of about 20-50 per cent across oilseed crops (Jha *et al.,* 2012; Sharma, 2016c), bridging this will not only enhance domestic availability of edible oils through higher production of oilseeds in the country, but the profitability, provided the remunerative prices are given to the farmers which would enhance the income of oilseed growers.

Profitability of oilseeds is an important concern for reducing import dependence through increasing domestic production of oilseeds. There are many challenges for reducing import dependency to save foreign exchange or attaining self-sufficiency and to make oilseeds cultivation profitable to farmers. Enhancing the yield and quality through research and technology dissemination under favourable policy environment could help achieve the goals. Earlier studies have estimated the farmers' income from different sectors such as agriculture and allied sectors and from non-farm sector and changes in the level of income over time (Bhatia, 2006; Chand *et al.,* 2015; Kannan, 2015; Chand, 2017). It is also important to understand the changes/trends in income from or profitability of different crops or crop groups and their underlying factors in order to prepare plan and strategies to enhance profitability and income from different crops. Under this backdrop, the

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present study makes an attempt to analyze the trends in real income from oilseed crops in selected states and discuss some of the underlying factors. The study also reviews the constraints in oilseeds production and marketing in order to deepen the understanding on this sector and help policy makers and research managers to make strategies to enhance yield and profitability, and in turn, farmers' income.

MATERIALS AND METHODS

The study was based on secondary data compiled from the Cost of Cultivation of Principal Crops in India for the period 2000-01 to 2014-15. The data from cost of cultivation surveys are used to analyse the trends in income from oilseeds at state level. The cost of cultivation survey is conducted annually by the Ministry of Agriculture and Farmers' Welfare to collect farm-level data on inputs, output and prices. To compute per hectare cost in and income from oilseeds, both inputs and output data were deflated by relevant price deflators at 2004-05 prices. Material inputs and other items were deflated by the respective wholesale price indices, and agricultural labour wages were deflated by the consumer price index for agricultural labourers. Various crop outputs were also deflated by using the respective wholesale price indices. The states were selected on the basis of continuous data availability for the respective oilseed crops from 2000-01 to 2014-15.

RESULTS AND DISCUSSION

Changes in cost in and income from oilseeds in major states: The cost of cultivation surveys provide details of input costs and the value of output of oilseed crops grown across major states. The states selected for the present study, based on data availability for the selected period without gap, included Andhra Pradesh, Gujarat, Karnataka, Maharashtra and Tamil Nadu for Groundnut; Assam, Gujarat, Haryana, Rajasthan, Uttar Pradesh and West Bengal for Rapeseed and Mustard; Maharashtra for Safflower; Odisha for Niger seed; Gujarat, Odisha, Rajasthan and Tamil Nadu for Sesamum; Madhya Pradesh, Maharashtra and Rajasthan for Soybean; and Andhra Pradesh and Karnataka for Sunflower.

On the basis of cost of cultivation survey data, Commission for Agricultural Costs and Prices (CACP) uses different cost concepts to work out the alternative incomes from crop production. The paid out cost, Cost A_2, is widely used for analytical purposes to track the changes in the welfare of farmers, which includes all actual expenses in cash and kind incurred by cultivators, and rent paid for leased-in land. Another cost concept, Cost A_2 plus family labour represent real farming costs and is relevant in assessing the expenses incurred in the cultivation of a crop (Kannan, 2015; Sen and Bhatia, 2004).

In order to understand the changes in income from cultivation of oilseeds, net income, farm business income and net income over cost A_2 plus family labour were estimated as the difference between gross value of output (GVO) and total cost of cultivation, paid out cost and paid out cost plus family labour, respectively. The average real cost in and income from groundnut cultivation for the periods 2000-01 to 2004-05 and 2010-11 to 2014-15 are presented on Table 1. The states for which the real cost in and income from groundnut cultivation were estimated included Andhra Pradesh, Gujarat, Karnataka, Maharashtra and Tamil Nadu. These states together accounted for 82 per cent of total area and 80 per cent production of groundnut in the country. It is evident from the table that the costs in and returns from groundnut cultivation were lower in Karnataka as compared to other states, as the use of material inputs and yield of the crop was lower in the state.

The average real net income per hectare from groundnut cultivation was negative in Andhra Pradesh, Karnataka, Maharashtra and Tamil Nadu, although per hectare loss has shown declining trend in all these states except in Karnataka. The net income from groundnut cultivation has declined over the period in Gujarat, while it improved and turned positive in Maharashtra. Since the increase in GVO was higher than the cost in Andhra Pradesh, Maharashtra and Tamil Nadu states, the improvement in farm income was higher in these states (Table 1). The average farm business income and net income over Cost A_2 plus family labour from groundnut cultivation was positive and has marginally improved over the period in all the states except in Gujarat. The improvement in average farm business income and net income over Cost A_2 plus family labour was mainly due to increase in productivity of the crop on account of higher use of productive inputs mainly nutrients from fertilizers and price realisation by the farmers over the period. Narayanmoorthy (2013) and Narayanmoorthy *et al.* (2014) also reported declining profitability of groundnut crop in Tamil Nadu and Gujarat states.

As an alternative measure, the changes in farm business income from groundnut cultivation are also presented in the form of the ratio of the GVO to Cost A_2 and to total cost (Fig. 1A to 1E). As expected, the income to total cost ratio was lower than the income to cost A_2 ratio. The point to worry is that the ratio of income to total cost was lower than one in all the states except in Gujarat, although it improved marginally in the recent period. Income to paid out cost ratio also marginally improved in all the states with some exceptions. This was mainly due to more than proportionate rise in the income on account of higher yield and higher prices realised by the farmers, as compared to changes in cost of material inputs and other costs.

For safflower, the cost of cultivation data was compiled for Maharashtra state that contributed more than 50 per cent area and production in the country. More than proportionate

increase in the income from sunflower cultivation as compared to input costs led to higher improvements in the farm business income as well as other income measures in Maharashtra (Table 2). Although there was a steep increase in the cost of material inputs and other input costs, more than proportionate rise in yield over the period resulted in higher increase in income from safflower cultivation in Maharashtra.

The trend in the ratio of gross value of output from safflower cultivation per hectare in Maharashtra to paid out cost and to total cost is depicted in Fig. 1.F. These alternative measures of farm income increased from 2003-04 till 2011-12 and then started declining mainly due to decline in price realisation and yield in the recent period due to drought. Ratio of gross value of output to total cost was >1 during this period.

In case of Rapeseed and Mustard, the states selected for analysis were Assam, Gujarat, Haryana, Rajasthan, Uttar Pradesh, and West Bengal, which together accounted for about 79 per cent of area and 82 per cent of production in the country. The proportionate rise in gross value of output from rapeseed and mustard was higher than the increase in costs in Gujarat, Haryana and Uttar Pradesh states leading to higher change in net income per hectare. The net income per hectare from rapeseed and mustard was negative in Assam due to low productivity and higher input costs, while it declined in Rajasthan (Table 3) on account of decrease in productivity and price realisation by farmers.

Although price realised by farmers have declined in all the states, more than proportionate rise in the yield realised coupled with low increase in input cost helped increase per hectare net income and farm business income in the states of Gujarat, Haryana, Uttar Pradesh and West Bengal. Costs in and returns from R&M cultivation were lowest in Assam and highest in Haryana due to larger differences in yield and input applications.

The trend in ratio of gross value of output to total cost of cultivation of rapeseed and mustard was >1 in all the states except in Assam where it was <1 and declining (Fig. 2.A to 2.F). The GVO to total cost ratio is improving in Gujarat, and West Bengal, while started declining recently in the states of Haryana, Rajasthan and Madhya Pradesh due to lower price realization in the recent years. The ratio of GVO to paid out cost fluctuated over the years, increased during the period from 2007-08 and 2010-11 to 2011-12. As expected, the ratio of GVO to paid out cost was above the ratio of GVO to total cost.

For sesamum, the states selected were Gujarat, Odisha, Rajasthan and Tamil Nadu based on the continuity in the data availability, although Madhya Pradesh, Uttar Pradesh and West Bengal also were among major producers of sesamum in the country. Per hectare cost in and returns from sesamum cultivation were higher in Gujarat and Tamil Nadu states as compared to Odisha and Rajasthan on account of higher use of productive and protective inputs such as fertilizers and manure, plant protection chemicals and irrigation. The average gross value of output per hectare from sesamum cultivation has decreased in all the selected states (Table 4) over the period due to decline in price realized except in Gujarat where yield increase was higher than the price decline.

With the more than proportionate increase in inputs cost as well as total cost in cultivation of sesamum as compared to gross value of output on account of decrease in prices realized, average net income as well as farm business income has declined in all the states (Table 4). The average net income per hectare from cultivation of sesamum turned negative in Gujarat and Rajasthan also during the period 2010-11 to 2014-15. Farm business income as well as net income over cost A_2 plus family labour also decreased in all the selected states due to decline in price realized by farmers and higher increase in inputs cost.

The ratio of gross value of output to total cost was <1 in Odisha and Tamil Nadu states for whole period under analysis (Fig. 3.A to 3.D) and started going <1 in Gujarat and Rajasthan due to decrease in yield in the recent period due to drought. The trend in ratio of gross value of output to paid-out cost is also declining due to higher proportionate rise in input cost as compared to gross revenue from crop. The gap between the two ratios is narrowing in all the states on account of faster growth in material input costs.

The states selected for soybean were Madhya Pradesh, Maharashtra and Rajasthan, which together accounted for about 94 per cent of area and production of the crop in the country. The paid out cost as well as total cost per hectare in cultivation of soybean was higher in Maharashtra as compared to Madhya Pradesh and Rajasthan (Table 5). Farmers in Maharashtra use higher amount of fertilizers (almost double of Madhya Pradesh and five times of Rajasthan) and manures, and apply irrigation to the crop in case of water stress and, thus, reap higher productivity and higher income. Sharma (2016a and 2016b) also reported the increasing net returns from soybean cultivation.

The rise in per hectare gross value of output from soybean cultivation was proportionately higher than the cost in Madhya Pradesh and Rajasthan, while increase in cost was higher than GVO in Maharashtra on account of larger change in inputs costs and decline in productivity growth. The net income as well as farm business income has increased in Madhya Pradesh and Rajasthan, while decreased in Maharashtra (Table 5).

The alternative measures of farmers income, the ratio of GVO to total cost and to paid out cost of soybean cultivation is declining in Maharashtra and gone below one on account of decline in productivity while the ratios have started declining recently in Madhya Pradesh and Rajasthan due to

decrease in yield on account of weather woes and fall in prices received. The gap between the two ratios is also narrowing indicating that the increase in cost of material inputs was much higher than the imputed value of rent of owned land and interest on fixed capital, as is evident from the steep fall in the ratio of GVO to Cost A_2 (Fig. 4A to 4C). Use of seed per hectare was higher than recommended in Madhya Pradesh and Rajasthan, while use of plant nutrients was much lower resulting in lower yields.

For niger seed, Odisha state was selected for analysis on the basis of cost of cultivation data availability on continued basis for selected period, although the area under the crop is highest in Madhya Pradesh. The productivity of niger seed is very low and the cost of cultivation, which comprises mainly human and animal labour inputs, is higher, and hence the net income per hectare was negative. With the higher proportionate rise in cost as compared to yield and GVO, the change in negative net income has increased (Table 6). The farm business income has increased from niger seed cultivation in Odisha over the period. The crop is grown without application of productive (fertilisers and manures, irrigation) and protective inputs (plant protection inputs) in Odisha. The ratio of gross value of output to total cost was <1 due to poor productivity realized and increase in cost. The ratio of gross value of output to paid out cost was fluctuating and declined till 2007-08 started improving again dropped in the recent year (Fig. 4D).

In case of sunflower, Andhra Pradesh and Karnataka, which together contributed to about 74 per cent of area and 65 per cent of the production of crop in the country, were selected. The per hectare cost in and returns from sunflower cultivation were higher in Andhra Pradesh as compared to Karnataka as the use of productive and protective inputs was higher in the state. Due to comparatively higher inputs and other cost, the net returns from the crop were negative in Andhra Pradesh, which further increased marginally during the recent period on the productivity decline. Whereas, in Karnataka average per hectare net income from sunflower cultivation turned positive in the recent period and the change in farm business income and net income over cost A_2 plus family labour was higher (Table 7). The productivity of the crop has improved in the state leading to higher proportionate change in income.

The ratio of gross value of output to total cost was <1 in both the states with year-to-year fluctuations and started declining in Andhra Pradesh after 2011-12 due to steep decline in average yield, while improving in Karnataka on account of higher yield and lower change in input costs. Ratio of gross value of output to paid-out cost fluctuated widely in both the states (Figure 5A and 5B).

Table 1 Average real crop cost, output value and income from groundnut

Items	Total Cost (₹/ha)	Cost A_2 (₹/ha)	Cost A_2+FL	GVO (₹/ha)	Net Income (₹/ha)	FBI (₹/ha)	NI/Cost A_2+FL
Andhra Pradesh							
2000-01 to 2004-05	17731.36	10179.22	11926.64	15732.96	-1998.4	5553.74	3806.32
2010-11 to 2014-15	33182.69	19053.95	22355.64	32789.67	-393.02	13735.72	10434.03
Change (%)	87.1	87.2	87.4	108.4	-80.3	147.3	174.1
Gujarat							
2000-01 to 2004-05	18423.63	11069.88	13606.79	24059.25	5635.62	12989.37	10452.46
2010-11 to 2014-15	26562.59	17222.19	20682.17	29911.57	3348.99	12689.38	9229.40
Change (%)	44.2	55.6	52.0	24.3	-40.6	-2.3	-11.7
Karnataka							
2000-01 to 2004-05	12676.17	8685.81	9609.56	11428.90	-1247.27	2743.09	1819.34
2010-11 to 2014-15	19442.54	12750.65	14977.67	17308.50	-2134.03	4557.85	2330.83
Change (%)	53.4	46.8	55.9	51.4	71.1	66.2	28.1
Maharashtra							
2000-01 to 2004-05	25244.71	16526.09	20117.64	21223.15	-4021.56	4697.07	1105.51
2010-11 to 2014-15	28376.54	17231.75	21951.19	29293.98	917.43	12062.22	7342.78
Change (%)	12.4	4.3	9.1	38.0	-122.8	156.8	564.2
Tamil Nadu							
2000-01 to 2004-05	28609.57	17139.46	20612.31	24124.18	-4485.39	6984.72	3511.87
2010-11 to 2014-15	30044.16	18365.8	24049.58	28022.31	-2021.85	9656.51	3972.73
Change (%)	5.0	7.2	16.7	16.2	-54.9	38.3	13.1

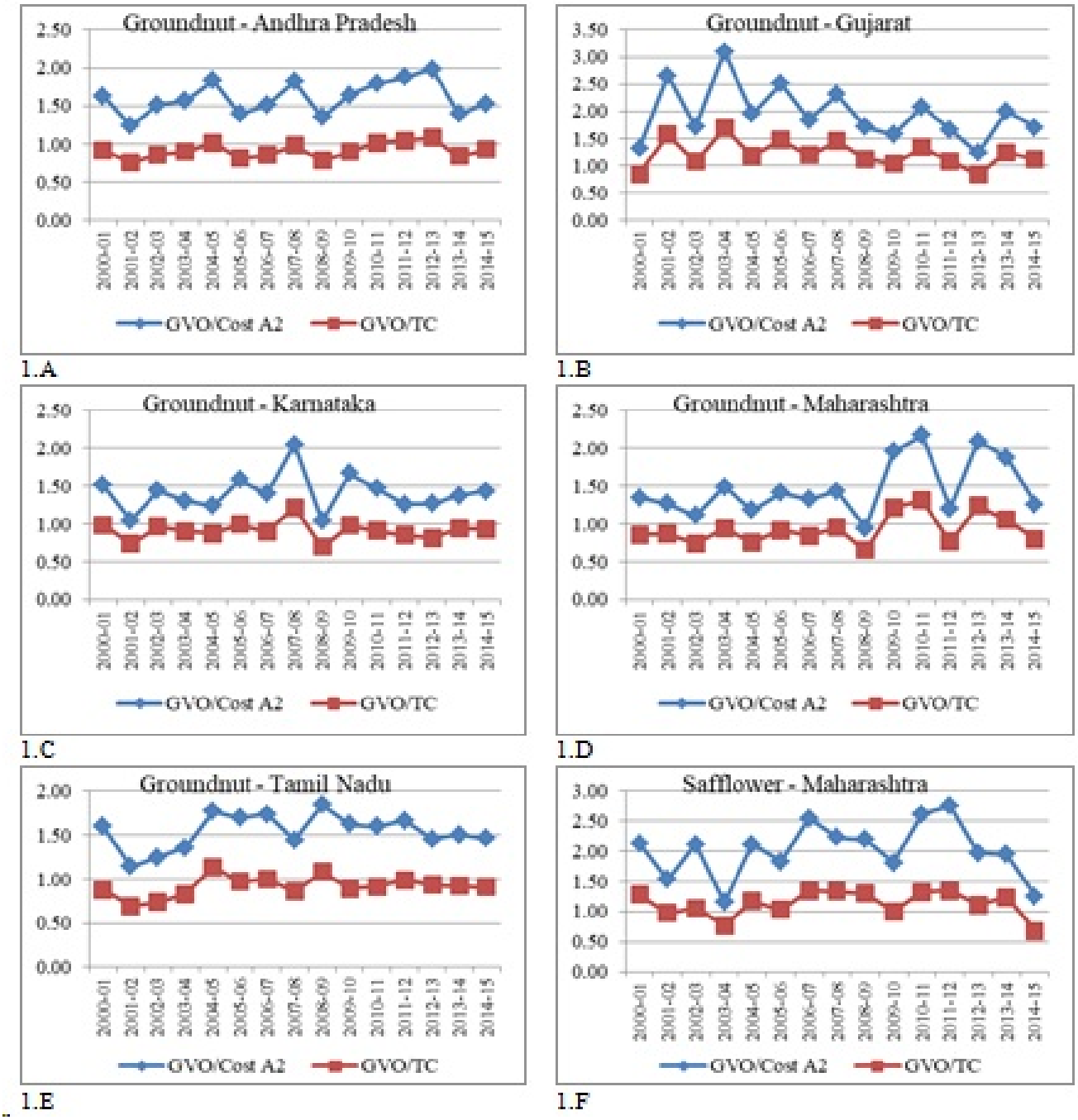

Fig. 1A-1F. Ratio of GVO to Cost A_2 and to total cost in groundnut and safflower

Income from oilseeds - some explanation of factors influencing: The level of income obtained from any crop is determined by several factors. The major factors include the level of productivity of crop, changes in input cost and price realized by farmers. Other supporting factors are water and soil management practices, market infrastructure and government policies and procurement support. Some of the factors have been discussed earlier in the paper; input use, price and procurement related factors are elaborated to improve the understanding.

Input use and productivity: Scholars have argued that oilseeds are mainly grown under rainfed ecosystem on marginalized lands (Jha *et al.,* 2012) with minimum use of productive and protective inputs (Sharma, 2014; IIOR, 2015) and hence, the average productivity of oilseeds in India is

low. Although, seed rate used by farmers was found to be in excess (10-30 per cent) of the rate recommended for some of the oilseeds, particularly for kharif oilseeds (Annexure-1). The higher seed rate results in higher plant population, which ultimately lowers the yield realization. Use of recommended seed rate by farmers not only can save 10-20 per cent in the seed cost to the farmers but also increase the productivity of the crop due to optimum plant stand without plant to plant competition for nutrients, space and other inputs. Sharma (2016b) also reported that soybean farmers use higher than recommended seed rate and lower dose of fertilizers and manures, impacting the yield realisation by the farmers.

Since oilseeds are mainly grown rainfed on marginal lands with minimal use of productive and protective inputs, the use of plant nutrients to the oilseed crops in almost all the states was lower than the recommended dose (Annexure-1). Applying recommended dose of plant nutrients to the crop can enhance the yield and thus increase gross value of output from oilseeds. Providing protective irrigation is critical to the yield realization from oilseeds particularly under moisture stress conditions. Since, most of the oilseeds are grown rainfed, by applying irrigation at critical stages under moisture stress condition there is scope for improving productivity and profitability of oilseeds, as the marginal rate of returns (varies between 1.45 to 3.77) from water use was considerably high across oilseed crops (Mruthyunjaya *et al.,* 2005).

Table 2 Average real crop cost, output value and income from safflower

Items	TC (₹/ha)	Cost A_2 (₹/ha)	Cost A_2+FL	GVO (₹/ha)	Net Income (₹/ha)	FBI (₹/ha)	NI/Cost A_2+FL
Maharashtra							
2000-01 to 2004-05	6520.08	3905.90	4654.71	6794.06	273.98	2888.17	2139.36
2010-11 to 2014-15	13393.25	7360.78	9698.71	15304.01	1910.76	7943.23	5605.30
Change (%)	105.4	88.5	108.4	125.3	597.4	175.0	162.0

Table 3 Average real crop cost, output value and income from Rapeseed and Mustard

Items	TC (₹/ha)	Cost A_2 (₹/ha)	Cost A_2+FL	GVO (₹/ha)	Net Income (₹/ha)	FBI (₹/ha)	NI/Cost A_2+FL
Assam							
2000-01 to 2004-05	10452.13	4307.54	7953.93	9157.07	-1295.06	4849.53	1203.14
2010-11 to 2014-15	14824.72	6770.09	11416.80	11662.98	-3161.74	4892.89	246.18
Change (%)	41.8	57.2	43.5	27.4	144.1	0.9	-79.5
Gujarat							
2000-01 to 2004-05	17923.95	10623.47	12514.10	25428.9	7504.95	14805.42	12914.8
2010-11 to 2014-15	18257.49	9069.07	11560.85	30725.87	12468.38	21656.81	19165.02
Change (%)	1.9	-14.6	-7.6	20.8	66.1	46.3	48.4
Haryana							
2000-01 to 2004-05	20097.8	7842.364	11063.02	26135.96	6038.16	18293.60	15072.94
2010-11 to 2014-15	23048.09	8193.297	11064.83	33950.13	10902.04	25756.83	22885.30
Change (%)	14.7	4.5	0.0	29.9	80.6	40.8	51.8
Rajasthan							
2000-01 to 2004-05	15611.81	6587.30	9145.31	26665.59	11053.78	20078.29	17520.29
2010-11 to 2014-15	15873.73	5863.19	9498.79	25809.85	9936.11	19946.66	16311.06
Change (%)	1.7	-11.0	3.9	-3.2	-10.1	-0.7	-6.9
Uttar Pradesh							
2000-01 to 2004-05	16835.93	7173.20	9356.30	20193.33	3357.40	13020.13	10837.03
2010-11 to 2014-15	19134.19	7158.27	10449.69	23884.79	4750.60	16726.52	13435.10
Change (%)	13.7	-0.2	11.7	18.3	41.5	28.5	24.0
West Bengal							
2000-01 to 2004-05	17301.93	8593.89	11671.8	19558.39	2256.46	10964.50	7886.59
2010-11 to 2014-15	20368.64	10537.46	14095.21	23064.20	2695.56	12526.74	8968.99
Change (%)	17.7	22.6	20.8	17.9	19.5	14.2	13.7

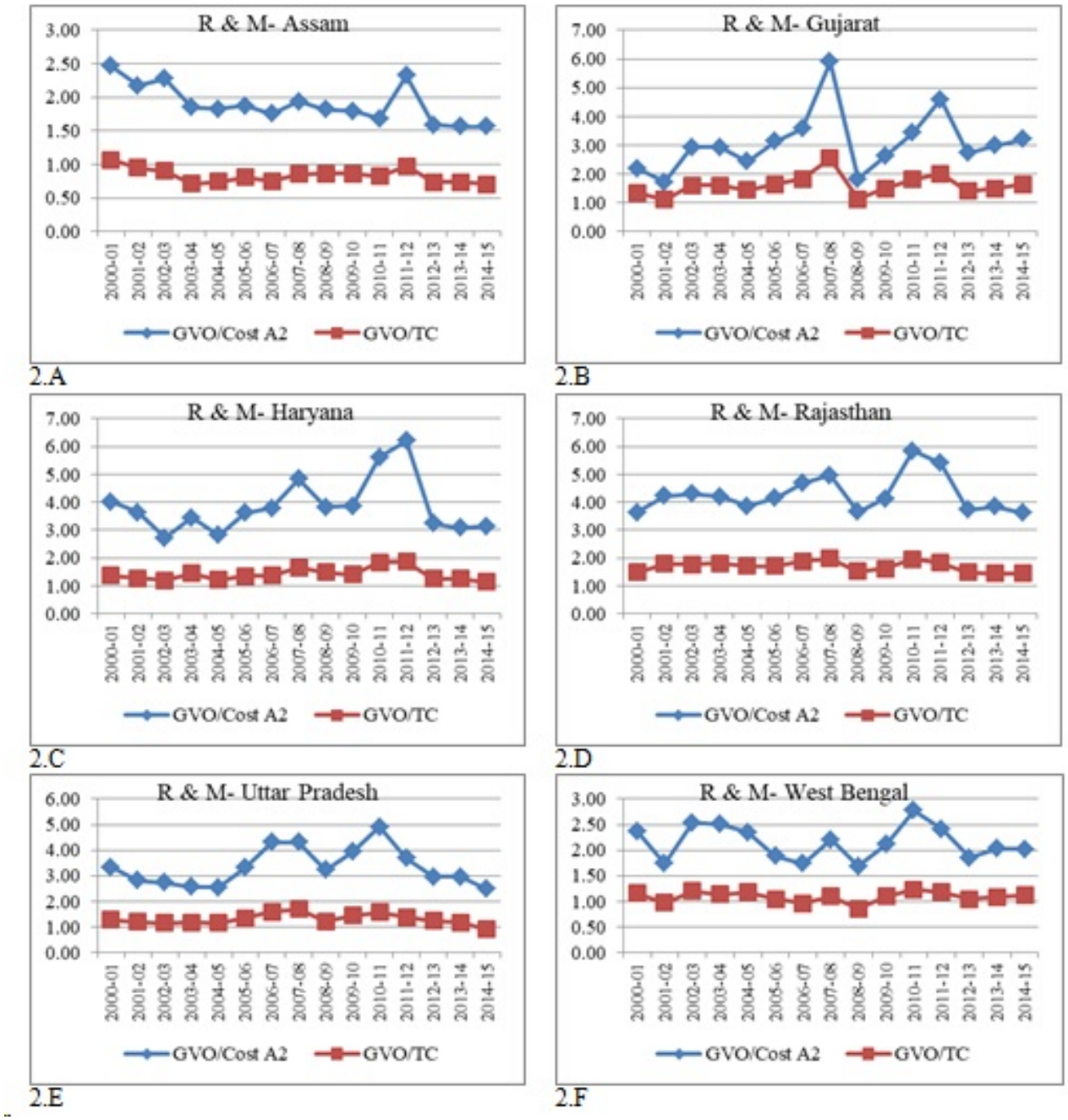

Fig. 2A-2F. Ratio of GVO to Cost A_2 and to total cost in Rapeseed and Mustard

Price policy and procurement: Minimum support prices (MSP) announced by the government for about 25 commodities including oilseeds every year which acts as a floor price and influences the price formation in the markets for agricultural commodities. Scholars reported that the MSP announced by the government for agricultural commodities has increased substantially over the period (Parikh *et al.* 2003). The fact is that the MSP has increased over time in nominal terms, but in real value (deflated by the respective commodity-specific wholesale price index) it has actually declined for some of the oilseeds (Fig. 6). Kannan (2015) also reported that the real MSP of agricultural commodities have declined over time. Although, real minimum support prices started improving after 2008-09 in case of rapeseed and mustard, safflower and sunflower.

Table 4 Average real crop cost, output value and income from sesamum

Items	TC (₹/ha)	Cost A_2 (₹/ha)	Cost A_2+FL	GVO (₹/ha)	Net Income (₹/ha)	FBI (₹/ha)	NI/Cost A_2+FL
Gujarat							
2000-01 to 2004-05	9111.11	5566.83	6872.57	11344.99	2233.881	5778.16	4472.42
2010-11 to 2014-15	12755.79	7685.24	10409.40	12234.26	-521.53	4549.02	1824.86
Change (%)	40.0	38.1	51.5	7.8	-123.3	-21.3	-59.2
Odisha							
2000-01 to 2004-05	6803.35	3966.94	4543.81	6585.02	-218.33	2618.09	2041.22
2010-11 to 2014-15	6976.12	3029.51	5357.12	5145.89	-1830.23	2116.38	-211.23
Change (%)	2.5	-23.6	17.9	-21.9	738.3	-19.2	-110.3
Rajasthan							
2000-01 to 2004-05	6665.22	1958.91	4438.79	7759.31	1094.10	5800.41	3320.52
2010-11 to 2014-15	6555.60	2235.25	4742.17	6316.02	-239.58	4080.77	1573.85
Change (%)	-1.6	14.1	6.8	-18.6	-121.9	-29.6	-52.6
Tamil Nadu							
2000-01 to 2004-05	14665.64	6723.14	8458.19	13219.70	-1445.94	6496.56	4761.52
2010-11 to 2013-14	12926.88	6881.13	9896.45	11462.69	-1464.19	4581.56	1566.25
Change (%)	-11.9	2.3	17.0	-13.3	1.3	-29.5	-67.1

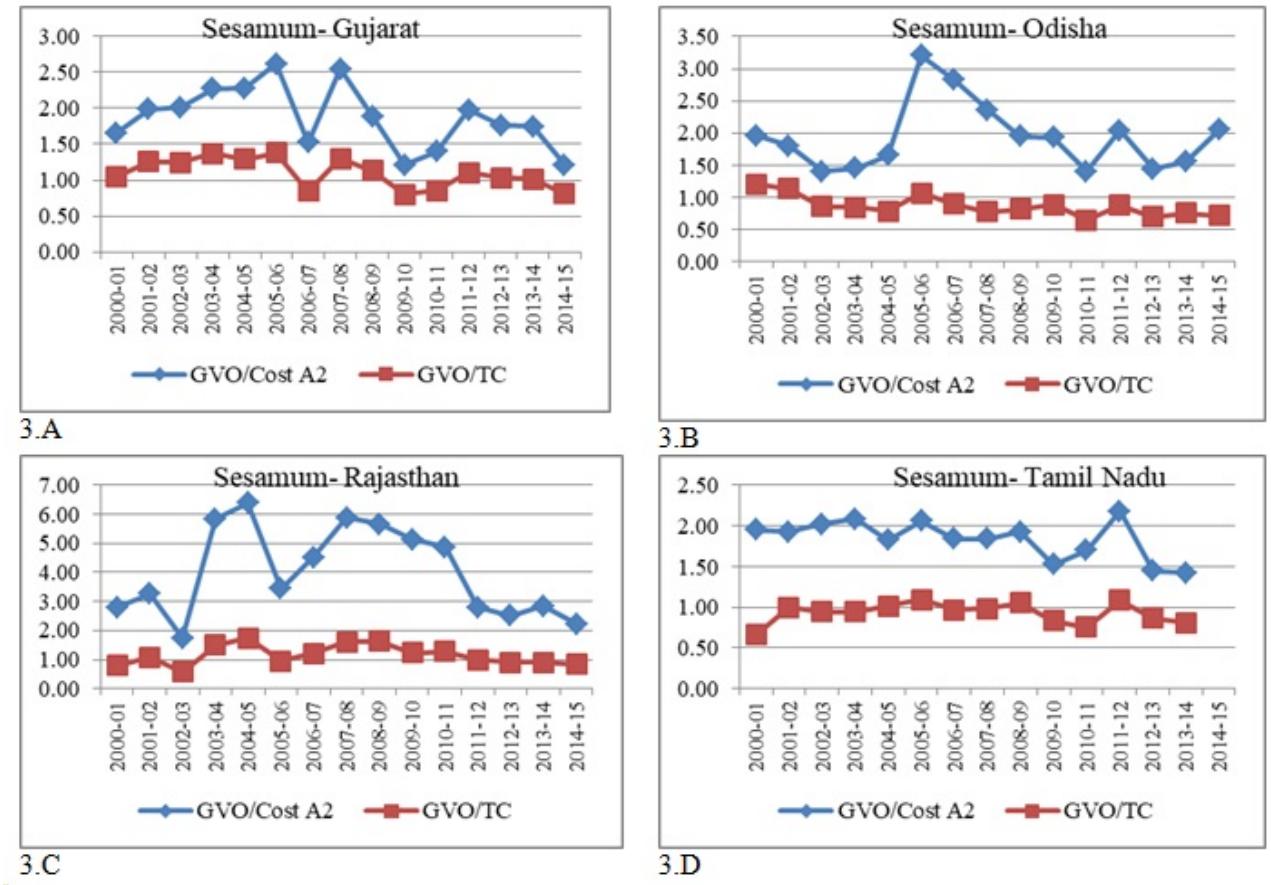

Fig. 3A-3D. Ratio of GVO to Cost A_2 and to total cost in sesamum

Table 5 Average real crop cost, output value and income from soybean

Items	TC (₹/ha)	Cost A_2 (₹/ha)	Cost A_2+FL	GVO (₹/ha)	Net Income (₹/ha)	FBI (₹/ha)	NI/Cost A_2+FL
Madhya Pradesh							
2000-01 to 2004-05	13578.88	7220.12	8657.93	15501.76	1922.89	8281.64	6843.84
2010-11 to 2014-15	15209.64	8184.91	9908.32	18914.12	3704.49	10729.21	9005.80
Change (%)	12.0	13.4	14.4	22.0	92.7	29.6	31.6
Maharashtra							
2000-01 to 2004-05	17672.82	12112.51	13032.35	20216.09	2543.26	8103.58	7183.74
2010-11 to 2014-15	20163.08	13684.36	15353.85	20971.81	808.73	7287.45	5617.96
Change (%)	14.1	13.0	17.8	3.7	-68.2	-10.1	-21.8
Rajasthan							
2000-01 to 2004-05	11522.72	6338.38	8141.34	13935.18	2412.46	7596.80	5793.84
2010-11 to 2014-15	12583.33	6456.85	8687.94	16044.51	3461.18	9587.67	7356.57
Change (%)	9.2	1.9	6.7	15.1	43.5	26.2	27.0

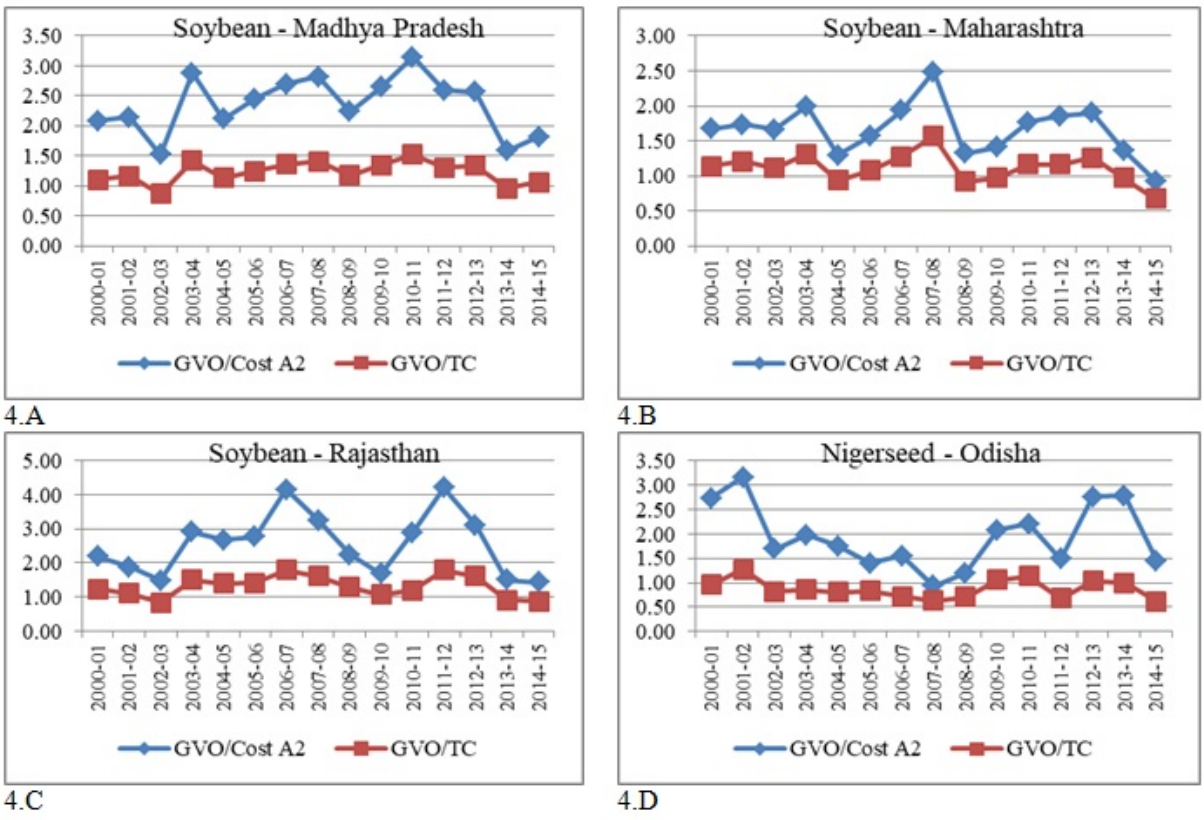

Fig. 4A-4D. Ratio of GVO to Cost A_2 and to total cost in soybean and nigerseed

Table 6 Average real crop cost, output value and income from Nigerseed

Items	TC (₹/ha)	Cost A_2 (₹/ha)	Cost A_2+FL	GVO (₹/ha)	Net Income (₹/ha)	FBI (₹/ha)	NI/Cost A_2+FL
Odisha							
2000-01 to 2004-05	6211.70	2609.68	4167.34	5910.07	-301.63	3300.39	1742.73
2010-11 to 2014-15	8348.20	3511.11	6006.20	7408.05	-940.146	3896.94	1401.86
Change (%)	34.4	34.5	44.1	25.3	211.7	18.1	-19.6

Table 7 Average real crop cost, output value and income from sunflower

Items	TC (₹/ha)	Cost A_2 (₹/ha)	Cost A_2+FL	GVO (₹/ha)	Net Income (₹/ha)	FBI (₹/ha)	NI/Cost A_2+FL
Andhra Pradesh							
2000-01 to 2004-05	14821.29	8476.46	10260.67	12182.68	-2638.61	3706.22	1922.01
2010-11 to 2014-15	18535.56	10689.73	13128.33	15868.65	-2666.90	5178.93	2740.32
Change (%)	25.1	26.1	27.9	30.3	1.1	39.7	42.6
Karnataka							
2000-01 to 2004-05	9530.46	6218.86	6979.82	8601.22	-929.24	2382.36	1621.40
2010-11 to 2014-15	10775.95	6809.75	7771.25	11249.37	473.42	4439.62	3478.12
Change (%)	13.1	9.5	11.3	30.8	-150.9	86.4	114.5

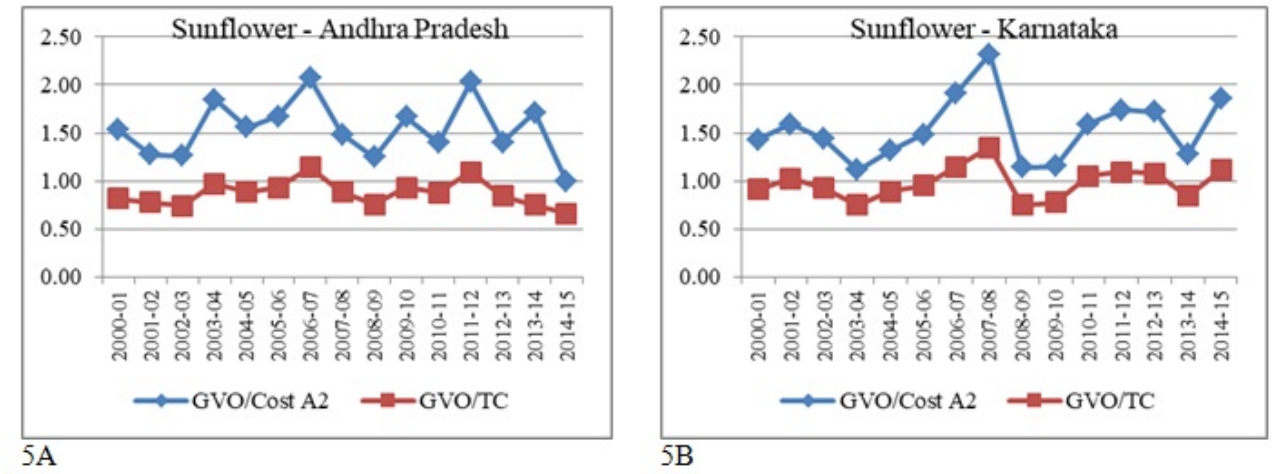

Fig. 5A-5B. Ratio of GVO to Cost A_2 and to total cost in sunflower

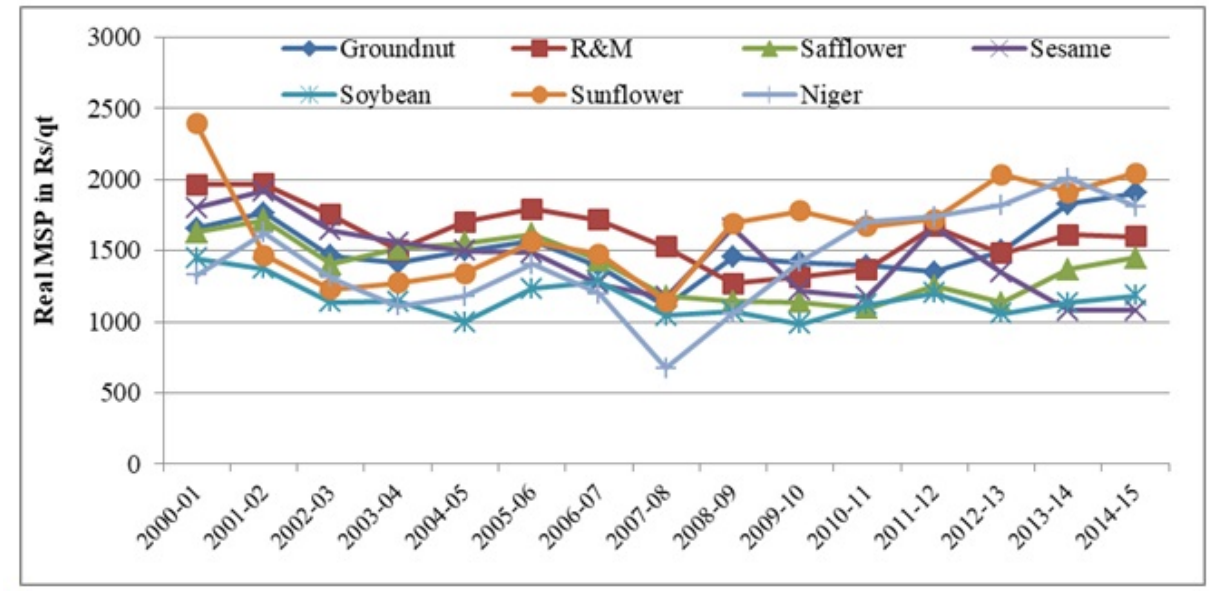

Fig. 6. The trend in real minimum support price of oilseeds (₹/qt)

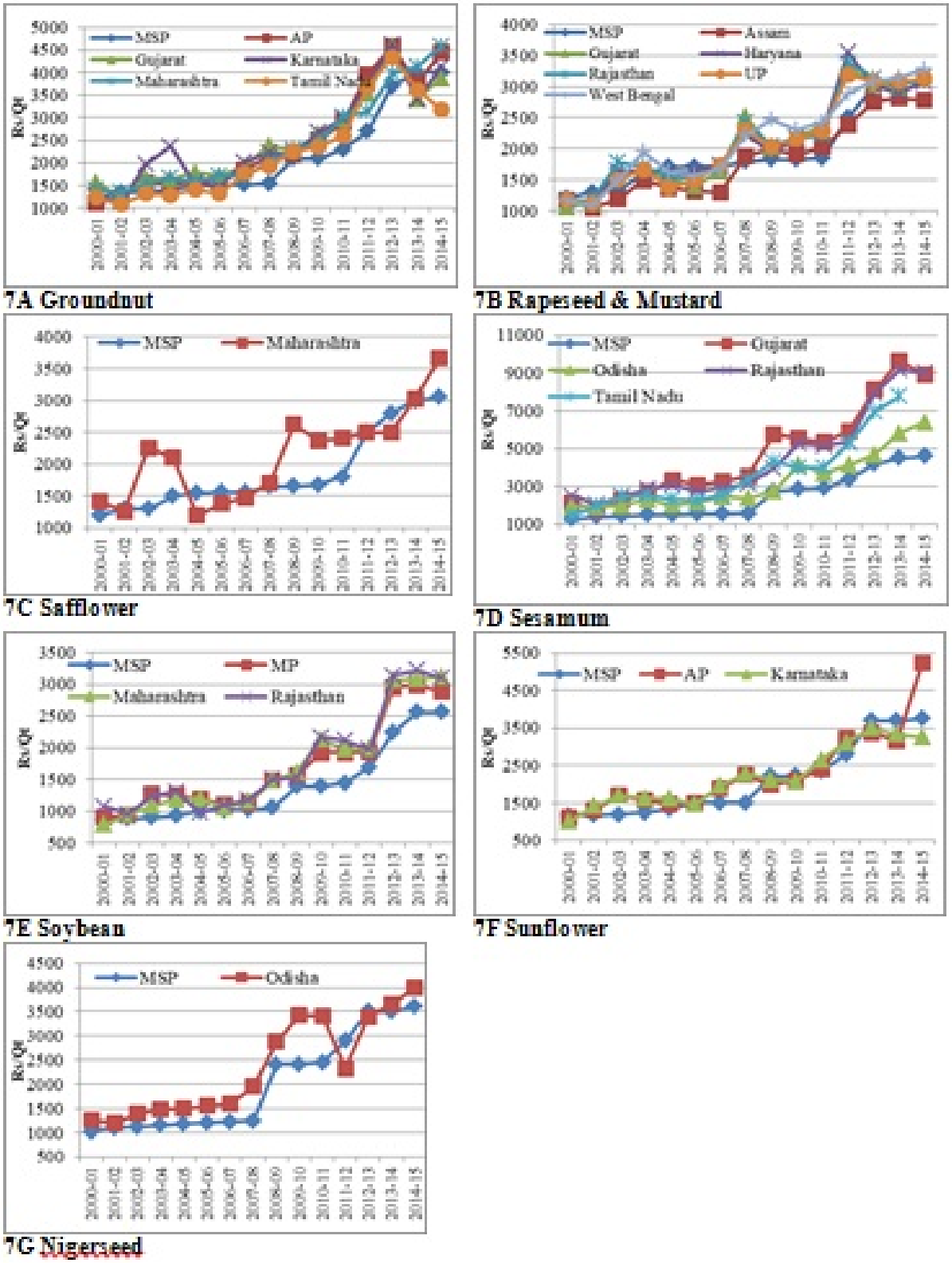

Fig. 7A to 7G. MSP and price of oilseeds in selected states at nominal prices

Annexure 1 Input use pattern in cultivation of oilseeds

Crop/State	Period	Seed (kg/ha)	Fertilizer (kg. Nutrs/ha)	Manure (Qtl/ha)	HL (Man Hrs/ha)	AL (Pair Hrs/ha)
GN_AP	2000/01-2004/05	102.27	52.73	16.74	557.94	50.98
	2010/11-2014/15	119.92	121.19	25.77	756.19	37.90
GN_Guj	2000/01-2004/05	102.82	59.14	30.22	498.03	57.28
	2010/11-2014/15	129.59	92.94	29.61	563.07	44.97
GN_Knk	2000/01-2004/05	88.28	56.03	9.47	591.48	66.83
	2010/11-2014/15	108.12	100.43	6.88	543.56	49.82
GN_Mah	2000/01-2004/05	91.50	53.50	27.08	1040.23	82.35
	2010/11-2014/15	89.23	92.17	13.82	927.97	43.35
GN_TN	2000/01-2004/05	116.88	67.87	31.96	916.18	40.84
	2010/11-2014/15	121.37	86.46	36.08	764.17	25.35
RM_Asm	2000/01-2004/05	9.82	22.95	9.67	526.69	221.47
	2010/11-2014/15	10.41	31.33	7.74	505.42	172.01
RM_Guj	2000/01-2004/05	5.18	112.97	5.01	506.73	16.96
	2010/11-2014/15	5.85	144.29	6.34	494.10	6.46
RM_Hry	2000/01-2004/05	4.52	110.79	1.31	284.28	15.09
	2010/11-2014/15	3.72	136.15	0.16	225.34	1.66
RM_Raj	2000/01-2004/05	5.79	79.97	1.07	334.61	8.05
	2010/11-2014/15	5.93	80.19	0.41	324.08	2.20
RM_UP	2000/01-2004/05	5.59	83.63	8.30	478.66	20.31
	2010/11-2014/15	5.60	113.94	0.68	421.28	9.41
RM_WB	2000/01-2004/05	7.83	99.53	8.62	680.82	111.65
	2010/11-2014/15	7.97	135.16	3.74	646.02	64.22
Sff_Mah	2000/01-2004/05	11.84	11.15	0.00	329.67	51.67
	2010/11-2014/15	14.79	41.29	0.00	445.67	49.80
Sesa_Guj	2000/01-2004/05	2.26	50.01	12.93	373.47	26.57
	2010/11-2014/15	4.80	96.31	7.40	478.62	12.74
Sesa _Ods	2000/01-2004/05	10.43	0.58	0.09	424.96	136.55
	2010/11-2014/15	10.78	4.27	0.00	400.32	89.82
Sesa _Raj	2000/01-2004/05	4.69	4.85	0.39	292.77	11.01
	2010/11-2014/15	3.97	6.04	0.21	281.17	9.99
Sesa _TN	2000/01-2004/05	6.65	36.84	2.28	466.86	23.72
	2010/11-2014/15	6.83	57.49	5.54	408.41	3.52
Soy_MP	2000/01-2004/05	93.54	41.04	5.19	340.32	48.57
	2010/11-2014/15	87.54	43.62	6.09	262.58	17.41
Soy_Mah	2000/01-2004/05	77.50	74.40	5.07	541.34	82.67
	2010/11-2014/15	77.97	79.33	8.98	446.23	53.88
Soy_Raj	2000/01-2004/05	93.77	14.39	0.36	362.30	25.77
	2010/11-2014/15	102.91	13.66	2.92	316.84	4.614
Sun_AP	2000/01-2004/05	6.93	84.89	8.87	430.77	62.70
	2010/11-2014/15	6.84	122.04	5.87	451.92	35.99
Sun_Knk	2000/01-2004/05	5.64	58.09	2.20	344.60	69.70
	2010/11-2014/15	5.48	63.43	0.73	257.90	38.59
NG_Ods	2000/01-2004/05	10.46	0.00	0.00	280.28	133.42
	2010/11-2014/15	10.03	0.00	0.00	353.38	126.62

The government also undertakes procurement of selected agricultural commodities through its procurement agencies, in order to maintain buffer stock of food-grains and in case of market prices crash for oilseeds, pulses and other commodities. However, the procurement of oilseeds was sporadic and negligible, as there was very low quantity procured as proportion of marketable surplus even on the event of market prices ruling below MSP. The procurement system for oilseeds is mostly non-existent, and thus farmers are left at the mercy of traders, who tend to pay low prices for agricultural commodities. It is evident from the figures 7.A to 7.G that the state level average price received by the farmers was even below MSP for most of the oilseed crops. To promote production of oilseeds and improve their profitability, procurement need to be ensured at MSP in all the states.

Yield gap and constraints in oilseeds production: Earlier studies (Jha *et al.,* 2012; Sharma, 2014; Sharma, 2017) have reported that there exists a large realisable yield gap in oilseed crops. The realisable yield potential in case of majority of the oilseed crops has not been achieved and there are large technology and extension gaps in the country. Average yields realised are only about 40-50 per cent, in many cases, of the potential yield. Significant gap between the maximum attainable and the farm-level yields (ranging from 10 to 30 percent) exists since long, which can be narrowed down by higher adoption of production technology by farmers. In majority of the oilseed crops there is a large scope for enhancement in productivity and therefore, efforts must be made to enhance productivity and profitability, and in turn increase farmers' income.

A study by Sharma, 2014 reported that socio-economic, biophysical, institutional and policy related, technological knowhow and market related factors were responsible for low yields of oilseed crops and large yield gaps. The study further enumerated the constraints and problems in production and marketing of oilseeds encountered by farmers hindering the productivity and profitability as lack of suitable varieties and availability of quality seeds, high-costs and timely availability of inputs, increasing incidence of diseases and insect pests, low and fluctuating prices, shortage of human labour, poor irrigation facilities, weak linkages between oilseed producers and processors and markets leading to exploitation by market intermediaries, poor extension services, etc.

The abovementioned study recommended that for achieving higher yield and profitability from oilseeds, balanced and integrated crop nutrition, mechanization, and timely availability of quality inputs including seeds of improved varieties need to be ensured and it should be complemented with effective market interventions through price support and effective procurement and strengthening market infrastructure. Efforts are to be diverted to promote water use efficiency through protective irrigation and a well-functioning, adequately funded and well-coordinated agricultural extension services in order to enhance productivity of oilseeds and improve income of oilseed producers. Efficient mechanism for yield and price risk management is of paramount importance, reach of which needs to percolate to the needy farmers.

Conclusions: Indian agriculture is undergoing a considerable change as the focus of government is on improving profitability and in turn farmers' income from the crops and the sector, and to ensure this, government has started numerous schemes. Oilseeds are of paramount importance for national economy as well as for the farmers' income, as the crops support income of farmers mainly in the rainfed/dryland areas. The present study has analysed the changes in income from oilseeds in the selected states in India, using data from Cost of Cultivation Surveys. The analysis revealed that net income as well as farm business income has increased in the states with higher proportionate rise in crop yield and/ or price realized by farmers as compared to increase in input cost. The decline in income from oilseeds crops was observed in the states where input costs have increased faster than the increase in yield or price of the crop or in the states where yields have not improved or rather decreased.

The major factors affecting the profitability of oilseeds include the level of productivity of crop, changes in input cost and price realized by farmers. Oilseeds are grown under rainfed ecosystem on marginalized lands with minimum use of productive and protective inputs leading to low average productivity. The real minimum support price for oilseeds has not increased and there is minimal procurement support for these crops. The average yield at state or national level is well below the achievable yield potential of oilseed crops. This large gap can be narrowed down through ensuring quality input supply at affordable prices, increase adoption of production technology and price support with effective procurement. Concerted efforts are to be directed to improve the efficiency of water use through protective irrigation, enhance the effectiveness of extension services to increase productivity and profitability, which will bolster the farmers' income.

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Export competitiveness of groundnut: A state wise analysis

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ABSTRACT

The export of agricultural commodities became competitive in post-WTO period as a result of increased interaction of world economies. Therefore, it is relevant to check competitiveness of groundnut export from India. Export competitiveness was assessed for major groundnut growing states *viz.,* Andhra Pradesh, Gujarat, Karnataka, Maharashtra and Tamil Nadu using Policy Analysis Matrix from 1996-97 to 2013-14. Groundnut was found export competitive in all the states except in Karnataka in almost all the years. The values of Nominal protection coefficient (NPC), Effective protection coefficient (EPC) and Effective subsidy coefficient (ESC) measured less than unity, indicating the export worthiness. Domestic resource cost ratio (DRCR) values were found below one indicating the efficient utilisation of domestic resources in this crop. Social profit was measured positive throughout years indicating the positive social welfare in producing and exporting groundnut from these states. Total policy transfer measured negative in all the states indicating that this crop is generating resources to the state economy of all the major groundnut producing states. The export competitiveness of groundnut from India was found to improve over years during the study period. Therefore, government support and promotional activities can help to boost groundnut export from India.

Keywords: DRCR, EPC, ESC, Groundnut, NPC, Policy Analysis Matrix, Policy transfer

Groundnut, popularly known as peanut, is grown in all the six continents in more than hundred countries round the globe. It's multiple uses mark it as world's 13th most important crop (Vijaya, 2007; Meena, 2017) and fifth most important oilseed (Flecher and Shi, 2016). Dr George Washington Carver, an African American agricultural scientist, invented more than 300 uses of groundnut. It's cultivation in India spreads over 4.77 Mha in 2014-15, with a of 7.40 million tonnes (Mt). Global trade in groundnut is very thin and concentrated, only 3.72 per cent of the world production was traded in international markets in post-WTO period (1996-97 to 2014-15). The top five groundnut exporting countries in the world are China (22.66%), India (18.64%), Argentina (13.59%), USA (14.30%) and Netherland (5.99%), jointly contributing to more than three fourth of the world's total export. During TE 2015-16, India exported 5.85 lakh tonnes of groundnut valued at 3.96 lakh crore. In last three years, India exported groundnut to more than hundred countries in one or another year. Agricultural trade reforms increased interaction in world economies, brought sea changes in India's farm economy and in oilseeds sector especially (Meena *et al*., 2015). Export of agricultural commodities became more competitive in liberalised era. Therefore, a study has become formidable and imperative to check its export competitiveness in term of social and private profit. Information on production and export competitiveness will be useful to all the stakeholders and agencies involved in production and export of groundnut.

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MATERIALS AND METHODS

Sources of data: This study is based on secondary data collected from various sources. Details on various type of costs (*viz.,* A1, A2, B1, B2 and C2), family labour charges, gross value of output, value of by-product along with details on item-wise cost of cultivation, use of inputs with their prices used in groundnut cultivation in major states was collected for the period 1996-97 to 2013-14, from the various published reports on "Comprehensive Scheme for the Study of Cost of Cultivation of Principal Crops", from Commission for Agricultural Costs and Prices (CACP), Ministry of Agriculture and Farmers Welfare. For analytical purposes and to make comparative analysis over the period, overall period was equally divided into two sub-periods, *viz*., Period 1 (1996-97 to 2004-05) and Period II (2005-06 to 2013-14) along with overall period.

Analytical framework: To find out the global competitiveness policy analysis matrix (PAM), developed by Monke and Pearson (1998) was used to measure the export competitiveness of Indian groundnut. PAM is a double-accounting matrix which summarizes budgetary information for on-farm and off-farm activities into a matrix form. In PAM, inputs and outputs are classified into tradable (fertilizers, pesticides and seeds) and non-tradable items (i.e. domestic factors like labour, land, and capital) and measured in two types of prices i.e. private and social (Table 1).

Private values/market/financial price are prices at which goods and services were actually exchanged like the price of crop, the cost of seeds, fertilizers, farm yard manures, pesticides and the wage rate. Social values are the prices, which would prevail in the absence of any policy distortions (such as taxes or subsidies) or market failures (such as monopolies).

Table 1 Policy Analysis Matrix (PAM)

Description	Value of output		Value of input		Profits/Surplus
	Tradable	Non-tradable	Tradable	Non-tradable	
1. Private values	A	B	C	D	PAI=(A+B)- (C+D)
2.Social/Economic values: i. Border prices	E	-	G	-	INTPAI=(E+B)- (C+D)
ii. Opportunity cost	-	F	-	H	SPAI=(E+F)-(G+H)
3.Divergence/Policy transfers	A-E	B-F	G-C	H-D	T=(A-E)+(B-F) +(G-C)+(H-D) =(A+B-C-D) –(E+F-G-H) = PAI-SPAI

Source: Datta (2000)

In terms of the PAM the following indices can be defined:

(1) Nominal Protection Coefficient (NPC) = A/E
(2) Effective Protection Coefficient (EPC) = (A-C)/(E-G)
(3) Effective Subsidy Coefficient (ESC) = [(A-C) + (H-D)]/(E-G)
(4) Domestic Resource Cost Ratio (DRCR) = (H-F)/(E-G)
(5) Private Profit under Autarky (PAI) = (A+B)- (C+D)
(6) Private Profit under Free Trade in Output (INTPAI) = (E+B) - (C+D)
(7) Social Profit under Free Trade (SPA1) = (E+F) - (G+H)
(8) Total Policy Transfer (T) = (A-E) + (B-F) + (G-C) + (H-D)

In this study the value of tradable output i.e. kernel was estimated based on domestic and export prices whereas non-tradable output like haulm was taken from value of by-product from cost of cultivation data. Private value of tradable inputs used in groundnut cultivation with their prices in major states was culled from details on item-wise cost of cultivation. In case of domestic factors, which are not traded in the international markets (like labour, land, and capital), figuring out social prices was difficult. For these social costs were calculated using Value of Marginal Product Approach suggested by Rani *et al.* (2014). This method uses factor share (Si) of various inputs (Xi) together with the mean values of outputs (Y) and prices (Py). The computation of the social cost of input was done as follows.

$$Pxi=[(Si/Xi)*Y] Py$$

Export competitiveness indices: There are different measures to assess the global competitiveness of agricultural commodities. But commonly used global competitiveness indices are Nominal Protection Coefficient (NPC), Effective Protection Coefficient (EPC), Effective Subsidy Coefficient (ESC) and Domestic Resource Cost (DRC). NPC is simplest one which measures the divergence of domestic price from the international price. Measurement of EPC and ESC requires distinction between tradable (like fertiliser, seed, plant protection chemicals) and non-tradable (like electricity, irrigation water, land resources, unskilled labor) inputs. EPC and ESC take care of distortions in the form of taxes/subsidies on tradable and non-tradable inputs.

NPC was estimated as ratio of domestic price to border prices

$$NPC = P^d/P^b$$

Where,
P^d = Domestic price and
P^b = Border price

An NPC greater than one discouraged the export of that particular commodity. On the other hand NPC less than unity measures the degree of competitiveness. It measures the competitiveness from the viewpoint of a trader.

EPC was estimated as the ratio of value added in private prices to value added in social prices. It indicates the combined effects of policies in the tradable commodities markets.

$$EPC = VP^d / VP^b$$

Where,
VP^d = Value added in domestic price
VP^b = Value added in border price

Value of EPC exceeding unity means lack of competitiveness. Whereas EPC less than one indicated the competitiveness of a commodity. Both EPC and the NPC ignore the effects of transfers in domestic factor market and therefore do not reflect the full extent of incentives to farmers. EPC has already accounted for distortion in tradable input markets, but possible distortions in the markets for non-tradable inputs are yet to be considered. This is done in ESC. It is defined as

$$ESC= (VA^{d}+NS)/VA^{b}$$

Where NS is the net subsidy (i.e. net of taxes) on non-tradable inputs like electricity, irrigation and credit are given to the farmers by government. ESC greater than unity indicate that protection is accorded to the commodity under consideration.

NPC, EPC and ESC examines the competitiveness of agricultural commodities from the traders point of view without taking into account the social cost of resources used in production. Domestic resource cost ratio (DRCR) compares the opportunity cost of using domestic resources (land, labour and capital) and of traded inputs in domestic production to the value added at border prices. It compares the value of domestic non-tradable resources used to a unit of foreign exchange saved and earned through production and export of the agricultural commodity respectively. It measures the comparative advantage (or) efficiency of domestic production in term of its international cost competitiveness in the world market.

$$DRCR = SP^{d} /VP^{b}$$

Where,
SPd= Shadow price of the agricultural commodities and
VPb= Value added measured at world prices.

DRCR greater than one indicate that production does not represent an efficient use of the country's resources. DRC less than one would imply that production is efficient and internationally competitive.

Equations system model used for estimating global competitiveness indices in PAM framework: The following equations were developed with base of equations developed for Indian rice to measure its global competitiveness using PAM framework by Datta (2000) and are follow:

1. Yield of full-grade kernels after moisture adjustment (qtl/ha; @70% Shelling percentage) = (1-Broken % @ 25%) * 0.7*Pod yield*(1-Moister level at marketing stage@7%)
2. Yield of off-grade kernels after moisture adjustment (qtl/ha) = (Broken@25%)*0.7*Pod yield*(1- Moister level at marketing stage@7%)
3. Domestic value of full kernels = Yield of full-grade kernels * Domestic price of kernels
4. Domestic value of off-grade kernels = Yield of off-grade kernels * Domestic price of off-grade kernels
5. Economic price of full-grade kernels = International price*Exchange rate
6. Economic value of full-grade kernels = Economic price of full-grade kernels * Yield of full-grade kernels
7. Domestic value of haulm = Value of by-product from groundnut cultivation
8. Yield of shell = 0.30* Pod yield (Pod contains 30% shell)
9. Domestic value of shell = Yield of shell * Price of shell
10. Domestic value of non tradable output = Domestic value of haulm + Domestic value of shell + Domestic value of off-grade kernels
11. Domestic value of tradable Inputs = Domestic value of fertilizer + Domestic value of seed + Domestic value of plant protection chemicals + Domestic value of machinery + 0.5* (Transportation cost + Marketing cost + (Processing cost*Pod yield* (1-Moisture%))+ Domestic value of depreciation).

    Note: 50% of domestic transportation cost, marketing cost, processing cost and depreciation were taken as tradable inputs (Dutta, 2000).
12. Economic value of fertiliser = International to domestic fertiliser price ratio* Domestic value of fertilizer
13. Economic value of seed = (Seed rate* International price*Exchange rate)
14. Economic value of plant protection chemicals was assumed same as domestic value
15. Economic value machinery = Domestic value machinery /1.11 +0.5 * (Domestic transportation cost + Marketing cost + (processing cost*Pod yield* (1-Moisture%)+ Domestic value of depreciation)/ 1.11. (Considering 11% import duty on machinery)
16. Economic value of tradable inputs = Economic value of fertiliser + Economic value of seed + Economic value of plant protection chemicals + Economic value machinery

17. Tax on procurement (@7%) = 0.07* Purchasing price
18. Domestic value of non-tradable inputs = Domestic value of irrigation + Domestic value of human labour + Domestic value of bullock labour + (Tax on procurement *Pod yield) + Domestic value of rent + Domestic value of fixed capital + Domestic value of working capital + Port charges + 0.5* (Domestic transportation cost + Marketing cost + (Processing cost*Pod yield*(1-Moisture%)) + Domestic value of depreciation
19. Economic value of irrigation/human labour/bullock labour/rent/capital) = Estimated using marginal value approach (Rani *et al.,* 2014)
20. Economic value of non-tradable inputs= Economic value of irrigation + Economic value of human labour + Economic value of bullock labour + (Tax on procurement *Pod yield) + Economic value of rent + Economic value of credit + Port charges + 0.5* (Domestic transportation cost + Marketing cost + (Processing cost* Pod yield* (1-Moisture%)) + Domestic value of depreciation

RESULTS AND DISCUSSION

Andhra Pradesh, Gujarat, Karnataka, Maharashtra and Tamil Nadu are the five major groundnut growing states, contributing 80 and 75 per cent of area and production, respectively to the nation's total (Table 2). Gujarat is the fate deciding state for groundnut crop in the country, as it alone contributes 40 per cent of national production from less than 30 per cent of national area. More than this, in 2013-14, Gujarat alone produced 50.88 per cent of total groundnut produced in the country just from 33.27 per cent of national area.

Table 2 Area, production and yield of groundnut in major producing states (2014-15)

State	Area (Mha)	Share to All India (%)	Production (Mt)	Share to All India (%)	Yield (kg/ha)
Andhra Pradesh	1.03	21.59	0.79	10.68	916.39
Gujarat	1.40	29.35	3.02	40.81	2154.2
Karnataka	0.65	13.63	0.5	6.76	767.58
Maharashtra	0.33	6.92	0.38	5.14	1159.02
Tamil Nadu	0.34	7.13	0.93	12.57	2752.91
Others	1.02	21.38	1.78	24.04	1124.88
All India	4.77	100	7.4	100	1552.16

Source: GoI, 2015.

Groundnut export is very thin (5 to 6% of production) in world market because domestic consumption is high in major groundnut producing countries like India and China. India is a major player in groundnut trade having long history in export. More than two third of the world export comes from just four countries viz., Argentina, India, China and USA. During 2013-14, India was the top groundnut exporter to the world with 5.50 lakh tonnes (30.27%) followed by USA with 3.77 lakh tonnes (20.78%), Argentina with 1.88 lakh tonnes (10.40%), Netherlands with 1.39 lakh tonnes (7.65%), and China with 1.24 lakh tonnes (6.85%) in term of volume (per cent share to world export). EU nations, Netherlands, Indonesia, Germany and Mexico were the leading importer of groundnut in the world with 6.18, 3.58, 2.51, 1.18 and 1.06 lakh tonnes improt, respectively (FAOSTAT, 2016). Groundnut is commonly traded as Shelled, in-shell and prepared form. Out of three, shelled groundnut is the most commonly traded in kernel form. From India, more than ninety per cent of total groundnut is traded in shelled form and only less than 2 to 3 per cent of total is exported as prepared groundnut product. Therefore, export competitiveness of groundnut was checked in terms of shelled or kernel form in all the major growing states.

Export competitiveness of groundnut produced in Andhra Pradesh: The year-wise export competitiveness of groundnut produced in Andhra Pradesh was assessed with price-competitiveness coefficients measured from PAM of respective years. From the perusal of Table 3, NPC, EPC and ESC confirmed Andhra groundnut as export competitive as all the coefficients measured were less than unity. Decrease in average NPC from period 1 (0.80) to 0.75 in period 2, showed that domestic prices of groundnut kernels found below international prices in both the periods and that gap widened over period. Even though NPC measures the divergence between domestic and international prices, it does not account for discretion in prices of tradable and non-tradable inputs. EPC adjusts NPC for the protection of tradable inputs. Further, ESC adjusts EPC for taxes and subsidies on non-tradable inputs. NPC is a suitable competitiveness measure for the final traders in agribusiness who are interested only in difference between domestic and international price.

EPC was measured as ratio of value added at domestic prices to the value added at border prices. It measures the ratio of surplus available with the domestic processor-cum-trader in domestic market to free trade

conditions. In all the studied years EPC was found below unity. In period 2, value of average EPC, decreased over period 1, indicating the increased competitiveness over the period. In Andhra Pradesh the value of NPC was found greater than EPC in all the studied years pointing out that processor were not provided with government protection.
ESC is a complete measure of competitiveness as it takes care of distortions in both tradable and non-tradable inputs. ESC less than unity in all the years which indicated the export worthiness of groundnut produced in Andhra Pradesh. ESC was measured as negative in 2001-02, 05-06 and 06-07 because domestic value of non-tradable inputs was found higher than economic value in respective years resulting in negating the negative ESC.

NPC, EPC and ESC estimates the competitive advantage without taking into consideration the potential use of by product. Therefore NPC, EPC and ESC under estimate social profits. Groundnut yields non-tradable by-product like haulm, pod shell and split kernels having economic value are not considered in estimating NPC, EPC and ESC. These limitations were taken care by estimating domestic resource cost ratio (DRCR). DRCR less than one is taken as an indicator of long run comparative advantage. The opposite is true when DRC ratio is >1 (Yao, 1997). In Andhra Pradesh, value of DRCR was found <1 in all the years included in the study except in 2001-02 and 05-06 confirming that domestic resources in the state were utilized efficiently in groundnut production. In these two years domestic kernel prices and pod yield were relatively lower compared to succeeding years against higher production and other processing costs that resulted in inefficient utilization of domestic resources. Rani *et al.* (2014) studied the trade competitiveness of groundnut in Andhra Pradesh during 1989 and 2004 using NPC, EPC and DRCR. These estimates measured <1 in post WTO period. The present results are in line with their findings. On the other hand, trade competitiveness coefficients during pre-WTO period were more than unity indicating poor competitiveness for groundnut exports in pre-WTO period (Chand, 2002; Gulati, 2002 and Rani *et al.*, 2014)). Thus, groundnut export competitiveness in Andhra Pradesh has improved in post-WTO periods.

Social profit (SPAI) represents the foreign exchange earned by expanding exports of a unit area of this commodity in state or saved by reducing its imports by the state. In case of groundnut produced in Andhra Pradesh, the social profit measured positive in all the years except in 2001-02 and 05-06 because domestic factors could not be efficiently utilized in these years (DRCR>1). Further, per hectare social profit was higher in period 2 (₹ 3,546) than in period 1 (₹ 1,266). The negative policy transfer in all the studied years indicated that groundnut production system is generating resources to the state's economy.

Export competitiveness of groundnut produced in Gujarat: In Gujarat, year-wise groundnut export competitiveness indices namely, NPC, EPC, ESC, DRCR, social profit and total policy transfer were worked out using PAM of respective years. Table 4 shows the outcome of policy analysis matrices for the period 1996-97 to 2013-14. The NPC coefficient was <1 in all studied years. EPC was estimated <1 in most of the years. The EPC was measured low in period 2 (0.46) than period 1(0.57) indicating the increased competitive strength of Gujarat groundnut over the period. The EPC was found negative in 2000-01 because pod yield harvested in this particular year was very low (4.7 qtl/ha), coupled with low domestic kernel price (₹ 1,885 per qtl) EPC was less than NPC in all the years indicating that domestic processors were not accorded with any protection in tradable inputs through government policy. The positive value of 1-EPC measures the ability of domestic processor to withstand price war *vis-à-vis* the foreign processor (Dutta, 2000), was found positive in all the years indicating that Gujarat processors were quite competitive, compared to foreign processors.

ESC was found less than one throughout the years except in 2000-01 (due to low surplus in domestic market). The positive value of 1-ESC in all the years indicated that Gujarat groundnut had competitive strength over the foreign groundnut in international market. DRCR values of less than unity in all the years, indicated the efficient utilisation of domestic resources by groundnut in the state. It is using less of domestic non-tradable resources (like land, labour and capital) as compared to value addition to the state's economy. Per hectare social profit under free trade (SPAI) estimated to the tune of ₹ 24,478 in year 2013-14, was positive in all the studied years. Further, social profit increased over the period, from ₹ 4,463 per hectare in period 1 to ₹ 9,565 in period 2 which meant that domestic resources were more efficiently utilized in latter period with advancement of technology in groundnut production and processing industry. The total policy change (T) in the state was found negative in all the years which clearly implied that groundnut export has generated resources to the agricultural economy of Gujarat. Result shows export from Gujarat is competitive enough to face the competition in international markets.

Export competitiveness of groundnut produced in Karnataka: The coefficients of NPC and EPC was measured less than unity in all the studied years, indicating the export competitiveness from traders' point of view. The EPC was found negative in 2003-04 because yield in this year was very low, only 4.37 qtl/ha. In period 2, values of NPC and EPC were less (0.75 and 0.40 respectively) than period 1 (0.80 and 0.48 respectively) revealed that export competitiveness of groundnut in Karnataka has improved over the period (Table 5). The value of ESC in Karnataka

was negative in many years because of low yield in the state which resulted in net loss in groundnut cultivation. The results indicated that it was not economically viable to produce and export groundnut from Karnataka (Meena *et al.,* 2018). These results are in line with the findings of Chand *et al.,* (2011) where they reported the un-sustainability of groundnut production and export in Karnataka. The overall profit to the society was found negative in most of the years as indicated by negative social profit. DRCR was found more than unity in most of the years and pointed that there was inefficient utilisation of domestic resources in groundnut production. It was using more of domestic non-tradable resources than value addition. The opportunity cost of spending domestic resources was larger than the net foreign exchange earned on export. It calls for greater need to improve groundnut productivity in the state by adopting advanced technologies in production, which will help in the efficient utilization of domestic resources. Overall, it will help in improving Karnataka's competitiveness in groundnut production and its export. Total policy transfer was negative.

Table 3 Results of Policy Analysis Matrix (PAM) and Competitiveness Indices of exports of groundnut from Andhra Pradesh during 1996-97 to 2013-14

Year	NPC	EPC	ESC	DRCR	SPAI	T
1996-97	0.77	0.63	0.44	0.78	1381.78	-3508.01
1997-98	0.84	0.74	0.40	0.81	1064.16	-3392.1
1998-99	0.93	0.85	0.54	0.75	2115.44	-3929.88
1999-00	0.83	0.67	0.00	0.90	487.93	-5003.85
2000-01	0.76	0.60	0.55	0.72	2533.86	-4100.14
2001-02	0.61	0.10	-0.75	1.01	-34.72	-7637.88
2002-03	0.98	0.92	0.23	0.75	1132.46	-3453.42
2003-04	0.71	0.53	0.26	0.89	895.04	-6259.67
2004-05	0.77	0.62	0.44	0.80	1820.65	-5159.25
2005-06	0.69	0.34	-0.38	1.03	-185.29	-9022.46
2006-07	0.64	0.38	-0.02	0.96	346.85	-9044.54
2007-08	0.70	0.57	0.48	0.85	2765.23	-9750.3
2008-09	0.74	0.59	0.40	0.85	2542.79	-10280.7
2009-10	0.77	0.62	0.36	0.81	3683.96	-12233
2010-11	0.92	0.81	0.51	0.81	5582.88	-14117.4
2011-12	0.78	0.61	0.24	0.88	4140.43	-25771.3
2012-13	0.70	0.58	0.59	0.80	12597.00	-26128.2
2013-14	0.85	0.70	0.47	0.99	442.31	-17976.1
Period 1	0.80	0.63	0.24	0.82	1266.29	-4716.02
Period 2	0.75	0.58	0.30	0.89	3546.24	-14924.89
Overall	0.78	0.60	0.27	0.86	2406.26	-9820.46

Note: NPC= Nominal protection coefficient, EPC= Effective protection coefficient, ESC= Effective subsidy coefficient SPAI= Social profit under free trade, T= Total policy transfer; Source: Estimated from PAM of respective year.

Export competitiveness of groundnut produced in Maharashtra: In Maharashtra, the groundnut export was found competitive on the basis of NPC, EPC and ESC coefficients. Their value was less than unity in all the studied years. NPC and EPC coefficient showed increase in competitiveness in period 2 compared to period 1 as indicated by decrease in their value in latter period. ESC, the complete measure of competitiveness analysis was also less than one indicated that groundnut production cum export system was competitive. In some years, ESC was estimated as negative indicating that groundnut production cum export system was net taxed. The 1-ESC value were found positive in all the years indicating the competitive strength of Maharashtra groundnut over its foreign rivals. Domestic resource cost ratio was found less than unity in all the years (except in 2004-05 and 08-09), indicating the efficient utilization of domestic resources. Social profit was recorded to the tune of ₹ 16,685 in 2012-13. It increased from ₹ 1,405 to ₹ 5,109 from period 1 to period 2. Higher social price indicates that Maharashtra is better off in terms of state income earned by producing groundnut rather than importing it. Total policy transfer (T) was found negative throughout the study years indicateing that export of groundnut kernels was subject to net taxation or resources were coming out. The revenue increased from ₹ 7,886 to ₹ 12,307 from period 1 to period 2 (Table 6).

Table 4 Results of Policy Analysis Matrix (PAM) and Competitiveness Indices of exports of groundnut from Gujarat during 1996-97 to 2013-14

Year	NPC	EPC	ESC	DRCR	SPAI	T
1996-97	0.77	0.66	0.73	0.48	4489.38	-2308.20
1997-98	0.84	0.75	0.81	0.46	4662.78	-1619.89
1998-99	0.93	0.86	0.85	0.46	4978.14	-1415.59
1999-00	0.83	0.53	-0.32	0.37	1868.48	-3926.45
2000-01	0.76	-0.16	-3.09	0.41	710.23	-4896.49
2001-02	0.61	0.41	0.55	0.47	6973.16	-5941.59
2002-03	0.98	0.94	0.28	0.39	3020.19	-3590.07
2003-04	0.71	0.60	0.84	0.48	10189.53	-3189.98
2004-05	0.77	0.55	0.25	0.54	3278.07	-5331.15
2005-06	0.69	0.45	0.38	0.54	5207.22	-7040.22
2006-07	0.64	0.23	-0.06	0.48	3753.71	-7643.67
2007-08	0.70	0.50	0.59	0.46	9244.54	-6996.44
2008-09	0.74	0.50	0.47	0.48	9410.12	-9533.12
2009-10	0.77	0.42	-0.17	0.38	6186.62	-11778.74
2010-11	0.92	0.77	0.64	0.36	11341.72	-6383.72
2011-12	0.78	0.51	0.23	0.37	11293.31	-13844.49
2012-13	0.70	0.12	-0.59	0.57	5175.17	-19101.26
2013-14	0.85	0.67	0.64	0.33	24478.54	-13102.90
Period 1	0.80	0.57	0.10	0.45	4463.33	-3579.93
Period 2	0.75	0.46	0.23	0.44	9565.66	-10602.73
Overall	0.78	0.52	0.17	0.45	7014.50	-7091.33

Note: NPC= Nominal protection coefficient, EPC= Effective protection coefficient, ESC= Effective subsidy coefficient SPAI= Social profit under free trade, T= Total policy transfer; Source: Estimated from PAM of respective year.

Table 5 Results of Policy Analysis Matrix (PAM) and Competitiveness Indices of exports of groundnut from Karnataka during 1997-98 to 2013-14

Year	NPC	EPC	ESC	DRCR	SPAI	T
1997-98	0.84	0.64	0.02	0.95	133.54	-2585.07
1998-99	0.93	0.82	0.61	0.80	1110.25	-2173.35
1999-00	0.83	0.62	-0.32	1.12	-335.41	-3713.45
2000-01	0.76	0.59	0.50	0.80	1167.08	-2943.63
2001-02	0.61	0.13	-0.40	1.13	-384.25	-4210.15
2002-03	0.98	0.92	-0.33	1.35	-875.67	-3347.01
2003-04	0.71	-0.26	-2.86	2.46	-1847.48	-4900.81
2004-05	0.77	0.37	-0.26	1.27	-828.37	-3922.23
2005-06	0.69	0.35	-0.07	1.04	-187.65	-5211.14
2006-07	0.64	0.09	-0.87	1.43	-1249.17	-5410.96
2007-08	0.70	0.57	0.70	0.81	2126.48	-3444.93
2008-09	0.74	0.36	-0.77	1.26	-1107.48	-7500.20
2009-10	0.77	0.61	0.32	0.95	458.01	-5993.67
2010-11	0.92	0.46	-2.00	1.38	-1278.58	-10156.45
2011-12	0.78	0.23	-1.20	1.15	-962.58	-14256.75
2012-13	0.70	0.27	-0.51	1.04	-423.19	-16835.29
2013-14	0.85	0.70	0.48	0.82	3243.85	-9483.74
Period 1	0.80	0.48	-0.38	1.23	-232.54	-3474.46
Period 2	0.75	0.40	-0.44	1.10	68.85	-8699.24
Overall	0.78	0.44	-0.41	1.16	-72.98	-6240.52

Note: NPC= Nominal protection coefficient, EPC= Effective protection coefficient, ESC= Effective subsidy coefficient DPAI=Private profit under autarky, INTPAI= Private profit under free trade, SPAI= Social profit under free trade, T= Total policy transfer; Source: Estimated from PAM of respective year.

Table 6 Results of Policy Analysis Matrix (PAM) and Competitiveness Indices of exports of groundnut from Maharashtra during 1996-97 to 2013-14

Year	NPC	EPC	ESC	DRCR	SPAI	T
1996-97	0.77	0.61	0.44	0.73	2013.31	-4191.66
1997-98	0.84	0.67	0.26	0.75	1529.85	-4518.41
1998-99	0.93	0.83	0.68	0.65	3323.82	-3052.20
1999-00	0.83	0.67	0.36	0.80	2036.72	-6446.11
2000-01	0.76	0.55	0.17	0.87	1053.80	-6986.72
2001-02	0.61	0.34	-0.21	0.92	825.72	-12840.30
2002-03	0.98	0.83	-0.26	0.91	473.33	-6687.32
2003-04	0.71	0.48	0.22	0.84	1909.72	-9286.68
2004-05	0.77	0.46	-0.24	1.07	-514.10	-9771.18
2005-06	0.69	0.35	-0.20	0.88	1029.80	-9995.85
2006-07	0.64	0.31	-0.22	0.90	919.29	-10774.09
2007-08	0.70	0.54	0.58	0.73	4915.86	-7748.31
2008-09	0.74	0.26	-0.69	1.03	-273.75	-13652.30
2009-10	0.77	0.69	0.84	0.75	7023.82	-4596.19
2010-11	0.92	0.86	0.77	0.77	6039.96	-6035.47
2011-12	0.78	0.49	-0.06	0.86	3269.96	-23918.19
2012-13	0.70	0.60	0.79	0.75	16685.90	-13781.04
2013-14	0.85	0.65	0.27	0.77	6375.33	-20270.34
Period 1	0.80	0.61	0.16	0.84	1405.80	-7086.73
Period 2	0.75	0.53	0.23	0.83	5109.58	-12307.98
Overall	0.78	0.57	0.19	0.83	3257.69	-9697.35

Note: NPC= Nominal protection coefficient, EPC= Effective protection coefficient, ESC= Effective subsidy coefficient DPAI=Private profit under autarky, INTPAI= Private profit under free trade, SPAI= Social profit under free trade, T= Total policy transfer; Source: Estimated from PAM of respective year.

Table 7 Results of Policy Analysis Matrix (PAM) and Competitiveness Indices of exports of groundnut from Tamil Nadu during 1996-97 to 2013-14

Year	NPC	EPC	ESC	DRCR	SPAI	T
1996-97	0.77	0.68	0.73	0.74	3236.16	-3304.95
1997-98	0.84	0.78	0.85	0.72	3832.38	-2107.78
1998-99	0.93	0.91	1.05	0.70	4406.10	759.17
1999-00	0.83	0.76	0.59	0.70	3796.75	-5241.09
2000-01	0.76	0.64	0.41	0.87	1454.27	-6791.06
2001-02	0.61	0.33	-0.27	1.06	-552.58	-10881.95
2002-03	0.98	0.94	0.36	0.86	1993.23	-8929.72
2003-04	0.71	0.57	0.53	0.85	2314.01	-7476.69
2004-05	0.77	0.66	0.69	0.80	3490.56	-5355.48
2005-06	0.69	0.53	0.55	0.79	3185.65	-6906.88
2006-07	0.64	0.46	0.49	0.83	2851.18	-8589.03
2007-08	0.70	0.57	0.59	0.78	3774.70	-7122.40
2008-09	0.74	0.56	0.39	0.79	3513.43	-10080.76
2009-10	0.77	0.61	0.21	0.91	1210.21	-10935.31
2010-11	0.92	0.82	0.44	0.82	3178.54	-9696.12
2011-12	0.78	0.61	0.37	0.82	4291.38	-15053.13
2012-13	0.70	0.54	0.51	0.82	6684.21	-18205.77
2013-14	0.85	0.71	0.30	0.78	6573.97	-21313.68
Period 1	0.80	0.70	0.55	0.81	2663.43	-5481.06
Period 2	0.75	0.60	0.43	0.82	3918.14	-11989.23
Overall	0.78	0.65	0.49	0.81	3290.79	-8735.15

Note: NPC= Nominal protection coefficient, EPC= Effective protection coefficient, ESC= Effective subsidy coefficient DPAI=Private profit under autarky, INTPAI= Private profit under free trade, SPAI= Social profit under free trade, T= Total policy transfer; Source: Estimated from PAM of respective year.

Export competitiveness of groundnut produced in Tamil Nadu: The results of policy analysis matrix for Tamil Nadu groundnut are presented in Table 7. The values of EPC was found less than NPC in all the years indicating that tradable inputs like seeds, fertilisers and pesticides were taxed at home. 1-ESC values were found positive in all the years (except in 1998-99) highlighted the competitive strength of groundnut produced in Tamil Nadu over its rivals. DRCR was less than unity except in 2001-02. In 2001-02, it was found more than one because DRCR is inversely related to value of output. Lowest domestic kernels price of 1298 ₹/qtl in all the studied years (was 45 per cent lower than previous year) coupled with low pod yield in this year was the main cause of DRCR. In rest of the years DRCR indicated that opportunity costs of using non-tradable and tradable inputs in domestic production was less than that of the value added by groundnut production at border prices. Social profit was measured positive in all the years (except in 2001-02). The size of total policy transfer was found negative in all the years which meant that groundnut production cum export activities were subject to net taxation of fairly high order in Tamil Nadu.

Overall, in nutshell it can be concluded from the state level policy analysis matrix (PAM) that the groundnut export was competitive enough from trader's point of view in all the major groundnut producing states. DRCR which indicates the efficient utilization of domestic resources was <1 in most of the states except in Karnataka. All the major states except Karnataka found groundnut export profitable from social perspective as social profit measured positive in almost all the study years. The total policy transfer in all the states in all the years measured negative indicating that groundnut production cum export system in all the states was net taxed that generated resources to the state economies. To boost the export competitiveness, concerned government should come up with tax benefit to the groundnut stakeholders and export promotion policies for the benefit of groundnut export from the country.

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Development of a mobile app for the effective dissemination of information on castor

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ABSTRACT

Castor is an important industrial, non-edible oilseed crop in India. India accounts for 81 per cent of world castor production and 59 per cent of global castor area. The crop is being cultivated in different agro-ecological regions of the country under both irrigated and rainfed conditions. Despite the phenomenal increase witnessed in the production and productivity of castor over the last two decades, there still exists wide gap in the per hectare yields of castor across states. A number of improved varieties/hybrids and technologies developed in castor production do not readily reach the famers due to multiple factors including low farmer - extension worker ratio and slow pace of technology transfer. In the recent years, Information Communication Technologies (ICTs) especially the Mobile Apps have emerged as accessible tools to strengthen the extension system by providing information on crops, market and advisory services. Hence, an android standalone mobile application on "ICARIIOR-Castor" was developed to reach the wider section of stakeholders through ICT from ICAR-Indian Institute of Oilseeds Research (ICAR-IIOR), Hyderabad. The App supports English language and available on Google play store. Features include offline and online mode and offer valuable information to the extension workers, farmers, castor researchers and other stakeholders, including state-wise preferred varieties and hybrids, crop production and protection technologies for management of insect pest and diseases, intercropping systems recommended for different states, contact details of AICRP (Castor) centres across India and commodity markets and important APMC's trading of castor. The ICT initiative can make latest and improved castor production technologies accessible to farmers and other stakeholders for realizing higher yield of crop.

Keywords: Android, Crop production and protection technologies, Mobile application, ICARIIOR-Castor app, ICT

Agriculture is the largest source of livelihood in India. Seventy per cent of its rural households still depend primarily on agriculture for their livelihood, with 82 per cent of farmers being small and marginal (FAO, 2018). The future of sustainable agriculture growth in India shall be factorized to the performance of small and marginal farmers. Access to timely, adequate, apt technology and related information is among the most important enabler for smallholders to improve productivity sustainably (Davis, 2008; Birner *et al.,* 2009). In spite of a wide range of restructuring initiatives in agricultural extension in the past decades, the coverage of access to and quality of information offered to small and marginal farmers is uneven. The varied agro-ecological, socio-economic and cultural conditions of the farmers demand for diverse extension methods (Singh *et al.,* 2018). The National Sample Survey Organization, 2010 results showed that the key sources of information to farmers till today are neighbors, input dealers, radio, television, newspaper and extension worker. Thus the present extension mechanism warrants a strong Information Communication and Technologies (ICT) support to reach the unreached farmers and speed up the knowledge transfer from researchers to end users. ICTs especially the Mobile applications (m-apps) have emerged as handy tools to strengthen the extension system by providing information on agricultural technologies (Qiang *et al.,* 2011).

Castor (*Ricinus communis* L.) occupies an important place in the country's vegetable oil economy. Presently, castor is cultivated in 19 states over an area of 8.07 lakh hectares in the country, the states of Gujarat and Rajasthan being the major contributors (DES, 2017). Productivity of castor (1701 kg/ha) is exceptionally high compared to the performance of many annual crops in the country. Growing demand of vegetable oils by industries and biofuel production is encouraging castor and making it one of the profitable cash crops in the country. In India, castor is grown under two distinct agro-ecological situations *viz*., under irrigation and high input management in Gujarat and Rajasthan (1338 to 2072 kg/ha) and rainfed conditions under low input application with low productivity (312 to 631 kg/ha) in Andhra Pradesh, Telangana, Tamil Nadu, Karnataka and Odisha (DES, 2017). Given the current level of improved technology, there exists a wide commercially untapped yield reservoir in castor. The current extension services delivered through trained officers at the local level is having limited scope and thus necessitates a strong ICT support to align with the requirements of farmers, their existing experience and knowledge base with modern agricultural technologies and practices. Hence, a mobile application on castor production technologies was developed by ICAR-IIOR, Hyderabad aiming to empower castor farmers and other stakeholders with additional or latest

information on castor for better yield. In the present paper, the design, requirement and development of ICAR IIOR-Castor Mobile App and its unique features are discussed.

MATERIALS AND METHODS

A mobile application on castor management practices was developed by ICAR-IIOR to facilitate the end users with handy information. The updated content with regard to castor was compiled and was categorised into: General Information, Agronomic Practices, Preferred cultivars, Cropping systems, Insect Pests, Diseases, AICRP centres dealing with R & D on castor crop and Commodity markets for ease of the end user. The application was created in English and can be downloaded and used in offline mode.

Design and Implementation

Requirement specification: The application was developed using Android Studio, an open source software for developing Mobile Apps. The Android studio uses Java development tools as its official language for coding. The greatest strength of the Android platform is the Java programming language. The Java platform supports different ways to work with XML, and most of Java's XML-related APIs are fully supported on Android. Android provides a functionally equivalent library. To test Android applications, a virtual Android device is created and launched. Before publishing the Application it is tested using the virtual device for its functionality.

Minimum system requirements: Operating System: Microsoft windows 7/8/10, 64-bit; RAM: Minimum 3 GB, Recommended up to 8 GB and 1 GB for Android Emulator; Disk space: Minimum 2 GB of available disk space, Recommended up to 4 GB; Java Version: Java Development Kit (JDK) 8.

Design approach

The Mobile App was developed using Android Studio, an open source software for developing Mobile Apps. Once the App is developed it is compiled and then published in the Google Play store. The castor Mobile App flow chart is presented in Fig.1.

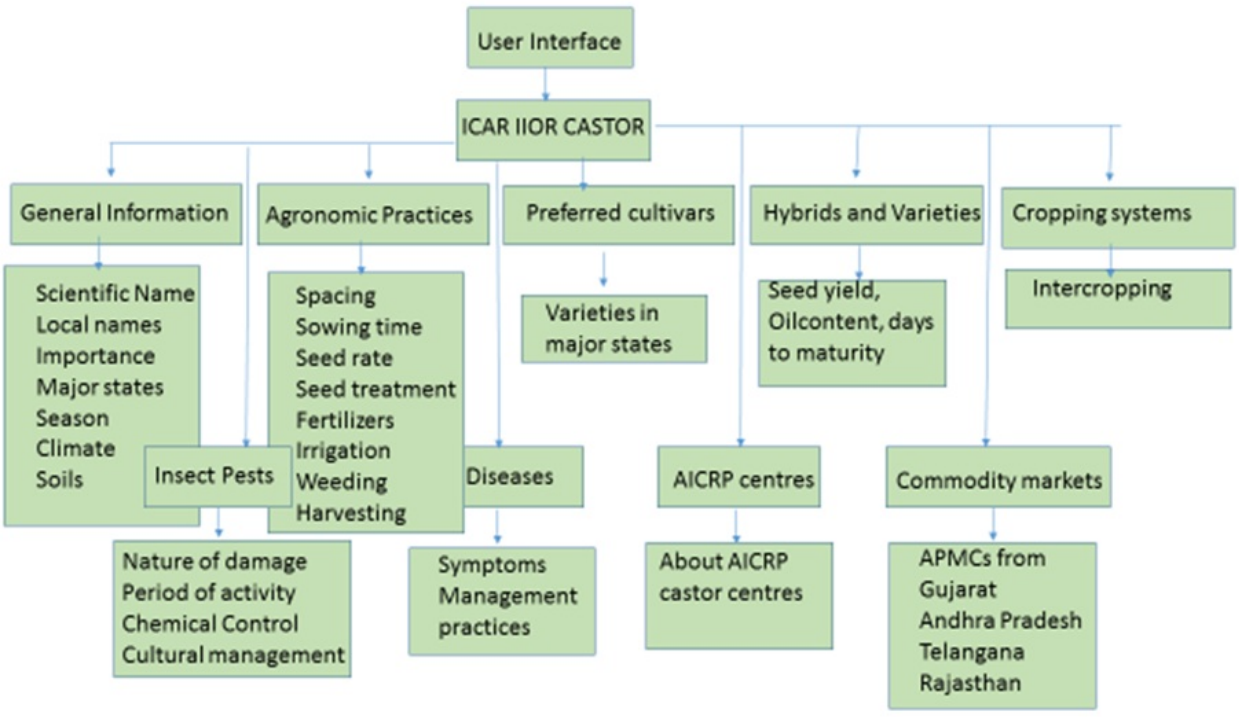

Fig. 1. Flow chart showing the structure of the "ICARIIOR-Castor" App

How to use the App

The Mobile App "ICARIIOR-Castor" can be downloaded from google playstore at: https://play.google.com/store/apps/details?id=in.org.icar_iior.icariiorcastor2&hl=en. Once the user installs the app in the android phone, the user can view the home page which has the list of chapters available in the app. With a simple touch the user can navigate to further screens. If the user wants to go back to the home page the user has to touch on the arrow mark which is there on the top left side of the mobile screen. From home page user can go to any topic of choice and can browse forward or backward any number of times. The app is user friendly, wherein the user can navigate from one point to other point for the information.

RESULTS AND DISCUSSION

Information is one of the most valuable resource and potential component for the advancement of agriculture. Information is presently viewed as a factor of production like other factors such as land, capital and labour. In order to bring substantial development in the agricultural sector, access to timely, reliable, and relevant agricultural information is a critical factor (Rao, 2007; Ogboma, 2010; Deribe, 2016). The present extension services provided through trained extension personnel at the local level is having a narrow scope and thus warrants a strong Information Communication and Technologies (ICT) support to provide information on modern agricultural technologies in a timely and cost effective manner to a larger audience cut across geographical jurisdictions. Among ICTs, there has been increasing use of mobile phones which is altering the agricultural communication method. Hence, a mobile application namely, "ICARIIOR-Castor" was developed to provide basic information of the castor crop and improved varieties/hybrids and production technologies developed at ICAR-Indian Institute of Oilseeds Research, Hyderabad and under All India Co-ordinated Research Project (AICRP) on Castor.

The general productivity level of castor in India is 30-40 per cent of the realizable potential because of inefficient crop management and inappropriate varietal choice (Hegde *et al*., 2003; Raghavaiah and Suresh, 2006). In this ICARIIOR-Castor App, home screen has the drop menu option and the information available in the drop menu are: general information, agronomic practices, preferred cultivars, hybrids and varieties, cropping systems, insect pests, diseases, AICRP centres and commodity markets (Fig. 2). The basic information of the castor crop *viz.,* scientific name, local names, importance, major castor growing states, seasons, climate and soils for cultivating castor have been provided under general information menu (Fig. 3). Under agronomic practices tab, the drop menu provides technical information on effective crop management techniques *viz*., optimum spacing, sowing time, seed rate, seed treatment, recommended dose of fertilizers, irrigation, weeding and interculture operations and harvesting and threshing practices (Fig. 4). Upon clicking the cropping system tab, the popular intercropping system recommended for different states along with information on additional net returns will be displayed. This page includes photographs of inter cropping system followed in different states and description of row ratio of main crop and inter crop, which would go a long way in suggesting risk management strategy during years of low rainfall and increase per unit productivity.

Fig. 2. Home screen and major contents of the drop menu option in ICARIIOR-Castor Mobile App

For realizing optimum productivity of any crop in any production environment, the choice of an appropriate variety/hybrid is extremely essential. Improper choice of the variety would result in low productivity, even when adequate quantities of inputs are applied. It is equally important to use the latest and improved recommended varieties/hybrids, since all varieties tend to lose disease resistance on account of evolution of pathotypes/biotypes of the disease. In castor, a total of 55 high yielding genotypes including 34 varieties and 21 hybrids were developed under the AICRP on castor

and recommended for different agro-climatic regions of the country (Sujatha *et al.*, 2017). In the ICARIIOR-Castor App, the basic information of castor hybrids and varieties released since last 40 years has been provided under the preferred cultivars and Hybrids and Varieties tabs along with photographs of the cultivars (Lavanya and Mukta, 2008). Upon selecting the preferred cultivars menu, information like seed yield, oil content, days to first picking, suitable area of cultivation and other special features of the popular varieties and hybrids of major castor growing states *viz*., Andhra Pradesh, Telangana, Gujarat, Karnataka, Maharashtra, Rajasthan, Tamil Nadu, Haryana and Odisha have been provided. Upon selecting the Hybrids and Varieties tab, the basic information of each variety and hybrid has been provided along with photographs (Fig. 5).

Fig. 3. General information on castor provided in the ICARIIOR-Castor Mobile App

Fig. 4. Castor agronomic practices contents covered in the ICARIIOR-Castor Mobile App

Fig. 5. Information of state-wise preferred cultivars and details of each hybrids and varieties of castor displayed in the ICARIIOR-Castor Mobile App

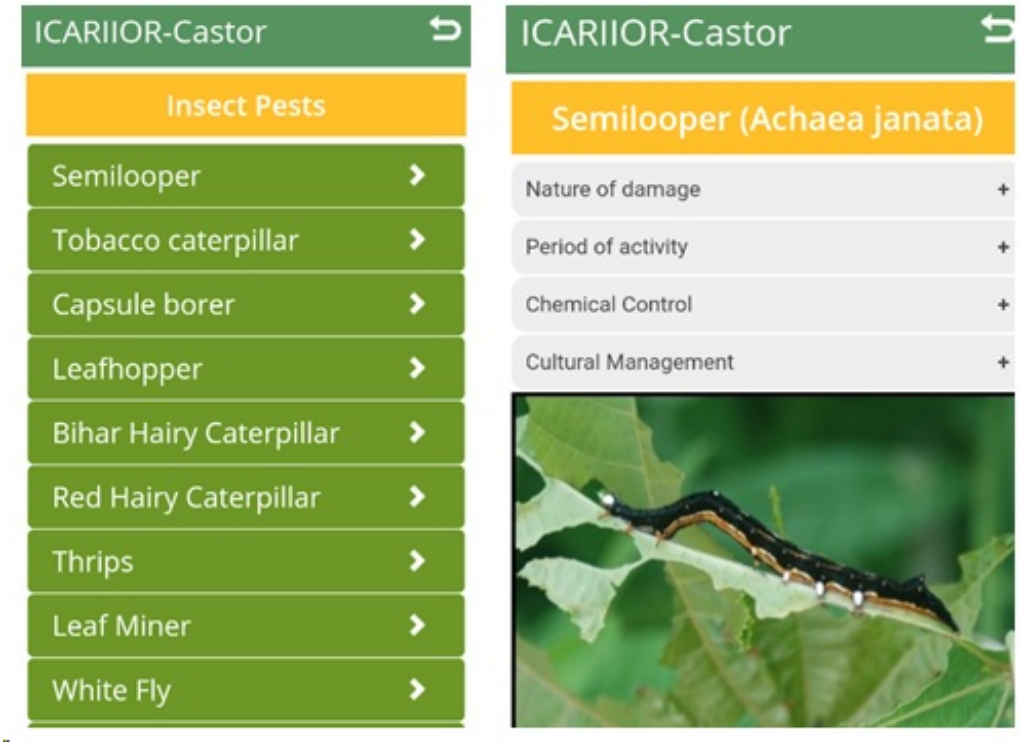

Fig. 6. Insect pests and their management tools available in the ICARIIOR-Castor Mobile App

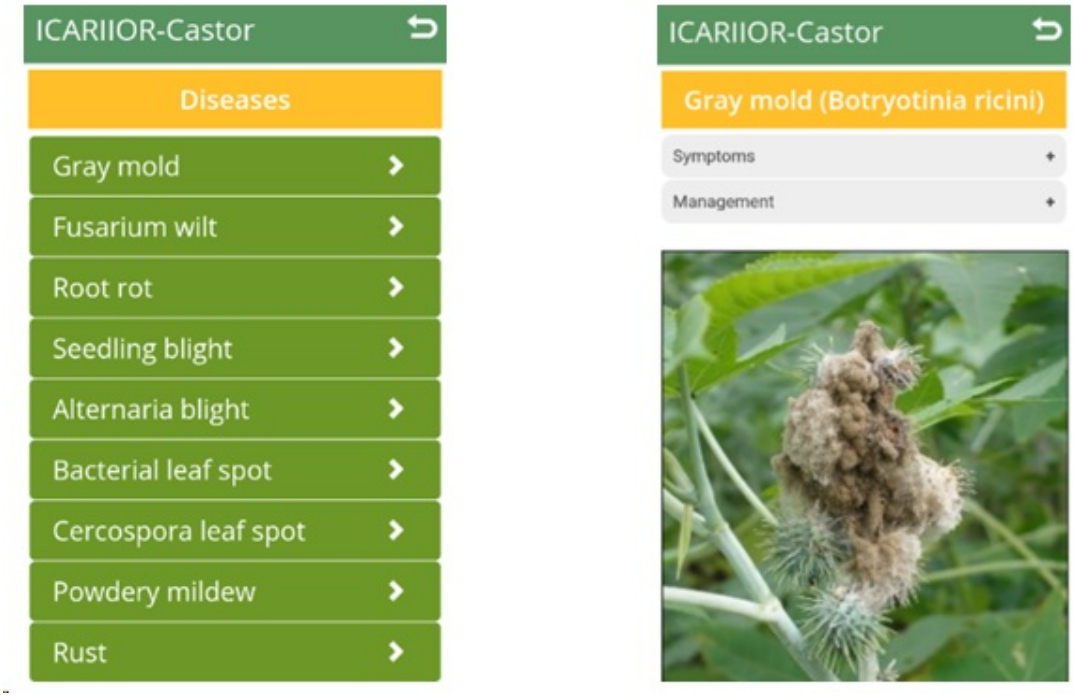

Fig. 7. Diseases and their management tools displayed in the ICARIIOR-Castor Mobile App

Out of a number of production constraints, biotic stresses *viz.*, insect pests and diseases steal the lion share of castor productivity in India (Lakshminarayana and Raoof, 2005). Identification of insect pests and their damage symptoms can facilitate the management of insect pests and diseases through appropriate management strategies and can improve productivity (Sindhuja *et al.*, 2010; Mansingh *et al.*, 2017; ICRISAT, 2018). In the Castor App under the insect pests sub heading, the list of major insect pests (semilooper, tobacco caterpillar, capsule borer, leafhopper, Bihar hairy caterpillar, red hairy caterpillar, thrips, leaf miner, whitefly) and mite pest (red spider mite) attacking the castor crop was displayed. Upon selecting the individual insect pest from drop menu, information on nature of damage, period of activity, chemical control and cultural management practices have been provided along with photographs of insects and their damage symptoms (Fig. 6). Disease identification based on the detection of early symptoms minimizes the yield losses and increases the effectiveness of the management practices (Alexander *et al.*, 2017). Under disease tab, in the App, the drop menu enlists the major diseases of castor in India *viz*., gray mold, Fusarium wilt, root rot, seedling blight, Alternaria blight, bacterial leaf spot, Cercospora leaf spot, powdery mildew and rust. Upon clicking the selected disease, the next screen provides information of the disease symptoms and disease management practices including photographs of disease symptoms (Fig. 7).

Market information can play an extremely important role in promoting agricultural development and it contributes towards strengthening farmers bargaining power and improving their awareness of market opportunities and options (FAO, 2017). In the "ICARIIOR-Castor" Mobile App, the details of the different AICRP centres in different states along with their addresses have been provided under the AICRP tab to get advice from experts. To facilitate the end user to sell the produce, the user need to identify the nearest market. Hence the details of the commodity markets from major castor growing states like Gujarat, Rajasthan, Telangana and Andhra Pradesh have been provided (Fig. 8). Linking the app to commodity markets in different agro-eco regions and making the selling price related information of each market in a dynamic mode can go a long way in helping the farmer / other stakeholder of castor in making right decisions at right time for increasing the farm profitability.

The increasing popularity, access, use of mobile phone technology and its diffusion in all the section of the society in India give a distinctive opportunity in ICT mediated extension for communicating agricultural information (Lahiri *et al.,* 2017). The 'ICARIIOR-Castor" Mobile App has been developed to offer valuable information on improved and latest varieties/hybrids and package of practices of castor to extension professionals, farmers, researchers, students and other stakeholders. The App can contribute to the knowledge empowerment of farmers about latest castor production technologies and helping them in improving their productivity.

Fig. 8. State wise commodity market information displayed in the ICARIIOR-Castor Mobile App

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Impact of technological interventions on productivity of mustard in Kymore Plateau and Satpura hills zone of Madhya Pradesh

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ABSTRACT

India is the fourth largest oilseed producer in the world. Among the edible oilseed crops cultivated in India, mustard occupies the second position after groundnut with a share of 27.5 per cent in Indian oil economy. It is also one of the important oilseed crops of Madhya Pradesh and is commonly grown in Sidhi district in Kymore Plateau and Satpura Hills zone of the state. Krishi Vigyan Kendra, Sidhi conducted 64 technological frontline demonstrations to know the yield gap between improved package of practices (IP) and farmers practices (FP) under limited irrigation conditions. The study revealed that the mustard yield in improved practice ranged from 8.75 to 13.23 q/ha whereas in farmers practice it was in the range of 6.70 to 10.09 q/ha. The technology demonstration registered highest yield (13.23 q/ha) in 2014-15 which was 31.11 per cent higher over the farmer's practice (10.09 q/ha). Extension gap and technology gap ranged between 1.87 to 3.60 and 2.95 to 11.43 q/ha respectively. The technology index ranged from 19.66 per cent to 57.15 per cent. The technology gap and index reflected farmer's collaboration in carrying out the technology demonstrations with encouraging results in preceding years. The benefit cost ratio was estimated to be 2.15 to 3.64 under demonstration, while it ranged from 1.91 to 2.85 under farmer's practice. The results indicated that these technology frontline demonstrations produced good impact on the farming community regarding the potential of technological interventions in increasing the production of mustard in the target areas.

Keywords: Extension gap, Indian mustard, Technology frontline demonstrations, Technology gap, Technology index

Oilseed constitutes the second largest agricultural commodity in India after cereals accounting for nearly 5 per cent of gross national product and 10 per cent of the value of all agricultural products. Despite the fact that India is one of the leading oilseed producing countries in the world, it is not able to meet the edible oil requirement for its own burgeoning population. Among the oilseeds, mustard is an important crop of India standing next to groundnut in terms of both area and production (Kumar *et al.,* 2017). India is one of the largest producers of rapeseed-mustard in the world and contributes 19.29 per cent and 11.18 per cent of total area and production respectively (USDA, 2012) but the average national productivity remains 1184 kg/ha which is far below the world average of 1950 kg/ha. It is cultivated in 5.76 million hectares with a production of around 6.822 million tonnes (Anonymous, 2016). In Madhya Pradesh, rapeseed- mustard is grown in an area of 0.617 million hectare with total production of 0.70 million tonnes with an average productivity of 1134 kg/ha (Anonymous, 2016). The area under mustard is 6.8 thousand hectares in the Sidhi district of Madhya Pradesh. However, average productivity of the district is 677 kg /ha which is very low in comparison to that of the state (1134 kg/ha). Low yield of mustard in the Sidhi district is attributed to the non availability of improved cultivars, inadequate dose of fertilizers, non-application of secondary plant nutrients, untimely management of diseases and pests etc. Among the various agronomic practices, date of sowing, plant spacing, seed treatment, application of biofertilizers and crop management practices play important role in determining the yield of mustard crop. Keeping in the view the above, technology frontline demonstrations were conducted by JNKVV-KVK to enhance the production of mustard. The aim of technology frontline demonstrations was to enhance the production through technology transfer and influence the farmers as well as the extension functionaries. Hence, present study was undertaken with the objective of exploring the production potential of mustard through the technological interventions under the actual farm situation in the district.

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MATERIALS AND METHODS

The present study was carried out by the Krishi Vigyan Kendra, Sidhi during *rabi,* 2009-10 to 2014-15 (six consecutive years) in the farmers' fields of randomly selected villages of Sidhi district under Kymore Plateau and Satpura Hills agro climatic zone of Madhya Pradesh. During the study, an area of 26.8 hectare was covered and the individual plot size was kept at 0.4 ha under technology frontline demonstrations in participatory mode with 64 farmers of five villages (Hadbado, Mamder, Jhalwar, Chorgarhi and Karwahi) of Sidhi district. Before conducting these

demonstrations, farmers were selected through group meeting and specific training as suggested by Venkattakumar *et al.* (2010). Training was given to the selected farmers regarding different aspects of cultivation that were to be followed. In general, the soils of the experimental sites were loam to sandy loam in texture, neutral in reaction (pH 7.0 to 7.9), low to medium in organic carbon (0.45 to 0.69%) and available nitrogen (249 to 312 kg/ha), medium in available phosphorus (12.9 to 21.31 kg/ha) and high in Potassium (282.5 to 315.21 kg/ha). The package of improved technologies included improved variety of mustard i.e., JM 3 sown in 2009, Pusa Tarak in 2010-11, 2012-13 and 2014-15 and Pusa Agrani in 2011-12 and 2013-14. Seeds treated with metalaxyl @ 6 g/kg seed for prevention of seed borne diseases (Chattopadhyay *et al.,* 2003) and inoculated with PSB @ 20 g/kg for increasing availability of phosphorus to the crop roots. Sowing was done between 15th October to 30th October every year with a seed rate of 5 kg/ha and 30x15 cm plant geometry. The recommended dose of NPKS fertilizers were supplied @ 60:40:20:40 kg/ha through DAP, urea, muriate of potash and sulphur dust in each demonstrations. Full dose of fertilizers were applied as basal except N which was supplemented in two splits. Weed control was done by use of pre-emergence herbicide pendimethalin @ 0.3 kg a.i./ha and once hand weeding at 35 DAS for effective control of weed. To prevent the yield losses in the crop from aphid, spray of NSKE @ 5 per cent was done when 10-15 aphid/plant were observed. Harvesting was done during first fortnight of March every year. The farmer's practice included use of seeds of local varieties @ 4-5 kg/ha and fertilizer doses were 18 kg N and 46 kg P/ha. Entire dose of N and P were broadcasted along with seed under mixed cropping of wheat/gram/lentil at the time of sowing. Sowing was done by farmers during second to third week of November every year. No protection measures were taken by the farmers for management of aphid. The seasonal rainfall data (during crop period) varied from 88.8 to 117.0 mm. Comparison between technology demonstration package and existing farmers' practice for mustard is given in Table 1.

Table 1 Details of technology demonstration package and farmers' practice in mustard

Particulars	Demonstration Package	Farmers' Practice
Variety	JM-3, Pusa Tarak and Pusa Agrani	Degenerated seeds of Varuna cultivar
Seed rate	5 kg/ ha	4-5 kg/ha
System of Sowing	Sole crop	Mixed with wheat/ gram/lentil
Seed treatment	Metalaxyl @ 6 g/ kg seed + PSB @ 5 g/kg seed	Nil
Sowing time	IInd fortnight of October	IInd – IIIrd week of November
Sowing Methods	Line Sowing at 30X 15 cm spacing	Broadcasting
Farming Situation	Irrigated (Two irrigation)	Rainfed
NPKS	@ 60:40:20:40 kg/ha	18:46:0:0 kg/ha
Insect pest management	Spray of NSKE @ 5% at ETL (30 % plant affected by aphid)	Spray of Dimethoate @ 1 ml/litre

Visit of farmers and extension functionaries was organized at the demonstration plots of improved technological interventions to disseminate the massage at large scale. KVK scientists facilitated the demonstrations by regular visit during field operations like sowing, fertilizer application, pest management, weed management and harvesting. The output data was collected from both FLD plot as well as farmer's practice plot and finally the extension gap, technology gap, technology index along with cost benefit ratio were calculated (Samui *et al.,* 2003) as given below:

Extension Gap (kg/ha) =
(Yield in improved practices - Yield in farmer's practice)
Technology Gap (kg/ha) =
(Potential yield - Yield in improved practice)
Technology index (%) =
(Technology Gap/Potential yield) x 100

RESULTS AND DISCUSSION

Yield: The productivity of mustard in Sidhi district of Madhya Pradesh under improved production technology ranged between 857 to 1323 kg/ha with a mean seed yield of 1069 kg/ha (Table 3). The productivity of mustard in technology demonstrations showed consistent increase across the years of demonstrations. Productivity ranged from 819 to 972, 807 to 953, 897 to 1091, 907 to 1310, 1176 to 1488 and 1207 to 1523 kg/ha with an average seed yield of 910, 857, 924, 1195, 1205 and 1323 kg/ha during 2009-10, 2010-11, 2011-12, 2012-13, 2013-14 and 2014-15 respectively over the farmer practice. Seed yield ranged between 695 to 1009 kg/ha with an average of 820.16 kg/ha. The additional yield under technological interventions over the farmer's practices ranged from 187 to 360 kg/ha with an average of 248.84 kg/ha. An increase of 31.5 %, 31.2%, 27.44 %, 43.11%,

28.19%, and 31.11% in productivity of mustard under improved technology demonstrations was noted in 2009-10, 2011-12, 2012-13, 2013-14 and 2014-15 respectively over farmers practice. The increased seed yield with improved production practice was mainly because of increased total dry matter, number of siliquae per plant and harvest index (Table 2). Similar results of yield enhancement in mustard front line demonstrations has been documented by Meena *et al.* (2012) in Rajasthan. The results are also in conformity with the findings of Katare *et al.* (2011), Dutta (2014) and Ram and Anand (2014).

Yield attributing characters: The data on yield attributing characters of mustard for six years (Table 3) revealed that number of siliquae per plant under improved technology demonstrations were 149, 159, 159, 179, 156.2 and 158.33 in comparison to farmers' practice (local check) which was 112, 117, 128, 121, 112 and 114.7 during 2009-10, 2010-11, 2011-12, 2012-13, 2013-14 and 2014-15 respectively. The increase percentage in number of siliquae per plant was 33.03, 35.89, 24.21, 47.93, 39.46 and 38.03 per cent over the local check (farmers' practice). The average number of siliquae per plant was 160.08 under technology demonstrations and 117.45 under farmers practice, thus there was 36.42 percent more siliquae per plant under technology demonstrations as compared to farmers' practice. Meena *et al.* (2012) and Dutta (2014) reported an increase of 22.22 to 31.48 percent in the number siliquae per plant in improved production technology in mustard front line demonstrations over farmers' practice.

Aphid population: The data on aphid infestation after spray of NSKE @ 5% during the study period presented in Table 3 clearly indicated that during 2009-10, 2010-11, 2011-12, 2012-13, 2013-14 and 2014-15 the per cent aphid infestation under technology demonstrations were 8.5, 6.75, 11, 9.5, 8.25 and 7.0 per cent with an average of 8.5 percent as compared to that in farmers practice which was 36.75, 76.23, 63.57, 56.3, 51.5 and 59.5 per cent respectively with an average of 57.33 percent aphid infestation. The percent reduction in aphid infestation under technology demonstrations during the study years was 74.82, 91.14, 82.69, 83.12, 83.98 and 88.23 per cent with an average of 83.99 from 2009-10 to 2014-15. These findings are in conformity with those of Singh and Lal (2009) and Chanchal and Lal (2009) who found that NSKE 5% was effective in reducing the mustard aphid population.

Table 2 Effect of improved production technology on yield of mustard under frontline demonstrations

Year	Variety	No. of demonostra-tions	Area (ha)	Demo yield (kg/ha)			Yield of Local Check (kg/ha)	Per cent increase over local check
				Highest	Lowest	Average		
2009-10	JM-3	05	2.0	972	819	910	695	31.5
2010-11	Pusa Tarak	12	5.0	953	807	857	670	31.20
2011-12	Pusa Agrani	11	4.8	1091	897	924	725	27.44
2012-13	Pusa Tarak	12	5.0	1310	907	1195	835	43.11
2013-14	Pusa Agrani	12	5.0	1488	1176	1205	987	28.19
2014-15	Pusa Tarak	12	5.0	1523	1207	1323	1009	31.11
Total/ Average		64	26.8	1222.83	968.83	1069	820.16	32.09

Table 3 Effect of improved production technology on aphid infestation and yield attributing character of mustard

Year	Aphid infestation (%)		% decrease in aphid infestation over farmers practice	Incidence of *Alternaria* blight (%)		% decrease in incidence of *Alterneria* blight over farmers practice	Yield attributing characters (No. of siliquae/plant)		% age Increase over farmers practice
	Improved Practice	Farmers Practice		Improved Practice	Farmers Practice		Improved Practice	Farmers Practice	
2009-10	8.5	36.75	74.82	9.6	34.2	71.90	149	112	33.03
2010-11	6.75	76.23	91.14	8.9	36.12	75.35	159	117	35.89
2011-12	11.0	63.57	82.69	10.75	31.5	65.87	159	128	24.21
2012-13	9.5	56.3	83.12	11.25	39.6	71.59	179	121	47.93
2013-14	8.25	51.5	83.98	10.5	38.12	72.45	156.2	112.0	39.46
2014-15	7.0	59.5	88.23	11.5	39.5	70.88	158.33	114.7	38.03
Average	8.5	57.33	83.99	10.41	36.50	71.34	160.08	117.45	36.42

Economic return: The Economic viability of improved technology over farmers' practice was calculated depending on prevailing price of inputs and outputs (Table 4). It was found that the additional cost of production of mustard under technology demonstrations varied from ₹1250.0 to 1520.90/ha with an average of ₹1352.73/ha over farmers' practice which varied from ₹7092 to 11577.25/ha with an average of ₹ 9002.62/ha. The additional cost incurred in technology demonstrations over farmers practice was mainly due to more cost involved in fertilizer, improved quality seed, seed treatment and IPM measures, However the improved technology resulted in higher net return which ranged from ₹8695 to 23589.30/ha with an average of ₹ 15909.70/ha as compared to farmers' practice which recorded ₹ 6506 to 17202.7/ha with an average of ₹ 10886/ha. The improved technology demonstrations also gave higher benefit cost ratio of 2.52, 2.15, 2.5, 3.64, 2.18 and 2.78 as compared to 1.91, 1.96, 2.29, 2.85, 2.00 and 2.55 under farmers' practice in the corresponding years from 2009-10 to 2014-15. The additional income could substantially benefit the mustard growers of the region and improve their livelihood too. These results are in conformity with findings of Meena *et al.* (2012), Dutta (2014) and Sarma *et al.* (2014) in front line demonstration of rapeseed-mustard.

Technology gap: The technology gap varied between 395 - 893 kg/ha (Table 4) at all the locations which proved that encouraging results were obtained in technology demonstrations on account of farmers' cooperation. The variation observed in technology gap may be attributed to the dissimilarity in soil-fertility status and weather conditions at different locations. Technology gap was noted to be highest in the year 2010-11 (893 kg/ha). Similar results of technology gap in rapeseed- mustard crop in front line demonstrations have been recorded by Ram and Anand (2014), Meena et al. (2012), Dutta (2014) and Sarma (2014) who opined that lower the value of technology index, more is the feasibility of the technology demonstrated.

Table 4 Economic impact of improved production technology of mustard under front line demonstrations

Year	Economics of Mustard Production (₹/ha)								
	Cost of cultivation (₹/ ha)		Net returns (₹/ha)		B:C ratio		Additional Cost (q/ha.)	Additional return (₹/ha)	Additional Benefit cost-ratio
	Improved Practices	Farmers Practices	Improved Practices	Farmers Practices	Improved Practices	Farmers Practices			
2009-10	7922.0	6692	13840.0	6506.0	2.52	1.91	1250.0	7334.0	5.86
2010-11	8005.0	6775	8695.0	6065.0	2.15	1.96	1230.0	2630.0	2.13
2011-12	7487.5	6315.0	11292.5	8185.0	2.57	2.29	1272.5	3107.5	2.44
2012-13	8389.0	7016.0	21686.5	15559.0	3.64	2.85	1373.0	6127.5	4.46
2013-14	12770.0	11300	16355.0	11800	2.18	2.00	1470.0	4555.0	3.08
2014-15	12589.1	11077.2	23589.3	17202.7	2.78	2.55	1520.9	6387.3	4.20
Average	9527.10	8195.86	15909.71	10886.0	2.64	2.26	1352.73	5023.58	3.71

Table 5 Technology gap, extension gap and technology index in mustard frontline demonstrations

Year	Potential yield (kg/ha)	Yield (kg/ha)		Technology gap (kg/ha)	Extension gap (kg/ha)	Technology Index (%)
		Improved Practices	Farmers Practices			
2009-10	1600	910	695	690.0	215	43.12
2010-11	1750	857	670	893.0	187	51.05
2011-12	1600	924	725	676.0	199	42.25
2012-13	1750	1195	835	555.0	360	31.71
2013-14	1600	1205	987	395.0	218	24.68
2014-15	1750	1323	1009	427	314	24.40
Average	1675	1069.0	820.16	606.0	248.83	36.20

Extension gap: The highest extension gap of 360 kg/ha and lowest 187 kg/ha were observed in year 2012-13 and 2010-11 respectively (Table 4). This emphasized the need to educate the farmers through various means for the adoption of improved production technologies of rapeseed-mustard to reverse the trend of wide extension gap. More and more use

of latest production technologies with high yielding variety will subsequently change this alarming trend of galloping extension gap. The new technologies will eventually lead farmers to discontinue the old variety/technology and to adopt new technology. These findings are in corroboration with the findings of Meena *et al.* (2012) and Sarma *et al.* (2014).

Technology index: The technology index show the feasibility of the evolved technology for the evaluation at farmers' field and lower the value of technology index more is the feasibility of the technology (Jeengar *et al.,* 2006). It was ranging between 24.40 to 51.05 per cent. The lower value of the technology index for the year 2014-15 was due to severe attack of aphid. This indicated that the yield gap exists between the technology generated at research station and farmers' fields. In comparative profitability of mustard, the additional benefit cost ratio was obtained in the year 2014-15 (1:4.2) due to the adoption of recommended mustard production technology (Table 5). Front line demonstrations are known to impact the production of mustard in a positive manner (Ahamad *et al.,* 2013).

In conclusion, the Improved production technology of varieties (JM-3/Pusa Tarak/Pusa Agrani) of mustard performed better (average yield 1069 kg/ha) over the control i.e. farmers' practice (average yield 820.16 kg/ha) at all the locations under technology demonstrations. From the above findings, conclusion can be drawn that use of improved technology with suitable variety can reduce the yield gap up to a considerable extent leading to increased productivity of mustard crop in the district. Moreover, extension agencies in the district need to provide proper technical guidance and support to the farmers through different educational and extension methods to reduce the extension gap for better mustard production in the district. KVK has also played a major role in serving as a linkage mechanism.

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Impact of frontline demonstrations on the yield and economics of castor in Saurashtra region of Gujarat under climate change conditions

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ABSTRACT

Sixty five frontline demonstrations (FLDs) were organized on farmers' fields to demonstrate the impact of improved technology on castor productivity in Saurashtra region of Gujarat state during the years 2011-12 to 2015-16 under irrigated conditions to ascertain the yield gaps between improved technology (IT) and farmer's practice (FP) in castor crop. The productivity and economic returns of castor crop in improved technologies were calculated and compared with the corresponding farmer's practices (local checks). In the FLDs, the results revealed that seed yield (3640 kg/ha) of improved technology was higher as compared to farmers' practice (3148 kg/ha). Higher gross returns, net returns and benefit cost ratio were recorded in FLD plots as compared to farmers' practice plots. The average technology gap, extension gap and technology index were 3360 kg/ha, 492 kg/ha and 94 per cent, respectively in FLD plots as compared to farmers' practice plots. Each year, extension gap was lower than technology gap indicating the need to educate farmers in adoption of improved technologies. It is suggested that location-specific approaches would be needed to bridge the productivity gap of castor crop in the region.

Keywords: Castor, Extension gap, Frontline demonstration, Technology gap

In India, castor (*Ricinus communis* L.) crop is grown in an area of 10.63 lakh ha, with a production of 17.27 lakh tonnes and productivity of 1624 kg/ha (Anonymous, 2015). Gujarat, Andhra Pradesh and Rajasthan are the major castor producing states. Frontline demonstration (FLD) is a long term educational activity conducted in a systematic manner on farmers' fields to show the worth of a new practice/technology. Farmers in India are still producing crops based on the knowledge transferred to them by their forefathers leading to a grossly unscientific agronomic, nutrient management and pest management practices (Kumar *et al,* 2015; Vaghasia *et al.,* 2016). As a result of these, they often fail to achieve the desired potential yield of various crops and new varieties. The major objective of the frontline demonstration project is to demonstrate, under real farm situation, the productivity potentials and profitability of the latest, improved technologies of oilseed crops vis-a-vis prevailing farmers' practices. Keeping in view the significance of transfer of technology, the present investigation was carried out to know the yield gaps between on FLD trial and farmers' field, extent of technology adoption and additional benefit and cost ratios.

MATERIALS AND METHODS

The frontline demonstrations (FLDs) on castor were carried out at farmers' fields in Junagadh, Rajkot and Amreli districts of Gujarat state during the years 2011-12 to 2015-16 under irrigated conditions. The soils of the region are medium black, low in nitrogen, medium in phosphorus and high in potash with pH ranging from 7.9 to 8.9. The critical inputs were applied as per the scientific package of practices recommended by the Junagadh Agricultural University, Junagadh. The component demonstration of frontline technology in castor comprised of improved technologies, including hybrid variety (GCH-7) and nutrient management (120-50 NP kg/ha). Whole of the phosphorus and 33 % nitrogen were applied in the form of DAP and urea as basal dose and remaining nitrogen in the form of Urea was top dressed in three equal splits at 40, 70 and 100 days after sowing of crop. For the control of weeds, Pendimethalin @ 1.0 kg/ha was applied two days after sowing of the crop. At the incidence of semilooper, methomyl @1.5 kg/ha was sprayed. Line sowing of the crop was taken up during the last week of July by using seed @ 5 kg/ha. The seeds were sown 5-7 cm deep with crop geometry of 120cm×60cm. Each FLD was conducted in an area of one acre and compared with existing farmer's practice adjacently taken up in one acre. A team of scientists including agronomist, plant breeder and plant pathologist visited and monitored the demonstration sites at regular interval during the crop growth period. The data on seed yield, cost of cultivation and net returns were collected after harvesting of the crop. The technology gap, extension gap and technology index were calculated as given by Samui *et al*. (2000) by using following formulae:

i) Technology gap = (Potential yield) - (Demonstration yield)

ii) Extension gap = (Demonstration yield) - (Farmer's yield)

$$\text{iii) Technology index} = \frac{Pi - Di}{Pi} \times 100$$

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Where,

Pi = Potential yield of the i^{th} crop

Di = Demonstration yield of the i^{th} crop

RESULTS AND DISCUSSION

The frontline demonstrations on castor for showing the production potential and profitability under real farm situation were conducted across five districts of Gujarat during the years 2011-12 to 2015-16. A total of 65 demonstrations were conducted, under irrigated conditions. The yield enhancement ranged from 14 to 19 %. The average yield in demonstration (Table 1) varied from 3292 to 4063 kg/ha during five years. The highest yield (4063 kg/ha) in demonstration was recorded during 2014-15 followed by 3917 kg/ha during 2013-14. The lowest yield (3292 kg/ha) was recorded during 2012-13. Similar trend in relation to highest and lowest yield was also observed in local check plot. However, the potential yield of the hybrid, GCH-7 is 7000 kg/ha. In general, in all the years, yield of demonstration plots was higher as compared to local check plot, which was due to timely sowing of crop with recommended hybrid and management practices. The gaps between the existing and recommended technologies of castor are presented in Table 1 and 2. A wide gap was observed in crop potential yield and frontline demonstration yield. This might be due to variation in soil fertility, poor irrigation facility, non- congenial weather and location specific management problems. Similar results have been reported earlier by Padmaiah *et al.* (2012) and Kumar *et al.* (2015).

Technology gap: The technology gap (Table 1) showed the gap in the demonstration yield over potential yield and it was the highest during 2012-13 (3708 kg/ha) in comparison to the rest of the years. On an average technology gap under five years of FLD programme was 3360 kg/ha. The observed technology gap was mainly attributed to dissimilarity in soil fertility status, agricultural practices and local climatic situation. The technology gap remained higher than extension gap during all the five years, which indicated that there is wide scope to further exploit the potential yield of the crop.

Table 1 Production potentials of component technologies in castor during the years 2011-12 to 2015-16

Year	Variety	No. of FLD	Area (ha)	Average yield (kg/ha)		Increase in yield (%)	Technological gap (kg/ha)	Extension gap (kg/ha)	Technology index (%)
				FLD	Local				
2011-12	GCH-7	20	8	3431	2990	15	3569	441	50.98
2012-13	GCH-7	10	4	3292	2781	18	3708	511	52.97
2013-14	GCH-7	10	4	3917	3458	14	3083	459	44.02
2014-15	GCH-7	10	4	4063	3563	14	2937	500	41.96
2015-16	GCH-7	15	6	3495	2948	19	3505	547	50.07
Mean	-	-	-	3640	3148	16	3360	492	48.00

Note: Potential yield of GCH-7 - 7000 kg/ha

Table 2 Economic viability and profitability of FLD (₹/ha)

Particulars	Years				
	2011-12	2012-13	2013-14	2014-15	2015-16
Production cost					
FLD plot	24731	23061	24296	27543	27232
Local plot (Check)	22431	20246	23787	26342	26035
Additional cost over local plot	2305	2815	509	1201	1197
Gross return					
FLD plot	137222	108625	137083	162500	110479
Local plot (Check)	119583	91781	121042	142500	93229
Net return					
FLD plot	112486	85564	112788	134957	83247
Local plot (Check)	97153	71535	96255	116158	67194
Additional return	15333	14029	16533	18799	16053
Per cent increase in net return	16	20	17	16	24
ICBR on additional input in demonstration	7	5	32	16	13

Extension gap: The highest extension gap of 547 kg/ha was recorded in the year 2015-16 as compared to other years and average extension gap was 492 kg/ha. This emphasized the need to educate the farmers through various extension means i.e., frontline demonstration for adoption of improved production and protection technologies to revert the trend of extension gap. More and more use of latest production technologies with high yielding varieties will subsequently change this alarming trend of galloping extension gap. Padmaiah *et al.* (2012) have also opined that depending on identification and use of farming situation, specific interventions may have greater implications in enhancing system productivity.

Technology index: The adoption of technology in FLD was studied through technology index and recommended package of practices being followed by the farmers. The lower the value of technology index, higher is the feasibility of technology. The technology index varied from 41.96 to 52.97 per cent (Table 2). The technology index was minimum for the year 2014-15 (41.96 %) as compared to the rest of the years. On an average, technology index was 48 per cent during the five years of FLD programme, which showed the efficacy of good performance of technical interventions. This indicates that a wide gap existed between technology evolved and technology adoption at farmer's field. Similar verdicts were also recorded by Thakral and Bhatanar (2002) and Kumar *et al.* (2015).

Economic impact: During the period of study, the inputs and outputs prices of commodities prevailed during each year of demonstrations were taken for calculating cost of cultivation, net return and benefit cost ratio (Table 2). The economic analysis of the data over five years revealed that average of five years' frontline demonstrations in improved technologies (IT) recorded higher productivity of seed yield (3640 kg/ha). The increase in the productivity of castor crop over local check (LC) was 16.0% and higher gross returns (Rs. 131182/ha), net return (₹105808/ha) and B:C ratio on additional input in demonstration (15.0) as compared to the local checks. The per cent increase in net return ranged from 16 to 24 % over local check plot. The higher per cent increase in net return (24%) during the year 2015-16 might be due to the highest per cent increase yield of FLD plot as compared to local check plot. The results clearly indicated higher productivity of castor under improved technologies over the years compared to local check due to knowledge and adoption of full package of practices i.e., sowing of latest high yielding hybrids, adoption of improved nutrient, moderate disease resistant hybrid and adoption of improved weed and pest management techniques. Similar results have been reported earlier by Padmaiah *et al.* (2012) and Kumar *et al.* (2015). The year wise fluctuation in yield was observed mainly on the account of variations in soil fertility status and moisture availability due to untimely rainfall every year.

The productivity gain under FLD over existing practices of castor cultivation created greater awareness and motivated the other farmers to adopt suitable production technology of castor. The constraints faced by the farmers were different for different technologies. Therefore, for enhancing the production and productivity of castor crop, strategy should be made for getting the more and more recommended technologies adopted by the farmers. Hence, it suggested that frontline demonstration trails are to be used as a transfer of technology tool for adoption of improved castor production technology.

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This section is meant to introduce the subject of the paper. Introduction should be short, concise and indicate the objectives and scope of the investigation. To orient readers, give a brief reference to previous concepts and research. Limit literature references to essential information. When new references are available, do not use old references unless it is of historical importance or a landmark in that field. Emphasis should be given among other things on citing the literature on work done under Indian conditions. Introduction must include: (a) a brief statement of the problem, justifying the need for doing the work or the hypothesis on which the work is based, (b) the findings of others that will be further developed or challenged, and (c) an explanation of the approach to be followed and the objectives of the research described in the paper. If the methods employed in the paper are new, it must be indicated in the introduction section.

Materials and methods (To be typed as side-heading, starting from the left-hand margin, a few spaces below the introduction)

This part of the text should comprise the materials used in the investigation, methods of experiment and analysis adopted. This portion should be self-explanatory and have the requisite information needed for understanding and assessing the results reported subsequently. Enough details should be provided in this section to allow a competent scientist to repeat the experiments, mentally or in fact. The geographical position of soil site or soils used in the experiment or site of field trial should be identified clearly with the help of coordinates (latitude & longitude) and invariably proper classification according to Soil Taxonomy (USDA), must be indicated to the level of Great-group, Suborder or Order as far as possible. Specify the period during which the experiment(s) was conducted. Send the article after completion of the experiment(s) not after a gap of 5 years. Instead of kharif and rabi use rainy and winter season respectively. Please give invariably the botanical names for local crop names like raya, bajra moong, cholam etc. Botanical and zoological names should confirm to the international rules. Give authorities. Go through some of our recent issues and find out the correct names. Give latest correct names from authentic source. For materials, give the appropriate technical specifications and quantities and source or method of preparation. Should a product be identified by trade name, add the name and location of the manufacturer or a major distributor in parenthesis after the first mention of the product. For the name of plant protection chemicals, give popular scientific names (first letter small), not trade names (When trade name is given in addition, capitalize the first letter of the name). Known methods of analysis should be indicated by referring to the original source, avoiding detailed description. Any new technique developed and followed should be described in fair detail. When some specially procured or proprietary materials are used, give their pertinent chemical and physical properties. References for the methods used in the study should be cited. If the techniques are widely familiar, use only their names in that case.

Results and Discussion (To be typed as a side-heading, a few spaces below the matter on "Materials and Methods")

This section should discuss the salient points of observation and critical interpretation thereof in past tense. This should not be descriptive and mere recital of the data presented in the tables and diagrams. Unnecessary details must be avoided but at the same time significant findings and special features should be highlighted. For systematic discussion, this section may be divided into sub-sections under side-heading and/or paragraph side heading. Relate the results to your objectives. While discussing the results, give particular attention to the problem, question or hypothesis presented in the introduction. Explain the principles, relationships, and generalizations that can be supported by the results. Point out any exceptions. Explain how the results relate to previous findings, support, contradict or simply add as data. Use the Discussion section to focus on the meaning of your findings rather than recapitulating them. Scientific speculation is encouraged but it should be reasonable and firmly founded in observations. When results differ from previous results, possible explanations should be given. Controversial issues should be discussed clearly. References to published work should be cited in the text by the name(s) of author(s) as follows: Mukherjee and Mitra (1942) have shown or It has been shown (Mukherjee and Mitra, 1942)..... If there are more than two authors, this should be indicated by et al. after the surname of the first author, e.g., Mukherjee et al. (1938).

Always conclude the article by clearly crystallizing the summary of the results obtained along with their implications in solution of the practical problems or contribution to the advancement of the scientific knowledge.

Acknowledgments (To be typed as given above, as a side-heading, well below the concluding portion of Conclusions)

The author(s) may place on record the help, and cooperation, or financial help received from any source, person or organization. This should be very brief, and omitted, if not necessary.

References (To be typed as above, as side heading below Acknowledgement)

The list of references must include all published work referred to in the text. Type with double line spacing. Do not cite anonymous as author; instead cite the name of the institute, publisher, or editor. References should be arranged alphabetically according to the surnames of the individual authors or first authors. Two or more references by the same author are to be cited chronologically; two or more in the same year by the letters a, b, c, etc. All individually authored articles precede those in which the individual is the first or joint author. Every reference cited in the article should be included in the list of References. This needs rigorous checking of each reference. Names of authors should not be capitalized.

The reference citation should follow the order: author(s), year of publication, title of the paper, periodical (title in full, no abbreviations, italics or underlined), volume (bold or double underlining), starting and ending pages of the paper. Reference to a book includes authors(s), year, title (first letter of each word except preposition, conjunction, and pronouns in capitals and underlined), the edition (if other than first), the publisher, city of publication. If necessary, particular page numbers should be mentioned in the last. Year of publication cited in the text should be checked with that given under References. Year, volume number and page number of each periodical cited under "References" must be checked with the original source. The list of references should be typed as follows:

Rao C R 1968. *Advances in Statistical Methods in Biometrical Research*, pp.40-45, John Wiley & Sons, New York.

Kanwar J S and Raychaudhuri S P 1971. *Review of Soil Research in India*, pp 30-36. Indian Society of Soil Science, New Delhi.

Mukherjee J N 1953. The need for delineating the basic soil and climatic regions of importance to the plant industry. *Journal of the Indian Society of Soil Science*, **1** : 1-6.

Khan S K, Mohanty S K and Chalam A B, 1986. Integrated management of organic manure and fertilizer nitrogen for rice. *Journal of the Indian Society of Soil Science*, **34** : 505-509.

Bijay-Singh and Yadvinder-Singh 1997. Green manuring and biological N fixation: North Indian perspective. In: Kanwar J S and Katyal J C (Ed.) *Plant Nutrient Needs, Supply, Efficiency and Policy Issues 2000-2025*. National Academy of Agricultural Sciences, New Delhi, India, pp.29-44.

Singh S, Pahuja S S and Malik R K 1992. Herbicidal control of water hyacinth and its effect on chemical composition of water *(in) Proceedings of Annual Weed Science Conference*, held during 3-4 March 1992 by the Indian Society of Weed Science, at Chaurdhary Charan Singh Haryana Agricultural University, Hisar, 127p.

AICRP on Soybean 1992. *Proceedings of 23rd Annual Workshop of All-India Co-ordinated Research Project on Soybean*, held during 7-9 May 1992 at University of Agricultural Sciences, Bangalore, Karnataka, National Research Centre for Soybean, Indore, pp.48.

Devakumar C. 1986. Identification of nitrification retarding principles in neem (*Azadirachta indic*a A.Juss.) seeds. Ph D Thesis, Indian Agricultural Research Institute, New Delhi.

Reference to unpublished work should normally be avoided and if unavoidable it may be mentioned only in the text.

Short Communication

Conceptually short communication is a first report on new concept, ideas and methodology which the author(s) would wish to share with the scientific community and that the detailed paper would follow. Short Communication is akin to an advance booking for the report on the findings. Short communications may include short but trend-setting reports of field or laboratory observation(s), preliminary results of long-term projects, or new techniques or those matters on which enough information to warrant its publication as a full length article has still not been generated but the results need to be shared immediately with the scientific community. The style is less formal as compared with the "full-length" article. In the short communications, the sections on abstract, materials and methods, results and discussion, and conclusion are omitted; but the material is put concisely in the same sequence but without formal sections. The other instructions are the same as in the case of the full-length articles.

Tables

Tables should not form more than 20% of the text. Each table should be typed on separate sheet and should have on the top a table number (in Arabic numerals *viz*. 1, 2, 3 etc.) and a caption or title which should be short, but sufficiently explanatory of the data included in the table. Information in the table should never duplicate that in the text and vice versa. Symbols (asterisks, daggers, etc. or small letters, *viz*., a, b, etc.) should be used to indicate footnotes to tables. Maximum size of table acceptable is what can be conveniently composed within one full printed page of the journal. Over-sized tables will be rejected out-right. Such tables may be suitably split into two or more small tables.

The data in tables should be corrected to minimum place of decimal so as to make it more meaningful. Do not use full stop with CD, SEm $\pm$, NS (not C.D., S.E.m $\pm$, N.S.). Do not put cross-rules inside the table. Tables should be numbered consecutively and their approximate positions indicated in the margin of the manuscript. Tables should not be inserted in the body of the text. Type each table on a separate sheet. Do not use capital letters for the tabular headings, do not underline the words and do not use a full-stop at the end of the heading. All the tables should be tagged with the main body of the text i.e. after references.

Figures

Figures include diagrams and photographs. Laser print outs of line diagrams are acceptable while dot-matrix print outs will be rejected. Alternatively, each illustration can be drawn on white art card or tracing cloth/ paper, using proper stencil. The lines should be bold and of uniform thickness. The numbers and letterings must be stenciled; free-hand drawing will not be accepted. Size of the illustrations as well as numbers, and letterings should be sufficiently large to stand suitable reduction in size. Overall size of the illustrations should be such that on reduction, the size will be the width of single or double column of the printed page of the Journal. Legends, if any, should be included within the illustration. Each illustration should have a number followed by a caption typed/ typeset well below the illustration.

Title of the article and name(s) of the author(s) should be written sufficiently below the caption. The photographs (black and white) should have a glossy finish with sharp contrast between the light and the dark areas. Colour photographs/ figures are not normally accepted. One set of the original figures must be submitted along with the manuscript, while the second set can be photocopy. The illustrations should be numbered consecutively in the order in which they are mentioned in the text. The position of each figure should be indicated in the margin of the text. The photographs should be securely enclosed with the manuscript after placing them in hard board pouches so that there may not be any crack or fold. Photographs should preferably be 8.5 cm or 17 cm wide or double the size. The captions for all the illustrations (including photographs) should be typed on a separate sheet of paper and placed after the tables.

Expression of Plant Nutrients on Elemental Basis

The amounts and proportions of nutrient elements must be expressed in elemental forms e.g. for ion uptake or in other ways as needed for theoretical purposes. In expressing doses of nitrogen, phosphatic, and potassic fertilizers also these should be in the form of N, P and K, respectively. While these should be expressed in terms of kg/ha for field experiments, for pot culture studies the unit should be in mg/kg soil.

SI Units and Symbols

SI Units (System International d 'Unities or International System of Units) should be used. The SI contains three classes of units: (i) base units, (ii) derived units, and (iii) supplementary units. To denote multiples and sub-multiples of units, standard abbreviations are to be used. Clark's Tables: Science Data Book by Orient Longman, New Delhi (1982) may be consulted.

Some of these units along with the corresponding symbols are reproduced for the sake of convenience.

Names and Symbols of SI Units

Physical Symbol for SI Unit Symbol Remarks quantity physical quantity for SI Unit

Primary Units					
length	l		time	t	
metre	m		second	s	
mass	m		electric current	I	
kilogram	kg		ampere	A	
Secondary Units					
plane angle	radian	rad	Solid angle	steradian	sr
Unit Symbols					
centimetre	cm		microgram	µg	
cubic centimetre	cm^3		micron	µm	
cubic metre	m^3		micronmol	µmol	
day	d		milligram	mg	
decisiemens	dS		millilitre	mL	
degree-Celsium	°C [=(F-32)x0.556]		minute	min	
gram	g		nanometre	nm	
hectare	ha		newton	N	
hour	h		pascal	Pa	
joule J	(=10^7 erg or 4.19 cal.)		second	s	
kelvin	K (=°C+273)		square centimetre	cm^2	
kilogram	kg		square kilometre	km^2	
kilometre	km		tonne	t	
litre	L		watt	W	
megagram	Mg				

Some applications along with symbols

adsorption energy	J/mol (=cal/molx4.19)	leaf area	m^2/kg
cation exchange capacity	cmol (p+)/kg (=m.e./100 g)	nutrient content in plants (drymatter basis)	µg/g, mg/g or g/kg
Electrolytic conductivity	dS/m (=mmhos/cm)	root density or root length density	m/m^3
evapotranspiration rate	$m^3/m^2/s$ or m/s	soil bulk density	Mg/m^3 (=g/cm^3)
heat flux	W/m^2	specific heat	J/kg/K
gas diffusion	$g/m^2/s$ or $m^3/m^2/s$ or m/s	specific surface area of soil	m^2/kg
water flow	$kg/m^2/s$ (or) m^3m^2s (or) m/s	thermal conductivity	W/m/K
gas diffusivity	m^2/s	transpiration rate	$mg/m^2/s$
hydraulic conductivity ion uptake	m/s	water content of soil	kg/kg or m^3/m^3
(Per kg of dry plant material)	mol/kg	water tension	kPa (or) MPa

While giving the SI units the first letter should not be in capital i.e cm, not Cm; kg not Kg. There should not be a full stop at the end of the abbreviation: cm, not cm. kg, not kg.; ha, not ha.

In reporting the data, dimensional units, viz., M (mass), L (length), and T (time) should be used as shown under some applications above. Some examples are: 120 kg N/ha; 5 t/ha; 4 dS/m etc.

Special Instructions

I. In a series or range of measurements, mention the unit only at the end, e.g. 2 to 6 cm2, 3, 6, and 9 cm, etc. Similarly use cm2, cm3 instead of sq cm and cu m.

II. Any unfamiliar abbreviation must be identified fully (in parenthesis).

III. A sentence should not begin with an abbreviation.

IV. Numeral should be used whenever it is followed by a unit measure or its abbreviations, e.g., 1 g, 3 m, 5 h, 6 months, etc. Otherwise, words should be used for numbers one to nine and numerals for larger ones except in a series of numbers when numerals should be used for all in the series.

V. Do not abbreviate litre to` l' or tonne to `t'. Instead, spell out.

VI. Before the paper is sent, check carefully all data and text for factual, grammatical and typographical errors.

VII. Do not forget to attach the original signed copy of `Article Certificate' (without any alteration, overwriting or pasting) signed by all authors.

VIII. On revision, please answer all the referees' comments point-wise, indicating the modifications made by you on a separate sheet in duplicate.

IX. If you do not agree with some comments of the referee, modify the article to the extent possible. Give reasons (2 copies on a separate sheet) for your disagreement, with full justification (the article would be examined again).

X. Rupees should be given as per the new symbol approved by Govt. of India.

Important Instructions

- Data on field experiments have to be at least for a period of 2-3 years
- Papers on pot experiments will be considered for publication only as short communications
- Giving coefficient of variation in the case of field experiments Standard error in the case of laboratory determination is mandatory. For rigorous statistical treatment, journals like Journal of Agricultural Science Cambridge, Experimental Agriculture and Soil Use and Management should serve as eye openers.

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