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IN VITRO EVALUATION OF OIL SEED CAKES (OSCS) AS SUSTAINABLE SOIL AMENDMENTS FOR THE MANAGEMENT *SCLEROTIUM ROLFSII* PATHOGEN IN GROUNDNUT

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ABSTRACT

The study evaluated the antifungal activity of six oil seed cakes (OSCs) namely neem, groundnut, sesame, mustard, castor and a mixture cake against *Sclerotium rolfsii* using a divided plate assay and poison food technique. Sesame cake demonstrated the highest efficacy, achieving 56.10 per cent mycelial inhibition with unautoclaved sesame cake, compared to 14.63 per cent with autoclaved cake. In aqueous extract assays, sesame cake achieved complete inhibition (100%) of fungal growth at a 25 per cent concentration, with significant inhibition observed at lower concentrations (93.80% at 20%, 71.98% at 15%, and 50.91% at 10%). Additionally, sesame cake reduced the formation of sclerotial bodies, with counts dropping to 15 at a 15 per cent concentration. In contrast, castor and neem cakes exhibited no inhibitory activity at any concentration, while mustard and mixture cakes displayed moderate antifungal effects, with maximum inhibition rates of 28.95 per cent and 31.72 per cent, respectively. The antifungal efficacy of sesame cake was attributed to its bioactive constituents, as identified through Gas Chromatography-Mass Spectrometry (GC-MS) analysis. Key bioactive compounds included oleic acid (42.62%), linoleic acid derivatives (31.58%), palmitic acid (13.86%), and sesamol (1.34%), which are known for their antimicrobial properties. At 3.0 per cent concentration, sesame cake reduced mycelial growth to 1.67 cm, corresponding to a 79.17 per cent inhibition rate. The findings of the study highlight sesame cake as a potent antifungal agent against *S. rolfsii*, with its bioactive components acting synergistically to inhibit fungal growth and reduce sclerotial formation, supporting its potential as a sustainable soil amendment in the management of soil borne pathogens.

KEYWORDS: Oil seed cakes, *S. rolfsii*, *in vitro* conditions, antifungal activity and GC MS analysis.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.), an allotetraploid crop (2n=4x=40, AABB genome), is a vital oil seed crop cultivated across tropical and subtropical regions of the world (Bosamia *et al.,* 2020). Known by various names like peanut, poor man's cashew nut, earthnut and monkey nut, it is believed to have originated in South America, particularly in Bolivia, Paraguay, Peru, Northern Argentina and Western Brazil. Today, groundnut is grown in over 100 countries, covering 327 lakh hectares globally, with a production of 539 lakh tonnes and an average productivity of 1648 kg/ha. India leads in cultivation area and ranks second in production, contributing 101.35 lakh tonnes with a productivity of 1777 kg/ha (FAOSTAT, 2021). However, India's productivity is lower than that of the USA (4497 kg/ha) and China (3913 kg/ha) (USDA, 2023). Major groundnut-growing states in India, including Gujarat, Andhra Pradesh, Rajasthan, Karnataka, Madhya Pradesh, Tamil Nadu and Maharashtra, contribute 80% of the country's production. According to estimates, production reached 11.90 million tons from 5.75 million ha with a average yield of 2067 kg/ha in 2024-24 (Annual report, 2024).

Groundnut production faces numerous challenges due to poor soil fertility and various biotic and abiotic stresses (Pujer *et al.,* 2021). Among biotic constraints, *Sclerotium rolfsii* is a significant soil-borne fungal pathogen causing stem rot and pod rot. The disease, first reported by Mc Clintock (1917) in Virginia, USA, is also known as white mold or southern blight. Stem rot leads to yield losses ranging from 10 per cent to 40 per cent, but severe outbreaks can reduce yields by upto 80% (Bera *et al.,* 2014). The pathogen affects pegs and pods, causing substantial harvest losses. In heavier soils, the infection is usually limited to the soil surface, while in lighter soils, it can penetrate deeper, affecting pods and pegs. Moist and warm weather favors stem rot development, while drier soil conditions promote pod rot (Mehan and Mc Donald, 1990).

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Managing stem rot is difficult due to the absence of resistant groundnut varieties and the pathogen's persistence in the soil. Fungicide application offers partial control but increases production costs and poses environmental hazards such as soil infertility, pollution, and contamination of water bodies. Continuous fungicide use may also lead to pathogen resistance (Mehan *et al.,* 1995). Therefore, sustainable, non-chemical approaches to disease management are essential. An integrated strategy combining host resistance, cultural practices, and biological control is necessary to manage stem rot effectively. Organic amendments, particularly oil seed cakes (OSCs), have demonstrated efficacy in suppressing soil-borne diseases due to their soil-enhancing properties (Adiver, 2003). These amendments provide essential nutrients to crops and stimulate the activity of beneficial bioagents. Neem cake, for example, increases soil nitrate availability, improving nitrogen metabolism in plants. The use of organic amendments like green manures, farmyard manure, compost and oil cakes has been linked to enhanced plant health and reduced disease incidence (Sivaprakasam, 1991). Blum and Rodriguez-Kabana (2004) highlighted the dual role of organic amendments in promoting plant growth and controlling soil-borne pathogens. Their ability to improve microbial activity in soil contributes to natural disease suppression.

Oil seed cakes such as neem, groundnut, sesame, mustard, castor, and mixed cakes exhibit suppressive effects against soil-borne pathogens by releasing bioactive compounds that inhibit fungal growth. These amendments have been shown to reduce the growth and sclerotia formation of *S. rolfsii*. Their integration into disease management strategies helps reduce the reliance on chemical fungicides. Blum and Rodriguez-Kabana (2004) emphasized the importance of organic inputs in improving soil health and enhancing resistance to soil-borne diseases. The use of OSCs as part of an integrated management strategy can significantly lower the environmental impact of disease control and support sustainable production practices for groundnut farmers. The present study aimed to evaluate the inhibitory potential of oil seed cakes (OSCs) against *S. rolfsii* under *in vitro* conditions.

MATERIAL AND METHODS

i. Source of the pathogen

The pathogen was isolated using two methods:

A. Direct isolation

Under aseptic conditions, a sterile pointed needle was used to pick fungal growth or sclerotia directly from infected groundnut stems. The collected material was transferred onto plates containing Potato Dextrose Agar (PDA). The plates were then incubated at 26 ± 2°C to allow fungal growth. Sclerotial bodies were collected from 14 days old culture plates and subsequently stored at 4°C for use in further studies.

B. Tissue isolation method

Infected stem segments were first washed thoroughly with tap water and then cut into small pieces. These pieces were surface sterilized using 1% NaOCl for 1 min, followed by three rinses with sterile distilled water under aseptic conditions. The sterilized tissue pieces were placed on PDA plates inside a laminar airflow chamber. The plates were incubated in a BOD incubator at 26 ± 2°C to promote fungal growth.

Hyphae emerging from the infected tissue were carefully sub-cultured onto fresh PDA plates. Pure cultures were obtained using the hyphal tip technique and further purified using a single sclerotium. The purified culture was examined microscopically for identification and maintained on PDA for subsequent studies. The initial isolation of the pathogen was carried out from groundnut plants exhibiting characteristic stem rot symptoms in the Patancheru fields.

ii. *In vitro* evaluation of aqueous extracts of OSCs against *S. rolfsii*

To prepare aqueous extracts of OSCs, 100 g of each OSC was powdered and soaked in sterile distilled water at a ratio of 1 g to 1.25 mL of water. The mixture was left to stand overnight, after which it was ground further using a pestle and mortar. The resulting material was filtered through a double layer of muslin cloth, and the filtrate was centrifuged at 10,000 rpm for 15 min. The supernatant was used as the standard organic amendment extract (100%) (Dubey, 2002 and Jangir *et al*. 2020). Before incorporation into the medium, the extract was sterilized at 1.4 kg cm^{-2} pressure for 15 min. A specific volume of the sterilized extract was aseptically mixed

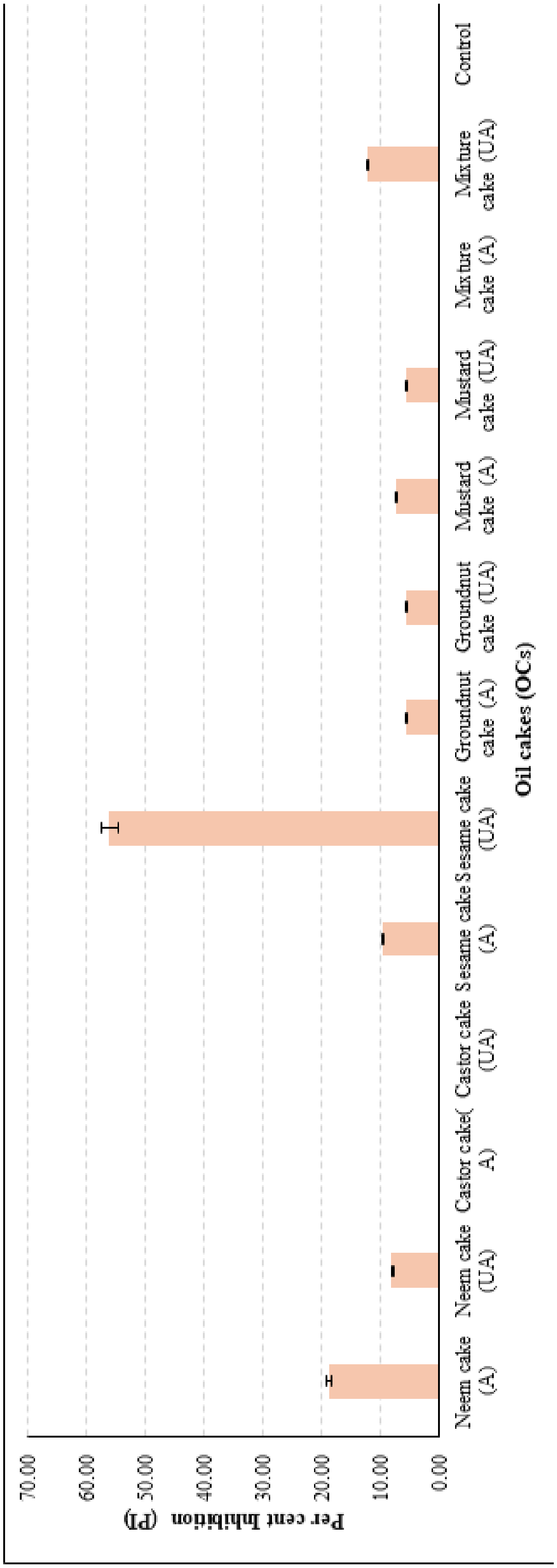
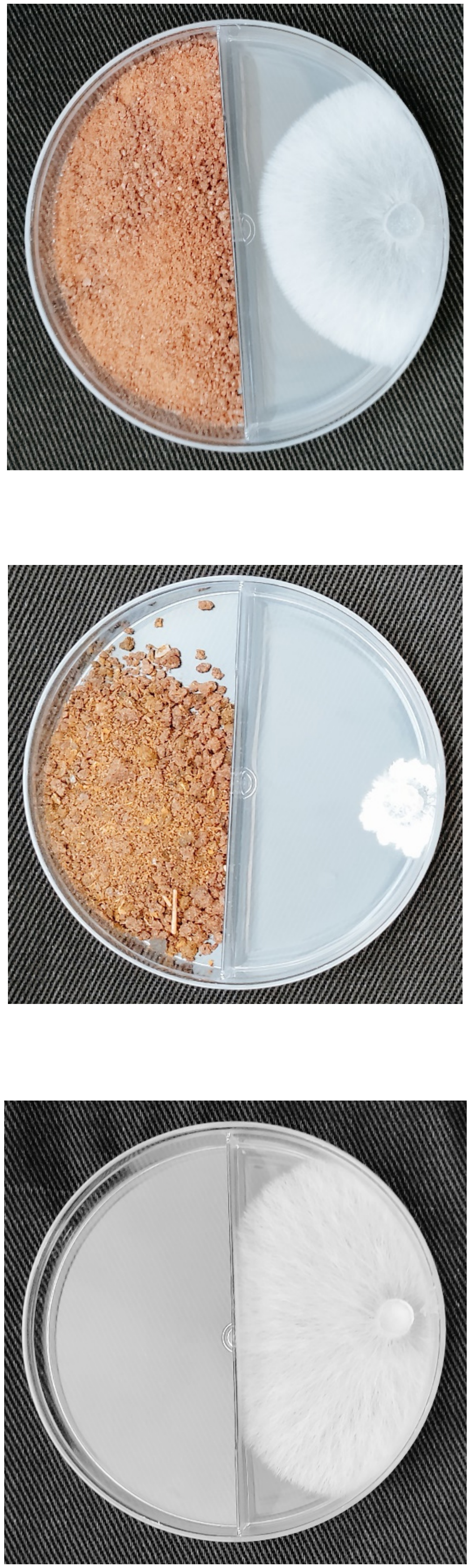


Fig. 1. Percent mycelial growth inhibition of *S. rolfsii* by different OSCs



Control

Sesame cake (Unautoclaved)

Sesame cake (Autoclaved)

Fig. 2. ***In vitro*** **assay of volatile compounds (VCs) from selected oil seed cakes (OSc) against** ***S. rolfsii***

with molten PDA to achieve the desired concentration.

To prevent bacterial contamination, a small amount of streptomycin sulphate (0.5g/1L) was added to the medium prior to pouring it into sterilized Petri plates. Each plate contained approximately 20 mL of the prepared medium, which was allowed to solidify. A 5 mm disc of 7 days old *S. rolfsii* culture was placed at the center of each plate. Plates without the extract served as the control. Each treatment, along with the control, was replicated three times. The inoculated plates were incubated at 28±2°C in a BOD incubator. Mycelial growth was monitored and sclerotia were counted 15 days post-inoculation (Thakkar *et al.,* 2018). The percent inhibition (PI) of mycelial growth was calculated using the following formula:

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

Where:

I = Percent inhibition

C = Radial growth (cm) in control

T = Radial growth (cm) in treatment

iii. *In vitro* assay for volatile compounds (VOCs) against *S. rolfsii*

The inhibitory effects of volatile compounds (VOCs) produced by OSCs were assessed using a divided plate assay. Powdered OSCs (5g, dry weight) were placed in one compartment of the divided plate, while PDA was poured into the other half and inoculated with a 5 mm mycelial disc of 7 days old *S. rolfsii* culture. Control plates consisted of PDA with only the fungal disc. Mycelial growth of the pathogen was recorded, and PI was calculated using the previously mentioned formula (Jangir *et al.,* 2020).

iv. Extraction and identification of antifungal bioactive compounds from OSCs (GC-MS analysis)

Bioactive compounds were extracted from aqueous OSC extracts using hexane, a low-polarity solvent. A 1:1 ratio of aqueous extract to hexane was prepared and shaken overnight to ensure complete extraction of compounds. The mixture was centrifuged at 10,000 rpm for 10 minutes, and the supernatant was collected. The hexane was removed using a rotary evaporator. The resulting extract was dissolved in DMSO (Dimethyl Sulphoxide - a neutral solvent) and filtered through a 0.45 µm Millipore filter. The filtrate was then tested for antifungal activity using the poisoned food technique. PDA medium was poisoned with various concentrations of the metabolite (0.1%, 0.5%, 1%, 1.5%, 2%, 2.5%, and 3%), and the medium was poured into sterilized petri plates. Once solidified, a 5 mm disc of *S. rolfsii* was placed at the center of each plate. Control plates contained PDA poisoned with only DMSO. All plates were incubated at 28°C for 7 days. Mycelial growth was recorded, and PI was calculated using above mentioned formula. The most effective extract was subjected to gas chromatography-mass spectrometry (GC-MS) analysis for compound identification (Jangir *et al.,* 2020).

For GC-MS analysis, a Shimadzu gas chromatograph equipped with a Turbo Mass Gold detector was used. The system included an Elite-1 column (100% Dimethyl Poly Siloxane) measuring 30 m × 0.25 mm ID × 1 mm df. The conditions for analysis were as follows: helium was used as the carrier gas at 1 mL/min; the oven temperature was programmed from 110°C (2 min hold) to 280°C (9 min hold); the injector temperature was set at 250°C, with a total GC run time of 45 minutes. A 1 mL aliquot of the hexane extract was injected into the system. The constituents were identified using a computer-assisted algorithm that matched the mass spectrum to the National Institute of Standards and Technology (NIST) library (Version 2.0, 2005). The GC-MS analysis was performed using Turbo Mass 5.1 software. This work was conducted in the Department of Entomology, ACI Programme, ICRISAT, Patancheru, Hyderabad.

RESULTS AND DISCUSSION

In recent years, the utilization of sustainable soil amendments, particularly oilseed cakes, has garnered significant attention for their potential role in managing soil borne diseases, including stem rot caused by *S. rolfsii* in groundnut. The persistence of the pathogen, attributed to its production of long-lived sclerotia, presents a formidable challenge to conventional chemical control strategies, necessitating the exploration of environmentally sustainable alternatives. Oilseed cakes, such as neem and castor cakes, are known for their high nitrogen content and antifungal properties, which enable them to suppress soil borne pathogens while simultaneously enhancing soil fertility. Additionally, their capacity for slow nutrient release supports long-term soil health and microbial activity. This study aims to evaluate

Table 1. ***In vitro*** **evaluation of aqueous extracts of OSCs against** ***S. rolfsii***

S. No	Treatments	Percent inhibition (PI) at 10 days after incubation	No. of sclerotia per plate
1.	Sesame cake (5%)	22.95 (28.63)[g]	26
2.	Sesame cake (10%)	50.91 (45.52)[d]	15
3.	Sesame cake (15%)	71.98 (58.04)[c]	0
4.	Sesame cake (20%)	93.80 (75.81)[b]	0
5.	Sesame cake (25%)	100.00 (90.00)[a]	0
6.	Castor cake (5%)	0.00 (0.00)[n]	80
7.	Castor cake (10%)	0.00 (0.00)[n]	64
8.	Castor cake (15%)	0.00 (0.00)[n]	53
9.	Castor cake (20%)	0.00 (0.00)[n]	48
10.	Castor cake (25%)	0.00 (0.00)[n]	35
11.	Neem cake (5%)	0.00 (0.00)[n]	90
12.	Neem cake (10%)	0.00 (0.00)[n]	78
13.	Neem cake (15%)	0.00 (0.00)[n]	59
14.	Neem cake (20%)	0.00 (0.00)[n]	34
15.	Neem cake (25%)	0.00 (0.00)[n]	26
16.	Groundnut cake (5%)	0.00 (0.00)[n]	91
17.	Groundnut cake (10%)	0.00 (0.00)[n]	86
18.	Groundnut cake (15%)	0.00 (0.00)[n]	65

Cont...

Table 1. *In vitro* evaluation of aqueous extracts of OSCs against *S. rolfsii*

S. No	Treatments	Percent inhibition (PI) at 10 days after incubation	No. of sclerotia per plate
19.	Groundnut cake (20%)	0.00 (0.00)^{n}	52
20.	Groundnut cake (25%)	9.56 (18.01)^{j}	34
21.	Mixture cake (5%)	7.50 (15.90)^{l}	98
22.	Mixture cake (10%)	8.33 (16.77)^{n}	86
23.	Mixture cake (15%)	19.19 (25.98)^{k}	66
24.	Mixture cake (20%)	22.95 (28.62)^{g}	42
25.	Mixture cake (25%)	31.72 (34.28)^{e}	37
26.	Mustard cake (5%)	5.40 (13.44)^{m}	75
27.	Mustard cake (10%)	10.07 (18.50)^{j}	63
28.	Mustard cake (15%)	13.53 (21.58)^{i}	51
29.	Mustard cake (20%)	22.54 (28.34)^{g}	46
30.	Mustard cake (25%)	28.95 (32.55)^{f}	38
31.	Control	0.00 (0.00)^{n}	125
	C.D. at 1%	0.98	
	SEm±	0.26	
	SE(d)	0.37	
	CV%	2.68	

*Values are the means of three replications in the table
Figures in parentheses represent angular transformed values. Means in a column followed by same superscript letters are significantly different according to DMRT test.
Note: C.D., critical difference; SE(d), standard error mean difference; CV, coefficient of variation.

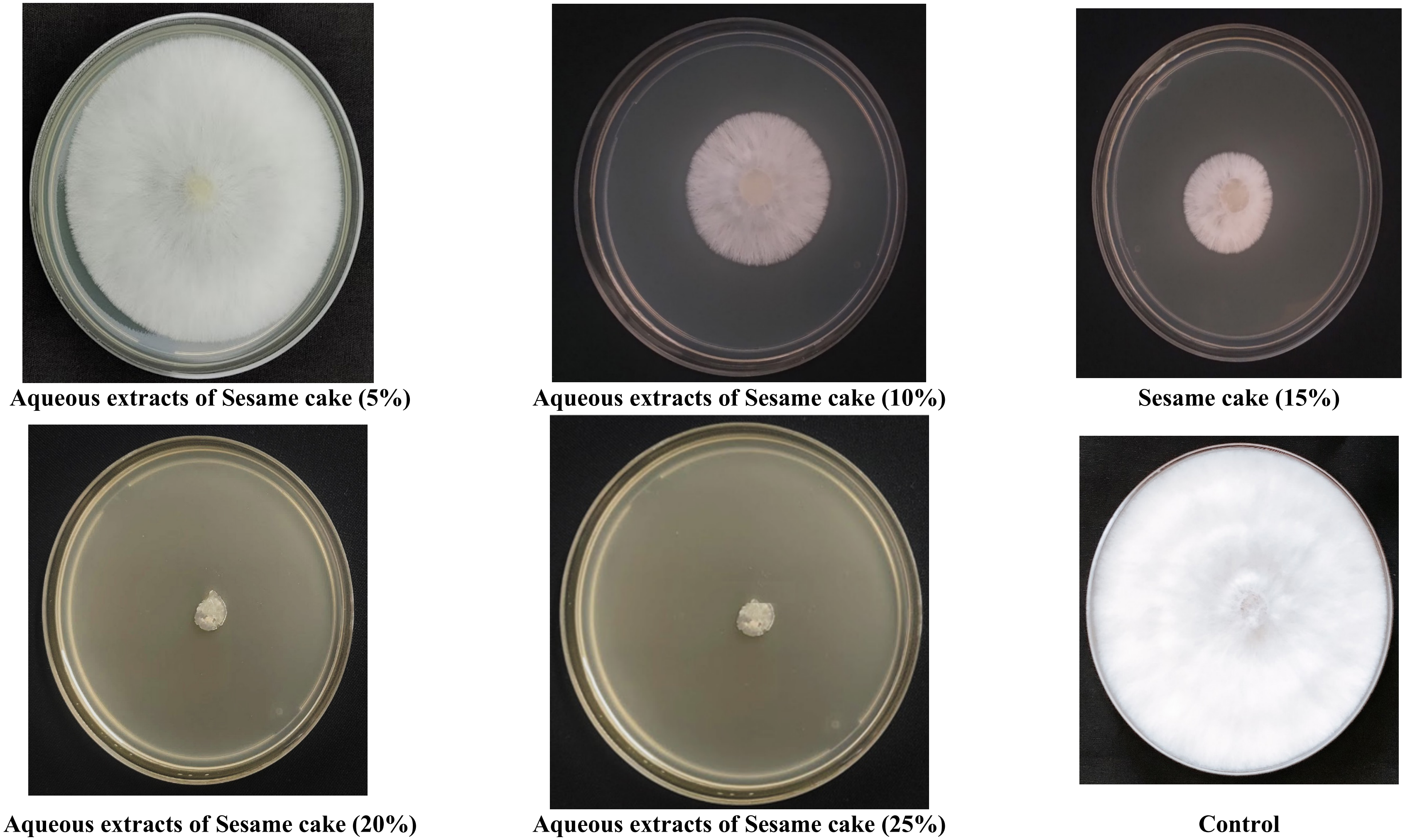


Fig. 3. ***In vitro*** **assay of aqueous extracts of autoclaved oil seed cakes (OSCs) against** ***S. rolfsii***

the efficacy of different oilseed cakes in mitigating stem rot incidence, thereby contributing to the development of Integrated Disease Management (IDM) practices that align with sustainable agriculture objectives.

i. Antifungal activity of OSCs in volatile assay

A total of six OSCs, including neem cake, groundnut cake, sesame cake, mustard cake, castor cake and a mixture cake (groundnut, flax seed and cotton seed), were evaluated for their antifungal efficacy against *S. rolfsii.* The inhibitory potential of volatile compounds (VCs) produced by these cakes was assessed using a divided plate assay. Among the tested OSCs, sesame cake exhibited the highest inhibition of mycelial growth, as evidenced by the reduced mycelial diameter of *S. rolfsii*, which measured 1.80 cm in the presence of unautoclaved sesame cake compared to 3.70 cm with autoclaved sesame cake. This corresponded to inhibition rates of 56.10 per cent and 14.63 per cent, respectively (Fig. 1&2). Additionally, the unautoclaved neem and mixture cakes exhibited inhibition rates of 18.70 per cent and 12.20 pe cent, respectively.

The superior inhibitory potential of sesame cake observed in the study is consistent with the findings of Jangir *et al*. (2020), who reported significant inhibition of *Fusarium oxysporum* using OSCs. Mustard cake was found to be the most effective in their study, achieving inhibition rates of 69.93 per cent (unautoclaved) and 40.51 per cent (autoclaved). Although the fungal pathogens differ, the inhibitory activity of OSCs against fungal growth is evident, suggesting that the response of fungal pathogens to OSC-derived volatile compounds may be species-specific. The use of a divided plate assay in both studies underscores the effectiveness of volatile compounds in inhibiting fungal mycelial growth. A comparative analysis of neem cake in the study and that of Jangir *et al*. (2020) revealed differences in inhibitory potential. In the study, unautoclaved neem cake inhibited *S. rolfsii* by 18.70%, while Jangir *et al.* (2020) reported a higher inhibition rate of 34.96 per cent against F. *oxysporum*. The variation could be attributed to differences in pathogen biology, the composition of volatile compounds, or experimental conditions. Collectively, the studies demonstrate the capacity of OSCs to inhibit soilborne fungal pathogens, though their efficacy is influenced by the pathogen type and OSC composition.

Further, the antifungal potential of volatile compounds was validated by the study carried by Thangaraj *et al.* (2023), who investigated the antifungal activity of volatile compounds emitted by medicinal herbs against Pythium aphanidermatum using the sealed plate method. Their results showed that volatiles from Mentha spicata were the most effective, achieving 45.56 per cent inhibition, followed by Cymbopogon citratus (24.70%) and Vitex negundo (18.88%). The finding aligns with the present study's observation of high inhibition rates associated with sesame cake volatiles, highlighting the potential of plant-based volatile compounds for controlling soilborne pathogens.

ii. Antifungal activity of aqueous extract of oil seed cakes (OSCs)

The antifungal efficacy of aqueous extracts of the six OSCs was evaluated against *S. rolfsii* at concentrations of 5, 10, 15, 20, and 25% using the poisoned food technique. The PI of mycelial growth and the number of sclerotial bodies produced after 10 days of incubation were recorded. Sesame cake demonstrated the highest inhibitory potential, achieving complete inhibition (100%) at 25% concentration. The inhibition rates observed at lower concentrations were 93.80 per cent (20%), 71.98 per cent (15%), 50.91 per cent (10%), and 22.95 per cent (5%). The number of sclerotial bodies also decreased significantly with increasing concentrations of sesame cake, with the lowest count (15) recorded at 15% per cent concentration (Table 1 and Fig. 3).

Other OSCs exhibited varying levels of antifungal efficacy. Castor and neem cakes displayed no inhibition at all tested concentrations, while groundnut cake exhibited minimal inhibition (9.56%) at 20 per cent concentration. Mustard cake showed modest inhibitory effects, with the highest inhibition (28.95%) observed at 25 per cent concentration. The mixture cake demonstrated concentration-dependent inhibition, with the highest inhibition rate of 31.72 per cent observed at 25%per cent concentration. In terms of sclerotial body production, the groundnut cake exhibited the highest sclerotial count (98) at 5 per cent concentration, while sesame cake resulted in the lowest count (15) at 15 per cent concentration. The results of the present study are consistent with those reported by Senjaliya and Nathawat (2015), who evaluated several OSCs, including mustard, groundnut, neem and castor cakes, for their efficacy against *S. rolfsii.* Their findings indicated that all OSCs, except FYM,

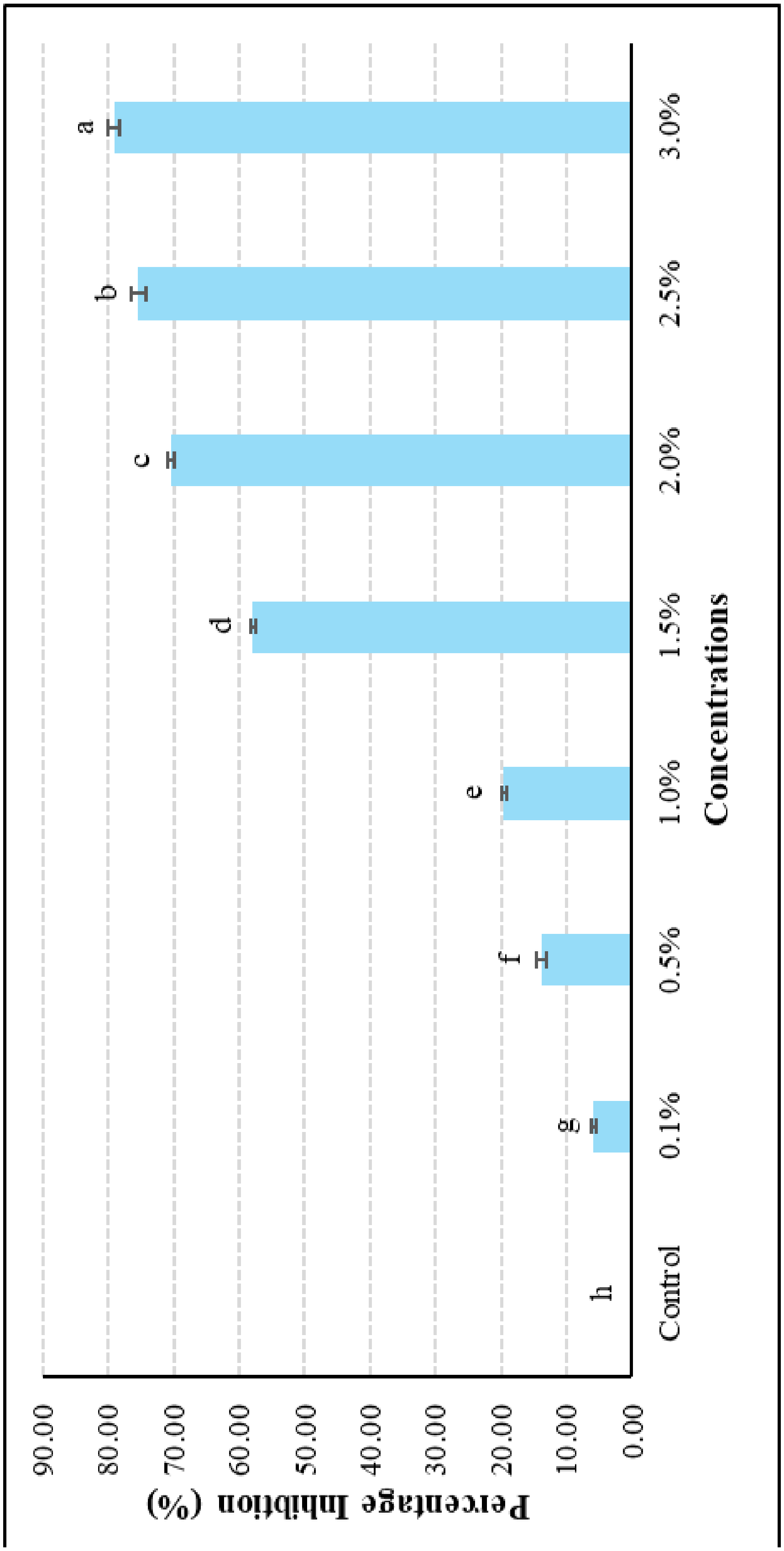
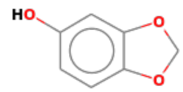
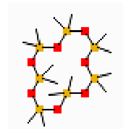
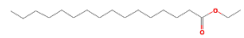
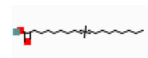
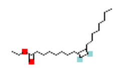
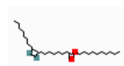


Fig. 4. **Assessment of different concentrations of sesame cake metabolite against** ***S. rolfsii***

Table 2. Compounds with their retention time identified in GC-MS analysis of n-hexane fraction of sesame cake

Peak#	Retention time (min)	Area	Area%	Name	Molecular formula	Molecular weight	Structure
1	12.240	82016	1.34	1,3-Benzodioxol-5-ol or Sesamol	$C_7H_6O_3$	138	
2	14.517	147203	2.41	1-Pentadecene	$C_{15}H_{30}$	210	
3	14.585	63107	1.03	Cycloheptasiloxane, tetradecamethyl	$C_{14}H_{42}O_7Si_7$	518	
4	19.979	847412	13.86	n-Hexadecanoic acid	$C_{16}H_{32}O_2$	256	
5	20.307	105600	1.73	Hexadecanoic acid, ethyl ester	$C_{18}H_{36}O_2$	284	
6	21.737	1283612	21.00	Octadeca-9,12-Dienoic Acid	$C_{18}H_{32}O_2$	294	
7	21.781	2605567	42.62	OCTADEC-9-ENOIC ACID	$C_{18}H_{34}O_2$	282	
8	21.984	646674	10.58	9,12-Octadecadienoic acid (Z, Z)	$C_{18}H_{32}O_2$	280	
9	22.034	283734	4.64	Ethyl Oleate	$C_{20}H_{38}O_2$	310	
10	23.419	48497	0.79	Decyl oleate	$C_{28}H_{54}O_2$	422	

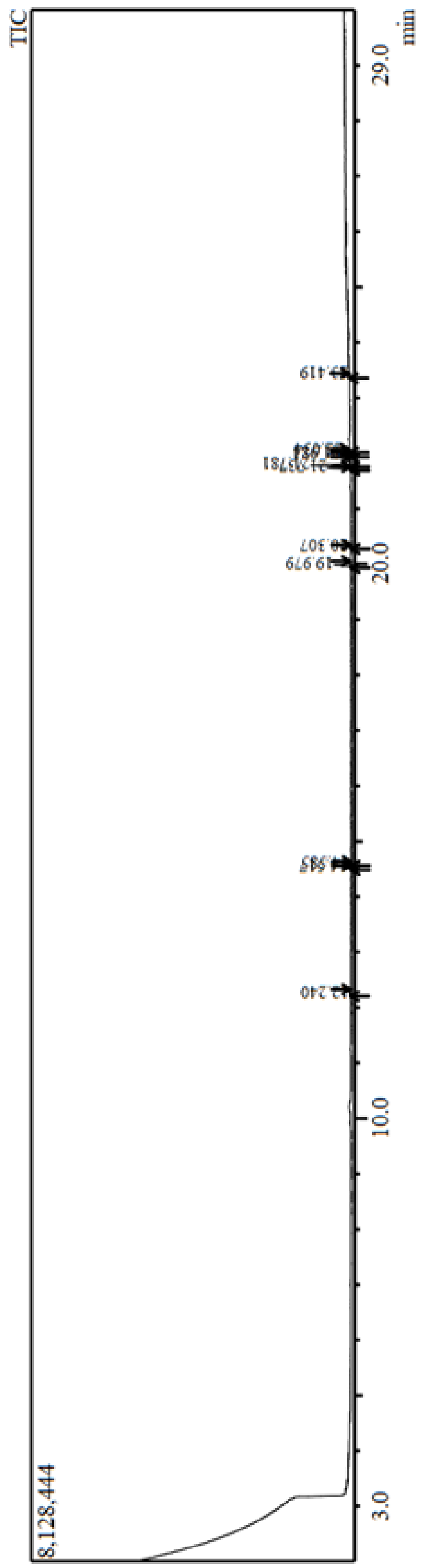


Fig. 5. GC-MS Chromatogram of metabolites extracted from sesame cake

significantly inhibited fungal growth, corroborating the results of the present study, where sesame cake and other OSCs showed substantial inhibitory effects. Similar inhibitory potential of OSCs against *S. rolfsii* has been reported by Anitha *et al.* (2019), who observed 80.11 per cent inhibition using mahua oil cake. The reduced efficacy of OSCs at lower concentrations may be attributed to differences in the bioactive compound concentrations and their thermostability, as suggested by You *et al.* (2019).

iii. Bioactive compounds extracted from sesame cake aqueous extract

The antifungal potential of bioactive compounds extracted from sesame cake was evaluated using GC-MS analysis. The antifungal efficacy of the metabolite was tested at varying concentrations (0.1%, 0.5%, 1.0%, 1.5%, 2.0%, 2.5%, and 3.0%), by poisoned food technique. Mycelial growth was significantly inhibited in a concentration-dependent manner ($p < 0.05$). The highest concentration (3.0%) achieved 79.17% inhibition, while lower concentrations resulted in moderate inhibition rates of 70.42 per cent (2.0%), 75.42 per cent (2.5%), and 57.92 per cent (1.5%) (Fig. 4).

GC-MS analysis revealed that the primary bioactive compounds responsible for the antifungal activity of the sesame cake extract included oleic acid (42.62%), octadeca-9,12-dienoic acid methyl ester (21.00%), and 9,12-octadecadienoic acid (10.58%). These fatty acids have well-documented antifungal properties, suggesting their role as key bioactive agents. Additional compounds, such as n-hexadecanoic acid (13.86%) and sesamol (1.34%), also contributed to antifungal activity. The presence of ethyl oleate (4.64%) and hexadecanoic acid ethyl ester (1.73%) may enhance the solubility and availability of active compounds, thereby increasing antifungal efficacy (Table 2 and Fig. 5). These results are consistent with those of Ali *et al.* (2017), who observed antifungal properties of 9-octadecenoic acid (Z)-, methyl ester in methanolic root extracts of Chenopodium album. Similarly, Jangir *et al.* (2020) identified oleic and linoleic acids as predominant bioactive compounds in mustard OSCs. Ayyandurai *et al.* (2022) further demonstrated that n-hexadecanoic acid, linoleic acid, and oleic acid present in mahua oil cake significantly inhibited *S. rolfsii* at 5% and 10% concentrations. Collectively, these findings highlight the potential of fatty acids as antifungal agents in OSCs, further emphasizing the role of sesame cake as a promising biocontrol strategy for managing *S. rolfsii* in groundnut.

Oilseed cakes (OSCs) have demonstrated significant potential as effective soil amendments for managing *S. rolfsii* in groundnut. Among the tested OSCs, sesame cake exhibited the highest antifungal activity, achieving complete inhibition of fungal growth and sclerotial germination at higher concentrations. The bioactive compounds present in sesame cake, such as oleic acid, linoleic acid derivatives, palmitic acid, and sesamol, play a crucial role in suppressing fungal growth. The superior performance of sesame cake compared to other OSCs highlights its potential as a sustainable and eco-friendly alternative to chemical fungicides. The findings emphasize the value of integrating sesame cake as a core component in the integrated management of *S. rolfsii* in groundnut cultivation.

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EVALUATION OF SESAME GENOTYPES FOR FIELD RESISTANCE AGAINST STEM AND ROOT ROT CAUSED BY *Macrophomina phaseolina* (Tassi) Goid.

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ABSTRACT

Stem and root rot caused by *Macrophomina phaseolina* is a devastating disease in sesame. Use of host plant resistance is the cheapest and effective disease management strategy. In the present study, 58 sesame genotypes were evaluated for their resistance against stem and root rot disease in 2025 in a sick field under artificial conditions. The results showed that there was significant difference in Percent Disease incidence (PDI %) of the genotypes tested. The mean disease incidence of genotypes ranged from 5.7 to 59.8 %. Eight genotypes VSP-16 (5.7 %), TPTS-40 (6.6 %), YLM-161 (8.6 %), Nirmala (8.9 %) and VS-16-009 (9.5 %), Madhavi (9.6 %), GT-10 (9.6) and VS-20-008 (10 %) were found to be resistant (R). These genotypes might be helpful in improving the breeding program of sesame crop. These sesame genotypes can be used for improvement of genetic resistance in already developed lines/varieties or development of new resistant varieties and cultivars through hybridization program.

KEYWORDS: Genotypes, percent disease incidence, resistance.

INTRODUCTION

The queen of oil seed, sesame is known for its high nutritional and therapeutic value (Biswas *et al.,* 2018). It have been consumed as traditional healthy food for its anti-inflammatory and antioxidative properties (Yadav *et al.,* 2022). The crops susceptibility to disease is the main barrier to the sesame production causing 7 million tons of yield loss for every year (Ara *et al.,* 2017) and it creates significant impact on growers. Stem and root rot caused by *M. phaseolina* is a devastating disease in sesame and causes 5-100 per cent yield loss (Vyas, 1981). Murugesan (1978) estimated that increase in 1 per cent of disease infection may lead to yield loss of 1.8 kg ha^{-1}.

As stem and root rot is a seed, stubble and seed borne disease, it is difficult to control by conventional management practices. Using chemicals not only increase input cost but also harmful to environment. Various management studies have been carried out by several researchers *viz.,* using bio-agent (Abdul sattar *et al.,* 2006), plant extracts (Ahmed *et al.,* 2010) and cultivating resistant varieties (Thiyagu *et al.,* 2007). Among these, host plant resistance is one of the important effective strategy for the management of disease (Salari *et al.,* 2012). Different genotypes of sesame will differ in their genetic potential of disease resistance. The screening of genotypes for resistance against stem and root rot will help to identify genotypes for resistance. Hence, the present research was planned out to evaluate the resistance of sesame genotypes against stem and root rot disease.

MATERIAL AND METHODS

Fifty eight sesame genotypes obtained from AICRP on sesame, Tirupati were evaluated for their resistance against stem and root rot disease under sick plot conditions during the year 2025. Each genotype was sown in a row of 3 m length with inter row spacing of 30 cm. A row of susceptible check was sown after every four genotypes. Two replications of each genotype was maintained. Two susceptible checks, YLM-66 and YLM-146 were used as infector rows. Disease incidence were recorded at 70 days and Percent Disease Incidence (PDI) was calculated.

$$PDI = \frac{\text{No of infected plants}}{\text{Total number of plants}} \times 100$$

Based on PDI, the genotypes were categorized as resistant, moderately resistant, moderately susceptible, susceptible and highly susceptible (Table 1).

RESULTS AND DISCUSSION

Results from the field experiment on screening of sesame genotypes against stem and root rot revealed that mean disease incidence of genotypes ranged from

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Table 1. Disease scale used for evaluation of disease resistance in sesame genotypes (Dinakaran and Naina Mohamed, 2001)

Scale	PDI	Reaction
1	1-10	Resistant
3	11-20	Moderately resistant
5	21-30	Moderately susceptible
7	31-50	Susceptible
9	51-100	Highly susceptible

5.7 to 59.8 per cent (Table 2). The least disease incidence was observed in genotype VSP-16 with 5.7 per cent, followed by genotypes TPTS-40 (6.6 %), YLM-161 (8.6 %), Nirmala (8.9 %) and VS-16-009 (9.5 %). The highest disease incidence was observed in genotype RMT-130 with 59.8 % followed by RMT-175 (58.5), Gowri (51.3 %), TPTS-01 (50.4) and SKL-2 (44.2 %). Remaining genotypes (48) showed disease incidence ranging from 9.6 to 43.4 per cent.

Based on the per cent disease incidence, out of 58 genotypes screened, 8 genotypes (YLM-161, TPTS-40, Madhavi, VS-16-009, VS-20-008, VSP-16, Nirmala, GT-10) were found to be resistant (R) with >10 per cent disease incidence, 17 genotypes (YLM-11, YLM-17, TPTS-29, Hima, VS-19-045, RMT-204, VSP-5, IC-204159, IC-326984, IIOS-3101, PCU-39, AT-324, PT-10, SVT-451, TKG-22, VZM-2, CUMS-19-4) were found moderately resistant with 11-20 per cent disease incidence, 16 genotypes (YLM-171, TPTS-06, TPTS-21, VS-18-005, VS-20-001, RMT-176, VSP-6, JCS-1020, JCS-3593, IC-204830, IC-326984, RT-54, RT-204, SKL-3, PCU-35, MT-2019-11) were found moderately susceptible with 21-30 percent disease incidence, 12 genotypes (YLM-165, TPTS-18, TPTS-24, TPTS-45, TPTS-46, Swetha, Chandna, JCS-706, JCS-2454, RT-68, SKL-2, DS-56) showed susceptible reaction with 31-50 percent disease incidence and 5 genotypes (TPTS-01, Gowri, RMT-130, RMT-175, RMT-253) were found to be highly susceptible with disease incidence of more than 51 per cent (Table 3).

Similarly, the disease reaction of sesame genotypes to stem and root rot disease was studied by Thiyagu *et al*. (2007). In sick plot method, fifteen parents and their F1's were screened against the disease. Three genotypes (ORM 7, ORM 14 and ORM 17) were found to be resistant with PDI of 7.69, 8.33 and 6.67 respectively in sick plot condition but the F1's screened against the disease showed that all crosses were susceptible to highly susceptible to root rot disease. Ramesh Nath Gupta *et al*. (2020) evaluated three hundred fifty germplasms lines for their relative resistance under natural sick plot conditions and majority of them showed moderately susceptible to susceptible reaction against stem and root rot. None of the germplasms showed resistant reaction. Similar studies by Deepthi *et al.* (2014) revealed that none of the cultivars showed complete resistance against *M. phaseolina.* Only one entry PKDS-91 was found as moderately resistant to charcoal rot. Ezhilarasi and Meena (2019) found most of the sesame lines were moderately susceptible to stem and root rot in their study.

Even though many lines have been identified as moderately resistant against the stem and root rot disease, complete resistant genotype are rarely available against this wide host range pathogen. In the study, eight genotypes showed resistant disease reaction against the stem and root rot. But further evaluation of these genotypes in different seasons under variable conditions will reveal the resistant potential. Hence resistant genotypes are recommended for further evaluation and potential cultivation. These lines might be helpful in improving the breeding program of sesame crop. These sesame lines can be used for improvement of genetic resistance in already developed lines/varieties or development of new resistant varieties and cultivars through hybridization program.

The identification of resistant genotypes in the study marks a significant step toward sustainable management of stem and root rot in sesame. Continued

Table 2. Screening of sesame genotypes against stem and root rot disease in sick plot

S. No	Sesame genotypes	Initial plant stand*	Final plant stand*	Percent disease incidence (%) *	Disease reaction
1.	YLM-11	45	41	12.7 (27.1)	MR
2.	YLM-17	36	36	20.0 (31.0)	MR
3.	YLM-161	41	40	8.6 (24.3)	R
4.	YLM-165	31	31	31.1 (35.5)	S
5.	YLM-171	45	42	29.5 (34.9)	MS
6.	TPTS-01	30	27	50.4 (42.2)	HS
7.	TPTS-06	45	38	22.9 (32.2)	MS
8.	TPTS-18	45	43	34.1 (36.7)	S
9.	TPTS-21	50	50	26.9 (34.0)	MS
10.	TPTS-24	46	45	41.5 (39.3)	S
11.	TPTS-29	30	30	11.7 (26.5)	MR
12.	TPTS-40	30	29	6.6 (22.4)	R
13.	TPTS-45	40	40	40.2 (38.8)	S
14.	TPTS-46	28	27	40.1 (38.8)	S
15.	Swetha	31	30	37.0 (37.7)	S
16.	Madhavi	30	24	9.6 (24.9)	R
17.	Gowri	35	31	51.3 (42.5)	HS
18.	Chandna	33	27	43.4 (39.9)	S
19.	Nirmala	32	31	8.9 (24.6)	R
20.	Hima	27	17	19.1 (30.5)	MR
21.	VS-16-009	24	21	9.5 (25.1)	R
22.	VS-18-005	33	30	22.5 (32.1)	MS
23.	VS-19-045	17	10	20.0 (31.0)	MR
24.	VS-20-001	34	29	20.6 (31.3)	MS
25.	VS-20-008	45	45	10.0 (25.5)	R
26.	RMT-130	32	27	59.8 (45.4)	HS
27.	RMT-175	26	23	58.5 (44.9)	HS
28.	RMT-176	17	15	30.0 (35.2)	MS
29.	RMT-204	33	31	11.3 (26.2)	MR
30.	RMT-253	35	33	39.1 (38.4)	S
31.	VSP-5	36	35	15.0 (28.2)	MR

Cont...

Table 2. Screening of sesame genotypes against stem and root rot disease in sick plot

S. No	Sesame genotypes	Initial plant stand*	Final plant stand*	Percent disease incidence (%) *	Disease reaction
32.	VSP-6	30	23	27.8 (34.3)	MS
33.	VSP-16	37	37	5.7 (21.1)	R
34.	JCS-706	24	23	42.7 (39.7)	S
35.	JCS-1020	20	18	27.0 (34.0)	MS
36.	JCS-2454	31	31	33.5 (36.4)	S
37.	JCS-3593	35	35	24.9 (32.9)	MS
38.	IC-204159	41	41	19.9 (30.6)	MR
39.	IC-204830	45	43	27.9 (34.4)	MS
40.	IC-326984	30	28	16.2 (28.7)	MR
41.	IC-326984	49	47	27.4 (33.3)	MS
42.	IIOS-3101	38	38	13.4 (27.4)	MR
43.	RT-54	34	33	29.5 (34.3)	MS
44.	RT-68	20	18	31.0 (35.1)	S
45.	RT-204	28	21	26.4 (32.8)	MS
46.	SKL-2	28	26	44.2 (40.0)	S
47.	SKL-3	32	31	25.4 (33.2)	MS
48.	PCU-35	25	24	25.5 (33.3)	MS
49.	PCU-39	29	23	15.7 (28.8)	MR
50.	GT-10	53	47	9.6 (24.9)	R
51.	MT-2019-11	28	28	21.0 (31.4)	MS
52.	AT-324	39	37	18.6 (30.3)	MR
53.	PT-10	23	22	16.6 (29.3)	MR
54.	SVT-451	29	29	19.5 (30.4)	MR
55.	TKG-22	27	24	14.2 (27.8)	MR
56.	VZM-2	47	41	15.9 (28.9)	MR
57.	CUMS-19-4	32	27	20.0 (31.1)	MR
58.	DS-56	34	26	41.3 (39.2)	S
59.	YLM-66 (Check)	35	47	44.8 (40.4)	S
60.	YLM-146 (Check)	49	44	40.3 (38.9)	S
	SE (m)±		2.43		
	C.D		6.90		
	C.V		10.48		

Note: R= Resistant, MR= Moderately Resistant, MS= Moderately susceptible, S= Susceptible, HS=Highly Susceptible;
* Mean of two replications. The values in parenthesis are arcsine transformed values

Table 2. Categorization of sesame genotypes based on their reaction to stem and root rot disease

S. No.	Disease score	Percent disease incidence (%)	Reaction	No. of genotypes	Genotypes
1.	1	1-10	Resistant	8	YLM-161, TPTS-40, Madhavi, VS-16-009, VS-20-008, VSP-16, Nirmala, GT-10
2.	3	11-20	Moderately resistant	17	YLM-11, YLM-17, TPTS-29, Hima, VS-19-045, RMT-204, VSP-5, IC-204159, IC-326984, IIOS-3101, PCU-39, AT-324, PT-10, SVT-451, TKG-22, VZM-2, CUMS-19-4
3.	5	21-30	Moderately susceptible	16	YLM-171, TPTS-06, TPTS-21, VS-18-005, VS-20-001, RMT-176, VSP-6, JCS-1020, JCS-3593, IC-204830, IC-326984, RT-54, RT-204, SKL-3, PCU-35, MT-2019-11
4.	7	31-50	Susceptible	12	YLM-165, TPTS-18, TPTS-24, TPTS-45, TPTS-46, Swetha, Chandna, JCS-706, JCS-2454, RT-68, SKL-2, DS-56
5.	9	51-100	Highly susceptible	5	TPTS-01, Gowri, RMT-130, RMT-175, RMT-253

efforts in screening, validation and breeding will contribute to securing sesame production and improving farmer livelihoods. The use of resistant varieties not only provides an eco-friendly and cost-effective management strategy but also reduces the dependency on chemical control measures.

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EFFECT OF GROUNDNUT BASED MILLET INTERCROPPING SYSTEM ON YIELD AND ECONOMICS OF GROUNDNUT (*Arachis hypogaea* L.)

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ABSTRACT

A field experiment was conducted during *kharif* 2024 at S.V. Agricultural College, Tirupati, to evaluate the yield and economic benefits of groundnut + millet intercropping systems. The experiment was laid out in randomized block design with ten treatments comprising of three millets *viz.,* foxtail millet, finger millet and little millet with groundnut in the replacement series of 5:2 and 5:4 row proportion and their sole crops replicated thrice. Results showed that sole crop of groundnut recorded the highest pod (2295 kg ha^{-1}) and haulm yield (3016 kg ha^{-1}), while groundnut + finger millet (5:2) recorded the highest groundnut pod equivalent yield (2906 kg ha^{-1}) and economic returns (benefit: cost ratio of 2.76). Millet yields in intercropping systems were reduced due to competition, with the 5:4 row ratio yielding higher than the 5:2 ratio. The study concluded that groundnut + finger millet at 5:2 ratio is the most productive and economically viable intercropping system in Southern Agro-climatic zone of Andhra Pradesh.

KEYWORDS: Groundnut, foxtail millet, finger millet, little millet.

INTRODUCTION

In the present day scenario, the greatest challenge is to meet the basic needs, such as food, fodder, fuel and fiber for the ever growing human and livestock population from the available land area. Agricultural production has to be increased to meet the expected demands for the world's fast growing population. However, this increase must come from the existing cultivated land, as expansion opportunities are limited due to factors such as the conversion of farmland for non-agricultural uses, climate change and the decreasing availability of land for extensive agriculture. Given these constraints, the most viable solution lies in maximizing the use of time and space in agriculture through intensification and diversification strategies. These include practices such as relay cropping, crop rotation and intercropping of major crops with compatible species. Nevertheless, the success of intercropping depends on several factors, including seeding ratios, planting patterns, crop varieties, and the level of competition among component crops.

Intercropping mitigates agricultural risks by cultivating two or more crops simultaneously or within the same season in a single field, optimizing resource use compared to monocropping. The effectiveness of intercropping hinges on the choice of intercrops and their spatial arrangement, which influence productivity, competition, and nutrient absorption. Intercropping groundnut with fast growing, short duration crops like millets is a viable system that maximizes land, solar energy, and water use, ensuring profitability and stability while reducing crop failure risks. Legumes, with their deep root systems, access moisture and nutrients from deeper soil layers, avoiding competition with paired cereals. Additionally, groundnut fix nitrogen in the soil, sharing some with intercropped cereals, boosting growth even in nitrogen poor soils. Keeping the above facts in view, the present study was conducted to evaluate the yield and economic benefits of groundnut + millet intercropping system in the Southern Agro-climatic zone of Andhra Pradesh.

MATERIAL AND METHODS

A field experiment was conducted at S. V. Agricultural College Dryland farm, Tirupati campus of Acharya N. G. Ranga Agricultural University, during *kharif,* 2024 to study the yield and economics of groundnut + millets intercropping system. The experimental site was loamy sand with soil pH (6.72), organic carbon (0.28 %), available nitrogen (183 kg ha^{-1}), available phosphorus (28 kg ha^{-1}) and available potassium (187 kg ha^{-1}). The experiment was laid out in randomized block design comprising of three intercrops *viz.,* foxtail millet (SiA-3159), finger millet (Vakula) and little millet (BL 6) with groundnut (Dharani) in 5:4 and 5:2 row proportion and their sole crops replicated thrice.

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Table 1. Pod and haulm yield (kg ha^{-1}) of groundnut as influenced by different groundnut based intercropping systems

Treatment	Pod yield	Haulm yield	Groundnut pod equivalent yield (kg ha^{-1})
T_1 : Sole crop of groundnut	2295	3016	2295
T_5 : Groundnut + little millet (5:2)	1819	2376	2154
T_6 : Groundnut + foxtail millet (5:2)	1927	2510	2293
T_7 : Groundnut + finger millet (5:2)	1976	2689	2906
T_8 : Groundnut + little millet (5:4)	1061	1405	1739
T_9 : Groundnut + foxtail millet (5:4)	1370	1879	2132
T_{10} : Groundnut + finger millet (5:4)	1480	2018	2747
SEm ±	97.4	102.4	69.21
CD (P=0.05)	300	316	213.2

Table 2. Grain and straw yield (kg ha^{-1}) of different intercrops in sole and in intercropping systems

Treatment	Grain yield	Straw yield
T_1 : Sole crop of groundnut	-	-
T_2 : Sole crop of foxtail millet	1365	2568
T_3 : Sole crop of finger millet	2180	3590
T_4 : Sole crop of little millet	1254	1619
T_5 : Groundnut + little millet (5:2)	502	864
T_6 : Groundnut + foxtail millet (5:2)	549	1632
T_7 : Groundnut + finger millet (5:2)	1395	2214
T_8 : Groundnut + little millet (5:4)	1017	1396
T_9 : Groundnut + foxtail millet (5:4)	1143	2253
T_{10} : Groundnut + finger millet (5:4)	1900	2920

Table 3. Gross returns, net returns (₹ ha^{-1}) and benefit: cost ratio as influenced by different groundnut based intercropping systems

Treatment	Gross returns	Net returns	Benefit: Cost ratio
T_1 : Sole crop of groundnut	106291	53731	2.02
T_2 : Sole crop of foxtail millet	42234	16219	1.62
T_3 : Sole crop of finger millet	67195	40400	2.51
T_4 : Sole crop of little millet	38430	11145	1.41
T_5 : Groundnut + little millet (5:2)	99723	49192	1.97
T_6 : Groundnut + foxtail millet (5:2)	106511	56121	2.11
T_7 : Groundnut + finger millet (5:2)	138346	87982	2.76
T_8 : Groundnut + little millet (5:4)	80358	29827	1.59
T_9 : Groundnut + foxtail millet (5:4)	98945	48556	1.96
T_{10} : Groundnut + finger millet (5:4)	128158	77794	2.54
SEm ±	2698	2698	0.09
CD (P=0.05)	8016	8016	0.3

The treatments included in the experiment were T_1 : Sole crop of groundnut, T_2 : Sole crop of foxtail millet, T_3 : Sole crop of finger millet, T_4 : Sole crop of little millet, T_5 : Groundnut + littlemillet (5:2), T_6 : Groundnut + foxtail millet (5:2), T_7 : Groundnut + finger millet (5:2), T_8 : Groundnut + little millet (5:4) T_9 : Groundnut + foxtail millet (5:4), T_{10} : Groundnut + finger millet (5:4).

RESULTS AND DISCUSSION

Significantly higher pod (2295 kg ha^{-1}) and haulm yield (3016 kg ha^{-1}) of groundnut was recorded in sole crop of groundnut (T_1) compared to any other intercropping systems. This might be attributed to optimum plant densities and lower competition environment in sole crop compared to intercropping which have a positive and significant impact on growth parameters and yield attributes, that in turn increased the yield. These results were in conformity with the findings of Maitra *et al.* (2000), Shivaraj (2015), Shwethanjali *et al.* (2018), Lenka *et al.* (2023). Among the different intercropping systems, highest pod yield was obtained with groundnut + finger millet (1976 kg ha^{-1}) at 5:2 row proportions, which was on par with groundnut + foxtail millet (1927 kg ha^{-1}) at 5:2 row proportion and groundnut + little millet (1819 kg ha^{-1}) at 5:2 row proportion. Among the different intercropping systems, highest haulm yield was obtained with groundnut + finger millet (2689 kg ha^{-1}) at 5:2 row proportion, which was on par with groundnut + foxtail millet (2510 kg ha^{-1}) at 5:2 row proportion and groundnut + little millet (2376 kg ha^{-1}) at 5:2 row proportion (Table 1). This increase in the haulm yield could be attributed due to higher plant population maintained in the sole crop along with least competition offered, which have increased the vegetative growth in turn the haulm yield. The highest groundnut pod equivalent yield was recorded in the intercropping system of groundnut + finger millet (5:2) (T_7) which is on par with groundnut + finger millet (5:4) (T_{10}) due to the additional advantage of foxtail millet yield and higher groundnut yield along with intercrop due to better complementary relationship.

Whereas lower pod, haulm and groundnut pod equivalent yield was recorded in groundnut + little millet (5:4) (T_8). The results corroborate the findings of Shivakumar and Yadahalli (1995), Maitra *et al*. (2000), Shwethanjali *et al*. (2018) and Lenka *et al*. (2023).

In the intercropping system, both grain and straw yields of millets were lower at both row ratios compared to sole cropping. Higher yields in sole cropping likely resulted from the absence of interspecific competition, with only intraspecific competition and a full plant population. Competition from groundnut for natural resources also hindered millet development in the intercropping system. Among the intercropping treatments, the 5:4 row ratio of groundnut + millets yielded higher grain and straw compared to the 5:2 ratio, primarily due to an additional millet row, greater spacing between millet rows, improved light availability, efficient resource use, and balanced intra and interspecific competition (Table 2). These factors enhanced yield attributing parameters, likely contributing to the increased yield. These results were in agreement with studies of Manjunath and Salakinkop (2017), Shwethanjali *et al.,* (2018) and Lenka *et al.* (2023).

Among the different treatments, groundnut + finger millet (5:2) (T_7) generated significantly higher gross and net returns, along with a superior benefit: cost ratio, followed by groundnut + finger millet (5:4) (T_{10}). This was mainly due to higher price and yield of groundnut. While the sole crop of little millet (T_4) registered the lowest gross returns, net returns, and benefit: cost ratio. These results were in agreement with studies of Manjunath and Salakinkop (2017), Shwethanjali *et al*., (2018) and Lenka *et al.* (2023).

The present study clearly indicates that intercropping of groundnut + finger millet at a 5:2 row proportion is found to be the best intercrop for getting higher yield and economic advantage in Southern Agro-climatic zone of Andhra Pradesh.

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Research Note

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A STUDY ON IDENTIFICATOIN OF CHALLENGES AND POTENTIAL OPPORTUNITIES FOR RURAL WOMEN ENTREPRENEURSIP IN PALNADU DISTRICT OF ANDHRA PRADESH

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ABSTRACT

The present study was carried out in 2024 to explore the challenges and opportunities of rural women in agripreneurship. It was purposively conducted in Palnadu district of Andhra Pradesh, India. The sample size of respondents taken was 90, who were randomly selected from six randomly selected villages. Data was collected through pre-structured interview schedule to gauge constraints and opportunities of the women entrepreneurs. Frequency and percentage analysis is the statistical tool employed to analyse the data. The empirical findings of the study revealed that constraints faced by the rural women entrepreneurs showed that Socio-cultural constraints ranked first (96.67%) followed by Marketing constraints second (94.44%), constraints in finance ranked third (87.78%), constraints in raw materials ranked fourth (82.22%), constraints in power ranked fifth (68.89%), entrepreneurial constraints ranked sixth (64.44%) and constraints in labour ranked seventh (53.33%). Opportunities for rural women in agri-preneurship perceived by the respondents were ranked by their importance according to the perception of sample respondents. Employment generation emerged as the top opportunity, with a mean score of 58.93, indicating its significant role in empowering rural women.

KEYWORDS: Women agripreneurship, challenges, opportunities.

INTRODUCTION

Women agripreneurship refers to the entrepreneurial activities undertaken by women in rural areas within the agricultural sector. This includes a wide range of enterprises such as crop production, livestock farming, agro-processing, and value-added agricultural activities. Rural women agripreneurs are key players in the local and national economies, driving innovation, ensuring food security, and contributing to poverty alleviation. Their involvement in agripreneurship not only provides them with income but also enhances their decision-making power within their households and communities, fostering greater gender equality. Hence, involvement of women in income generating activities helps to empower them economically (Mubeena *et. al.,* 2017).

Despite their significant contributions, rural women face multiple challenges that limit their entrepreneurial potential. These challenges often stem from socio-cultural norms that restrict women's roles, limited access to financial resources, inadequate infrastructure, and lack of training and education in modern agricultural practices. Additionally, rural women agripreneurs frequently encounter difficulties in accessing markets and technology, which further hampers the growth of their enterprises. Devi *et. al.* (2023) highlighted the challenges faced by women agri startups in Manipur such as lack of funding, poor transportation, non-availability of skilled workers or weavers, limited market access, and lack of guidance and technical assistance. They indicated that business in value addition has great scope and with the aid of incubators, the women's startup can achieve tremendous growth. Jebadurai (2013) explored the issues faced by rural entrepreneurs such as finance shortages, raw material scarcity, purchasing power of rural populations, and competition and suggested educating the rural population about entrepreneurship, providing low-interest finance, and government support for new ventures. Roy *et. al.,* (2025) explored factors such as education, socio-cultural norms, access to resources, and psychological barriers that influence their involvement in agripreneurship and suggested implementing targeted policies and interventions focused on continued investments in education, financial inclusion, capacity building, and infrastructure development. Rural women need capacity building and training in functional areas such as finance, literacy skills, marketing, production, and managerial skills to enhance their ability to run an entrepreneurial business (Charitha *et. al.* 2023).

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The agripreneurship offers numerous opportunities for rural women. It provides a pathway for economic empowerment, allowing women to diversify their income sources and invest in their families' futures. Sehrawat *et. al.,* (2025) in their study highlighted the status of the women Agri-entrepreneurs, their importance and the problems and obstacles faced by them in terms of opportunities and challenges faced with a view to improve their contribution to the economy and for true inclusive growth. Mari Selvam (2024) in his study discussed the challenges and sustainable development opportunities available to women entrepreneurs in the agricultural sector. Agripreneurship promotes sustainable agricultural practices, which are crucial for long-term food security and environmental conservation. By identifying and addressing the specific challenges faced by rural women in agripreneurship, there is a potential to unlock these opportunities, leading to more resilient and prosperous rural communities.

MATERIAL AND METHODS

Purposive and multistage random sampling technique was employed for the selection of sample in the present study. Three mandals with good number of women entrepreneurs were selected randomly in Palnadu district. Similarly, following the same criteria, two villages in each mandal were selected. From each village, 15 women agripreneurs were selected randomly making a total of 90 respondents. Based on exhaustive review of literature and expert's opinion a pre-structured interview schedule was developed to collect the primary data from respondents and then analysed using frequency and percentage analysis for constraints and Garett ranking technique for analyzing opportunities.

Garrett's Ranking Technique

To find out the major constraints faced by the farmers; Garrett's ranking technique was used. The prime advantage of this technique over simple frequency distribution is that the constraints were arranged based on their severity from the point of view of respondents. Hence, the same number of respondents on two or more constraints may have been given different rank. Garrett's formula for converting ranks into percent is:

$$Percentage\ position = 100 * \frac{R_{ij} - 0.5}{N_j}$$

Where,

R_{ij} = Rank given for ith factor by j^{th} individual

N_j = Number of variables ranked by the j^{th} individual

With the help of Garrett ranking table given by Garret and Woodworth (1969), the per cent position estimated is converted into scores. Then for each constraint, the scores of each individual were added and then the total value of scores and mean values of score was calculated. The constraints having the highest mean value was considered to be the major constraint. The final ranking of the constraints in order to fix their relative priority was done on the basis of their mean score.

RESULTS AND DISCUSSION

1. Challenges encountered by rural women in agriprenuership

1.1 Distribution of overall challenges

From the table 1, among the challenges faced by the rural women entrepreneurs, Socio-cultural challenges ranked I (96.67%) followed by marketing challenges II (94.44%), challenges in finance III (87.78%), challenges in raw materials IV (82.22%), challenges in power V (68.89%), entrepreneurial challenges VI (64.44%) and challenges in labour ranked VII (53.33%).

1.2 Challenges in procuring raw materials

Challenges in raw materials ranked IV was conceived as the fourth main problem (table 1) in which high prices (30.00%), transportation problem (25.56%), scarcity (14.44%), low quality (12.22%), were the major challenges with respect to raw material availability.

1.3 Challenges in accessing finance

Challenges in finance ranked III was conceived as the third main problem (table 1) in which shortage of in-hand finance for fixed and working capital (34.44 %) was viewed as the main problem followed by high rate of interest (23.33 %), low benefit-cost ratio (17.78 %), lack of financial assistance from banks and government agencies (8.89 %), lack of knowledge regarding financial scheme (3.33 %) were the major problems under challenges in accessing finance.

Table 1. Distribution of challenges faced by rural women agripreneurs

S. No	Challenges	Respondents Frequency	Respondents (%)	Individual constraint ranking	Sub total Frequency	Sub total (%)	Overall rank
I	**SOCIO-CULTURAL FACTORS**						
1.	Tradition / culture which prevent women from taking up business	37	41.11	I			
2.	Multiple workload and related conflicts	12	13.33	IV	87	96.67	**I**
3.	Gender discriminated socialization	16	17.78	II			
4.	Lack of support from family and society	14	15.56	III			
5.	Criticism/ ridicule of the society	8	8.89	V			
II	**CHALLENGES IN RAW MATERIALS**						
1.	Scarcity	13	14.44	III			
2.	High prices	27	30.00	I	74	82.22	**IV**
3.	Low quality	11	12.22	IV			
4.	Problems of transport	23	25.56	II			
III	**CHALLENGES IN FINANCE**						
1.	Shortage of in-hand finance for fixed and working capital	31	34.44	I	79	87.78	**III**
2.	Lack of financial assistance from banks and government agencies	8	8.89	IV			
3.	Lack of knowledge regarding financial scheme	3	3.33	V			
4.	High rate of interest	21	23.33	II			
5.	Low benefit-cost ratio	16	17.78	III			
IV	**CHALLENGES IN LABOUR**						
1.	High labour cost	18	20.00	I	48	53.33	**VII**
2.	scarcity of labour	8	8.89	III			
3.	non availability of skilled labour	16	17.78	II			
4.	absenteeism	6	6.67	IV			
V	**CHALLENGES IN POWER**						
1.	Absenteeism	14	15.56	III	62	68.89	**V**
2.	uncertainty	27	30.00	I			
3.	high cost	21	23.33	II			
VI	**CHALLENGES IN MARKETING**						
1.	Lack of demand for product	7	7.78	VII	85	94.44	**II**
2.	Low price for the produce	11	12.22	IV			
3.	Frequent price fluctuation	8	8.89	VI			
4.	Competition from other units	3	3.33	VIII			
5.	Difficulty in establishing market	18	20.00	I			
6.	Lack of market information	10	11.11	V			
7.	Exploitation by middlemen	15	16.67	II			
8.	Lack of transporting facilities	13	14.44	III			
VII	**ENTREPRENEURIAL CHALLENGES**						
1.	Lack of technical knowledge	11	12.22	III	58	64.44	**VI**
2.	Lack of management training	8	8.89	IV			
3.	Lack of consultancy	13	14.44	II			
4.	Lack of awareness about entrepreneurial development agencies	20	22.22	I			
5.	Lack of contact with developmental organizations	6	6.67	V			

Table 2. Opportunities available to rural women agripreneurs

S. No	Particulars	Garett Score	Rank
1.	Growing demand for agri-based products	54.21	3
2.	Employment generation	58.93	1
3.	Potential for technological advancements to improve operational efficiency	53.62	4
4.	E-commerce platforms for trading	54.42	2
5.	Branding of processed products	49.53	5
6.	Exploring new markets	46.54	6
7.	Increasing women empowerment schemes and programmes	38.18	7

1.4 Challenges in Labour

Challenges in case of labour which was ranked VII was conceived as the seventh main problem (table 1) in which high labour cost (20.00 %), non-availability of skilled labour (17.78 %), scarcity of labour (8.89 %), absenteeism (6.67 %) were the major challenges.

1.5 Challenges in power

Challenges in power which was ranked V was conceived as the fifth main problem (table 1) in which uncertainty (30.00%), high cost (23.33%), absenteeism (15.56%), were the major challenges.

1.6 Challenges in marketing

Challenges in marketing which was ranked II was conceived as the second major problem (table 1) in which difficulty in establishing market (20.00%), exploitation by middlemen (16.67%), lack of transporting facilities (14.44%), low price for the produce (12.22%), lack of market information (11.11%), frequent price fluctuation (8.89%), lack of demand for product (7.78%), competition from other units (3.33%) were the major marketing challenges.

1.7 Entrepreneurial challenges

Entrepreneurial challenges which were ranked VI was conceived as the sixth main problem (table 1) in which lack of awareness about entrepreneurial development agencies (22.22%), lack of consultancy (14.44 %), lack of technical knowledge (12.22%), lack of management training (8.89 %), lack of contact with developmental organizations (6.67 %) were the major entrepreneurial challenges.

1.8 Socio-Cultural challenges

Among all challenges, the socio-cultural factors were overall ranked I was conceived as the main problem (table 1) in which tradition / culture prevent women from taking up business found to be the major constraint (41.11%) followed by gender discriminated socialization (17.78%), lack of support from family and society (15.56%), multiple workload and related conflicts (13.33%) and criticism/ ridicule of the society (8.89%) were the main socio-cultural factors faced by the respondents. Similar results were obtained by Pharm and Sritharan (2013) wherein the key challenges faced by women entrepreneurs in rural settings include social barriers, lack of financial support, and issues with training and skill development. Similar study was conducted by Mubeena *et. al.* (2017) which revealed that marketing constraints, technical constraints, economic constraints, social constraints were the major constraints faced by rural women entrepreneurs in Kurnool district.

2. Potential opportunities of rural women in agripreneurship

Ramesh (2020) reviewed agri-entrepreneurial opportunities across various sectors, including inputs, bio-pesticides, bio-fertilizers, vermicomposting, soil testing and modification, organic farming, balanced use of fertilizers and pesticides, agrochemicals, and crop rotation. From table 2, it reveals that there are several key opportunities for rural women in agri-preneurship, which are ranked by their importance according to the perception of sample respondents. Employment generation emerges as the top opportunity, with a mean score of 58.93, indicating its significant role in empowering rural women. E-commerce platforms for trading follow closely as the second-ranked opportunity, with a mean score of 54.42, highlighting the growing importance of digital avenues for expanding market reach. The increasing demand for agri-based products is the third-ranked opportunity, with a mean score of 54.21, reflecting the potential for rural women to capitalize on this trend. Technological advancements to improve operational efficiency ranked fourth, with a mean score of 53.62, showing the potential opportunity for innovation to enhance productivity. Branding of processed products is the fifth-ranked opportunity, scoring 49.53, which emphasizes the value of differentiating products in the market. Exploring new markets ranked sixth, with a mean score of 46.54, indicating the importance of expanding beyond traditional markets. Finally, increasing women empowerment schemes and programs ranked seventh, with a mean score of 38.18, highlighting the ongoing efforts to support and empower women in the agricultural sector. Similar results were found in the studies of Gautam and Mishra (2016) and Jayabal and Soundarya (2016) which emphasized that supporting rural women entrepreneurs with needed assistance from government bodies, family, male colleagues, and financial agencies could significantly boost rural economic development. Similarly, Siddiqui (2012) in his paper stated that the problems of women entrepreneurs can be eradicated by appropriate training, incentives, encouragement and motivation, social recognition of their entrepreneurial abilities, and family's moral support.

Rural women agripreneurs in Palnadu district face significant challenges, with socio-cultural barriers being the most critical, followed by marketing and financial difficulties. Challenges in accessing raw materials, labor, and power further complicate their efforts. Despite these hurdles, there are substantial opportunities, such as employment generation, e-commerce platforms, and growing demand for agri-products. Technological advancements, branding, market exploration, and increased support through women empowerment schemes offer pathways for overcoming obstacles and achieving entrepreneurial success.

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STUDIES ON COMBINING ABILITY FOR GRAIN YIELD AND ITS ATTRIBUTING TRAITS IN MAIZE (*Zea mays* L.)

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ABSTRACT

An investigation was conducted to assess the Combining ability for yield and its attributing traits in maize (*Zea mays* L.) during *rabi*, 2024–25 at S. V. Agricultural College, Tirupati. A Line × Tester mating design was carried out for 30 inbred lines and 2 testers to evaluate the GCA and SCA effects for grain yield and associated traits. For the considered 12 traits, *sca* variance exceeded GCA variance for all traits except for ear length, confirming the predominance of non-additive gene action. Based on *per se* performance and *gca* effects, the lines PL 23084 and PL 23110 were identified as best general combiners for grain yield and its components. Among hybrids, PL 23100 × LM 14, PL 23090 × CML 451, and PL 23059 × LM 14 exhibited significant positive *sca* effects for grain yield and its components, identifying them as the best crosses for exploiting hybrid vigour. The two crosses PL 23100 × LM 14 and PL 23059 × LM 14 were identified based on the *per se* performance and *sca* effects for grain yield. These hybrids need to be further evaluated across locations and over seasons to select best hybrids for commercial exploitation.

KEYWORDS: Combining ability, non-additive gene action, line x tester mating design.

INTRODUCTION

Maize (*Zea mays* L.) originated from South and Central America and belongs to the Poaceae family and subfamily Panicoideae with chromosome number 2n=20. It is considered as the "queen of cereals" owing to its high genetic production potential. It is a globally significant staple crop vital for human and animal food (Wang *et al.,* 2023). In India, Maize is the third most important cereal crop, after rice and wheat, accounting for approximately 10 per cent of the country's total food grain production (Anonymous, 2023-24a). Maize grains contains nearly 70 per cent starch, 10 per cent protein, 4 per cent oil and 2.7 per cent crude fibre (Bisen *et al.,* 2017) also offers substantial nutritional benefits to combat malnutrition through QPM variety and it has having wide range of utilities like starch, pharmaceuticals, cosmetics, textiles and biofuel production (Vidadala *et al.,* 2025). Being an allogamous and C_4 plant, it is physiologically more efficient as well as resilient to changing climatic conditions and able to grow successfully throughout the world (Rajesh *et al.,* 2018). It has been successfully exploited in the production of hybrids which played a vital role in increasing the acreage and productivity of maize. Constant efforts have been made to improve grain yield and its contributing characters through hybridization in maize.

Developing a hybrid with high vigour and productivity requires the careful selection and crossing of parent lines that show a favourable combining ability to harness the potential of heteros is fully (Bhavana *et al.,* 2011). In this perspective, L × T analysis has widely been used for evaluation of inbred lines by crossing them with testers (Vardhini *et al.,* 2024). Combining ability gives insights into the potential of inbred lines that can be used to develop hybrids and also reveals the nature and magnitude of different types of gene action, assisting the breeders in selecting parental lines with superior performance. This analysis encompasses both general combining ability (GCA) and specific combining ability (SCA) (Hayman, 1954; Griffing, 19566). GCA reflects the average performance of an inbred line when crossed with various other lines (Chiuta *et al.,* 2020). It reveals the parental line's overall genetic contribution to the hybrid's performance. This information enables the breeder to evaluate and classify selected parental material for their utility in development of high yielding F_1 hybrids in maize, where hybrids are being cultivated on a commercial scale. The *sca* effects help breeders

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to determine heterotic patterns among populations or inbred lines to identify promising single crosses and assign them into heterotic groups (Lahane *et al.* 2014). The ratio of GCA to SCA variance determines the gene action involved in the inheritance of those traits. If ratio that is less than unity represents the predominance of non-additive gene action, while it is greater than unity represents the predominance of additive gene action (Kumawat *et al.* 2021). The current experiment consisted of sixty hybrids and thirty two parents of maize to determine the combining ability for Grain yield and its attributing traits.

MATERIAL AND METHODS

The 60 F_1 hybrids and their 32 parents (30 lines, 2 testers) and 4 checks were planted in separate 8 blocks with 2 replications in an alpha lattice design, during *rabi*, 2024-25, at wetland farm, S.V. Agricultural College, Tirupati (Table 1). Each genotype was planted in two row plots of 4 meter in length with a spacing of 60 cm between rows and 20 cm within rows. All management practices were followed as and when required to establish a good crop. Observations were recorded on 12 grain yield and its attributing traits *viz.,* Days to 50 per cent Anthesis, Days to 50 per cent Silking, Anthesis-Silking Interval, Plant height (cm), Ear height (cm), Days to maturity, Ear length (cm), Ear girth (cm), Kernel rows ear^{-1}, Number of kernels row^{-1}, 100 kernel weight (g) and Grain yield plant^{-1} (g). Data from all the characters studied were exposed to analysis of variance technique on the basis of model proposed by Panse and Sukhatme (1961). The combining ability analysis was carried out according to the method suggested by Kempthorne (1957).

RESULTS AND DISCUSSION

Results

Analysis of variance for combining ability in a Line × Tester mating design for yield and yield components revealed that breeding material registered highly significant differences among themselves for all the characters.

Analysis of variance for combining ability

The parents differed significantly for all the characters except for anthesis silking interval indicating the existence of sufficient variability in the material studied and also revealed that the mean sum of squares for parents vs crosses exhibited significant differences ($p \leq 0.01$) for all the traits except for kernel rows cob^{-1}, revealing manifestation of differences among parents and their F_1 crosses in all the characters. The crosses effects were partitioned into line effect, tester effect and line × tester effect. Mean sum of squares line effects exhibited significant differences ($p \leq 0.01$) for all the traits except for anthesis silking interval, ear length, ear girth and number of kernels per row, suggesting a larger contribution of lines towards general combining ability variance components for most of the traits. Mean sum of squares of testers are also significant ($p \leq 0.01$) for the traits ear height and 100 kernel weight, representing the presence of variability for these traits among testers. Crosses recorded significant differences($p \leq 0.01$) for all the yield contributing characters. The interaction effects were significant for all the traits except for ear girth; significant interaction effects ($p \leq 0.01$) revealed the significant contribution of crosses for specific combining ability variance components (Table 2).

Per se performance

A perusal of the *per se* performance of parents for grain yield and yield components indicated that the lines, PL 23065, PL 23071, PL 23095, PL 23110 and PL 23066 registered superior performance for grain yield and most of the yield contributing characters. Among these, the lines PL 23065, PL 23095 and PL 23066 also exhibited superior performance for early maturity traits *viz.,* days to 50 per cent anthesis, days to 50 per cent silking, anthesis silking interval and days to maturity. Hence, it is suggested that these lines could be utilized as parents in the development of hybrids possessing high yield coupled with earliness. Further, the hybrids PL 23110 × CML 451, PL 23043 × CML 451, PL 23043 × LM 14, PL 23077 × CML 451 and PL 23047 × CML 451 has shown superior *per se* performance for grain yield and most of the attributing traits when compared to the high yielding best check hybrid P3396 (151.8g). These outstanding hybrids could be exploited for commercial cultivation after verification of their performance in different locations and environments.

The General combining ability (GCA) effects

Six parents PL 23043, PL 23047, PL 23105, PL 23107, PL 23110 and PL 23084 shown positive significant *gca* effects for grain yield. Among these parents, the line PL 23084 recorded positive significant *gca* effects in desirable direction for ten traits *viz.,* days to 50 per

Table 1. List of list of thirty (30) lines and two (2) testers used in present experiment

	Lines (30)
1	PL 23040
2	PL 23041
3	PL 23043
4	PL 23045
5	PL 23047
6	PL 23048
7	PL 23050
8	PL 23050A
9	PL 23053
10	PL 23056
11	PL 23059
12	PL 23065
13	PL 23066
14	PL 23067
15	PL 23071
16	PL 23077
17	PL 23078
18	PL 23079
19	PL 23082
20	PL 23084
21	PL 23085
22	PL 23090
23	PL 23095
24	PL 23100
25	PL 23102
26	PL 23105
27	PL 23107
28	PL 23108
29	PL 23109
30	PL 23110
	Testers (2)
1.	CML 451
2.	LM 14

cent anthesis, days to 50 per cent silking, plant height, ear height, days to maturity, ear length, ear girth, kernels row^{-1}, hundred kernel weight and grain yield plant^{-1}, whereas the line PL 23110 was identified as the best general combiner as it exhibited significant *gca* effects in desirable direction for Days to 50 per cent anthesis, Days to 50 per cent silking, Plant height, Ear height, Days to maturity, number of kernels row^{-1} and grain yield plant^{-1} and the line PL 23107 exhibited positive significant *gca* effects for anthesis silking interval, plant height, ear height, ear girth, kernel rows ear^{-1} and grain yield plant^{-1}. Crosses involving these parents might produce heterotic hybrids with high *per se* performance for the respective traits. As *gca* effects are attributed to additive gene effects, the lines PL 23084 and PL 23110 might be considered as potential parents for maize improvement programmes aimed at earliness, yield and its contributing traits (Table 3).

Selection of parents based on either *per se* performance or *gca* effects would be misleading as *per se* performance of parents was not always associated with high gca effects. Hence, both *gca* effects and *per se* performance are to be given due importance while selecting parents for use in breeding programmes. Consideration of both *per se* performance and *gca* effects would result in the selection of the best parents possessing desirable genes (Singh and Harisingh, 1985). In the present investigation, among the 32 parents studied, based on *per se* performance and *gca* effects among parents, PL 23110 and PL 23105 were identified as the best parents for grain yield and most of its contributing characters. Hence, these parents could be utilized in the development of the high yielding and early maturing hybrids in maize and also utilized in developing superior recombinants in further selection programmes for the improvement of yield parameters in maize (Table 5).

The specific combining ability (SCA) effects

A perusal of *sca* effects recorded in the present investigation, out of 60 hybrids none of the cross combinations recorded significant *sca* effects in desirable direction for all the 12 traits studied. Hence, apart from *sca* effect of grain yield, the *sca* effects recorded by a hybrid for other yield components were also considered judiciously to identify a good specific combiner.

Among 60 hyrbids, three hybrids *viz.,* the hybrid PL 23100 × LM 14, PL 23090 × CML 451 and PL 23059

Table 2. Analysis of variance for combining ability in L × T design for grain yield and its attributing traits

Source of variation	DF	Days to 50% anthesis	Days to 50% silking	Anthesis silking interval	Plant height	Ear height	Days to maturity
				Mean sum of squares			
Replications	1	0.6576	0.6576	0.000	0.5434	10.048	0.440
Treatments	91	27.2538**	26.39 **	0.4271*	1782.869**	504.382**	26.390**
Parents	31	23.9833**	23.1688**	0.2721	1453.467**	399.926**	23.168**
Parents vs Crosses	1	1292.9188**	1274.5935**	0.0654	75247.242**	19701.741**	1274.593**
Crosses	59	7.520**	6.927**	0.515**	710.786**	233.88**	6.927**
Line Effect	29	12.162**	10.902**	0.582	1075.868**	346.547**	10.902**
Tester Effect	1	0.133	1.200	0.533	1147.008	730.133*	1.200
Line × Tester Effect	29	3.133**	0.3059**	0.447*	330.945**	104.116**	3.148**
Error	91	0.3169	0.422	0.2637	87.323	45.708	0.286

*, ** Significant at 5% ($p \leq 0.05$), 1% ($p \leq 0.01$) respectively; Df = Degrees of Freedom.

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Table 2. Analysis of variance for combining ability in L × T design for grain yield and its attributing traits

Source of variation	DF	Ear length	Ear girth	Kernel rows ear^{-1}	Number of kernels row^{-1}	100 kernel weight	Grain Yield $plant^{-1}$
				Mean sum of squares			
Replications	1	0.00049	0.177	0.356	0.808	0.208	159.849
Treatments	91	13.824 **	3.817 **	2.831 **	81.801 **	42.217 **	3871.822 **
Parents	31	13.114 **	3.149 **	2.170 **	65.097 **	39.390 **	2652.770 **
Parents vs Crosses	1	539.750 **	192.210 **	57.871 **	3326.231 **	1253.442 **	193970.331 **
Crosses	59	5.283 **	0.975 **	2.247 **	35.587 **	23.174 **	1290.333 **
Line Effect	29	6.173	1.116	3.094 *	5.118	29.154 *	1824.470 **
Tester Effect	1	0.252	2.028	2.160	0.630	110.592 **	1832.227
Line × Tester Effect	29	4.556 **	0.798	1.403 **	27.261 **	14.179 **	737.510 **
Error	91	1.939	0.553	0.630	8.523	5.515	299.776

*, ** Significant at 5% ($p \leq 0.05$), 1% ($p \leq 0.01$) respectively; Df = Degrees of Freedom.

Table 3. Estimates of general combining (*gca*) effects of lines and testers for grain yield and its attributing traits in maize

Parents	Days to 50% anthesis	Days to 50% silking	Anthesis silking interval	Plant height	Ear height	Days to maturity	Ear length	Ear girth	Kernel rows ear^{-1}	Number of kernels row^{-1}	100 kernel weight	Grain yield $plant^{-1}$
LINES												
PL 23040	-1.950**	-1.583**	0.367*	15.775**	-2.617	-1.583**	0.251	-0.350	-1.253**	-2.869	2.595*	-14.589
PL 23041	-0.950**	-1.083**	-0.133	22.775**	16.633**	-1.083**	-0.324	0.225	-0.152	-1.969	2.470*	2.461
PL 23043	-0.950**	-0.833**	0.117	15.025**	9.633*	-0.833**	2.051**	0.500	-0.953**	4.381**	4.945**	36.211**
PL 23045	-1.450**	-1.833**	-0.383*	-19.225**	-10.117**	-1.833**	-0.924	-1.150**	-0.652	2.031	-4.630**	-12.489
PL 23047	0.300	0.417	0.117	3.775	7.883*	0.417	0.876	0.250	-0.053	4.781**	1.620	30.736**
PL 23048	-0.200	-0.583*	-0.383*	-4.975	2.133	-0.583*	0.851	0.000	-0.653	1.231	1.720	6.186
PL 23050	-1.450**	-1.333**	0.117	-7.725	-2.117	-1.333**	-0.524	-0.725*	-0.553	-1.319	-2.030	-14.614
PL 23050A	-2.450**	-2.333**	0.117	-25.975**	-17.117**	-2.333**	-2.624**	-0.175	0.148	-5.569**	-3.030*	-36.664**
PL 23053	0.050	0.167	0.117	-1.225	-1.617	0.167	0.451	-0.075	-0.253	1.081	-1.655	-12.214
PL 23056	4.050**	3.667**	-0.383*	-28.475**	-14.117**	3.667**	-0.799	-0.725*	0.747*	-5.269**	-1.780	-35.964**
PL 23059	2.050**	2.667**	0.617**	-19.725**	-8.867*	2.667**	0.026	-0.200	0.247	-2.594	-2.130	-14.814
PL 23065	-0.200	-0.083	0.117	8.275	4.133	-0.083	0.826	0.725*	-0.053	1.731	1.495	15.561
PL 23066	-0.700*	-0.083	0.617**	19.275**	10.883**	-0.083	0.151	0.275	-0.752*	-0.019	1.970	0.786
PL 23067	2.550**	2.167**	-0.383*	13.525*	6.383	2.167**	-0.124	0.100	-0.753*	-3.919**	3.795**	12.861
PL 23071	0.300	0.167	-0.133	17.025**	9.633*	0.167	0.526	-0.225	-1.053**	-0.269	4.195**	8.561
PL 23077	-1.700**	-1.833**	-0.133	-2.225	-7.367*	-1.833**	0.376	0.300	1.247**	4.281**	-3.705**	13.761
PL 23078	0.800**	0.917**	0.117	-6.725	-5.867	0.917**	0.351	0.475	1.848**	0.781	-4.205**	-3.814
PL 23079	3.050**	3.167**	0.117	-7.475	-3.617	3.167**	0.151	-0.650*	0.448	-0.094	-3.355**	7.436
PL 23082	0.050	0.417	0.367*	3.525	3.133	0.417	-1.224	0.200	-0.153	1.431	-1.130	-3.514
PL 23084	-0.950**	-1.083**	-0.133	13.775*	9.633*	-1.083**	2.051**	0.825*	-0.277	3.506*	4.595**	20.586*
PL 23085	-0.700*	-1.083**	-0.383*	4.275	-3.867	-1.083**	1.201	0.225	-0.352	4.481**	0.845	16.186
PL 23090	-1.450**	-1.833**	-0.383*	-46.725**	-22.117**	-1.833**	-3.924**	-0.650*	-0.552	-9.819**	-2.230	-55.114**
PL 23095	-0.700*	-0.333	0.367*	-11.725*	-5.617	-0.333	-0.699	-0.125	-0.253	-1.619	-0.855	-15.614
PL 23100	0.800**	0.667*	-0.133	-7.225	0.383	0.667*	-0.474	-0.650*	-0.053	0.881	-2.130	-5.939
PL 23102	0.050	0.167	0.117	9.525	5.883	0.167	0.851	0.525	1.347**	-0.019	1.670	14.136
PL 23105	4.050**	3.167**	-0.883**	11.275*	5.133	3.167**	0.026	-0.225	1.348**	2.731	-0.955	26.936**
PL 23107	1.800**	1.167**	-0.633**	16.525**	13.133**	1.167**	1.076	1.300**	2.447**	1.081	1.320	23.336*
PL 23108	-0.700*	0.167	0.867**	-3.975	-3.367	0.167	-0.299	0.125	-0.253	0.531	-0.455	-5.714
PL 23109	-2.450**	-2.333**	0.117	0.525	-6.117	-2.333**	-1.399	-0.275	-0.553	-2.819	-0.705	-25.464**
PL 23110	-0.950**	-0.833**	0.117	18.525**	9.883**	-0.833**	1.251	0.150	-0.253	3.231*	1.745	20.786*
SE (g_i)	0.2751	0.2721	0.1826	5.3019	3.6241	0.2759	0.7177	0.3180	0.3543	1.4555	1.2183	9.0434
CD at 5%	0.5506	0.5444	0.3653	10.6091	7.2518	0.5521	1.4362	0.6362	0.7089	2.9124	2.4379	18.0958
CD at 1%	0.7324	0.7241	0.4860	14.1124	9.6465	0.7344	1.9104	0.8463	0.9430	3.8742	3.2429	24.0713
TESTERS												
CML 451	-0.033	-0.1	-0.067	-3.092*	-2.467*	-0.1	0.046	0.129	0.134	-0.073	0.960**	3.907
LM 14	0.033	0.1	0.067	3.092*	2.467*	0.1	-0.046	-0.129	-0.134	0.073	-0.960**	-3.907
SE (g_j)	**0.0710**	**0.0702**	**0.0471**	**1.3690**	**0.9357**	**0.0712**	**0.1853**	**0.0821**	**0.0915**	**0.3758**	**0.3146**	**2.3350**
CD at 5%	**0.1422**	**0.1406**	**0.0943**	**2.7393**	**1.8724**	**0.1426**	**0.3708**	**0.1643**	**0.1830**	**0.7520**	**0.6295**	**4.6723**
CD at 1%	**0.1891**	**0.1870**	**0.1255**	**3.6438**	**2.4907**	**0.1896**	**0.4933**	**0.2185**	**0.2435**	**1.0003**	**0.8373**	**6.2152**

*, ** Significant at 5% ($p \leq 0.05$), 1% ($p \leq 0.01$) respectively

Table 4. Estimates of specific combining ability (*sca*) effects of crosses for grain yield and its contributing traits in maize

Crosses	Days to 50% anthesis	Days to 50% silking	Anthesis silking interval	Plant height	Ear height	Days to maturity	Ear length	Ear girth	Kernel rows ear^{-1}	Number of kernels row^{-1}	100 kernel weight	Grain yield $plant^{-1}$
PL 23040 × CML 451	-0.033	0.15	0.183	6.158	-2.467	0.15	0.521	-0.07	0.134	0.578	-0.39	3.982
PL 23040 × LM 14	0.033	-0.15	-0.183	-6.158	2.467	-0.15	-0.521	0.07	-0.134	-0.578	0.39	-3.982
PL 23041 × CML 451	-0.467	-0.15	0.317	-0.158	-2.283	-0.15	-0.296	0.195	-1.234*	0.622	5.115**	0.467
PL 23041 × LM 14	0.467	0.15	-0.317	0.158	2.283	0.15	0.296	-0.195	1.234*	-0.622	-5.115**	-0.467
PL 23043 × CML 451	-1.467**	-1.900**	-0.433	-0.908	-0.783	-1.900**	0.179	0.22	-0.434	-0.428	2.09	-2.282
PL 23043 × LM 14	1.467**	1.900**	0.433	0.908	0.783	1.900**	-0.179	-0.22	0.434	0.428	-2.09	2.282
PL 23045 × CML 451	-0.467	-0.4	0.067	3.342	-3.033	-0.4	0.554	0.12	-0.334	2.222	0.215	1.017
PL 23045 × LM 14	0.467	0.4	-0.067	-3.342	3.033	0.4	-0.554	-0.12	0.334	-2.222	-0.215	-1.017
PL 23047 × CML 451	-0.217	-0.65	-0.433	9.842	0.467	-0.65	0.404	0.42	0.466	0.873	-2.135	-2.308
PL 23047 × LM 14	0.217	0.65	0.433	-9.842	-0.467	0.65	-0.404	-0.42	-0.466	-0.873	2.135	2.308
PL 23048 × CML 451	0.783*	0.850*	0.067	11.592	3.717	0.850*	-0.821	0.42	0.066	-3.677	3.015	-5.657
PL 23048 × LM 14	-0.783*	-0.850*	-0.067	-11.592	-3.717	-0.850*	0.821	-0.42	-0.066	3.677	-3.015	5.657
PL 23050 × CML 451	1.533**	1.100**	-0.433	11.342	9.467	1.100**	2.254*	0.095	-0.434	5.973**	0.715	14.642
PL 23050 × LM 14	-1.533**	-1.100**	0.433	-11.342	-9.467	-1.100**	-2.254*	-0.095	0.434	-5.973**	-0.715	-14.642
PL 23050A × CML 451	0.533	1.100**	0.567*	-3.408	0.967	1.100**	0.254	0.145	0.066	0.923	-0.235	6.593
PL 23050A × LM 14	-0.533	-1.100**	-0.567*	3.408	-0.967	-1.100**	-0.254	-0.145	-0.066	-0.923	0.235	-6.593
PL 23053 × CML 451	1.033*	1.100**	0.067	0.342	1.467	1.100**	0.429	-0.055	0.066	1.172	-0.56	5.642
PL 23053 × LM 14	-1.033*	-1.100**	-0.067	-0.342	-1.467	-1.100**	-0.429	0.055	-0.066	-1.172	0.56	-5.642
PL 23056 × CML 451	-0.967*	-0.900*	0.067	-5.408	-2.033	-0.900*	-0.021	-0.705	-0.734	1.122	-3.585*	-13.108
PL 23056 × LM 14	0.967*	0.900*	-0.067	5.408	2.033	0.900*	0.021	0.705	0.734	-1.122	3.585*	13.108
PL 23059 × CML 451	1.033*	1.100**	0.067	-12.658	-9.783	1.100**	-0.646	-0.68	-0.434	-1.403	-1.885	-29.208*
PL 23059 × LM 14	-1.033*	-1.100**	-0.067	12.658	9.783	-1.100**	0.646	0.68	0.434	1.403	1.885	29.208*
PL 23065 × CML 451	-0.717	-1.150**	-0.433	-7.658	-7.783	-1.150**	-0.346	0.445	0.266	-0.777	0.49	-7.233
PL 23065 × LM 14	0.717	1.150**	0.433	7.658	7.783	1.150**	0.346	-0.445	-0.266	0.777	-0.49	7.233
PL 23066 × CML 451	0.283	0.35	0.067	-4.158	-3.033	0.35	0.079	-0.205	-0.234	-0.027	0.715	-3.458
PL 23066 × LM 14	-0.283	-0.35	-0.067	4.158	3.033	-0.35	-0.079	0.205	0.234	0.027	-0.715	3.458
PL 23067 × CML 451	-0.967*	-0.900*	0.067	0.592	-4.033	-0.900*	0.504	0.12	-0.034	1.873	0.59	0.767
PL 23067 × LM 14	0.967*	0.900*	-0.067	-0.592	4.033	0.900*	-0.504	-0.12	0.034	-1.873	-0.59	-0.767
PL 23071 × CML 451	-0.217	-0.4	-0.183	3.092	2.217	-0.4	0.404	0.695	0.266	0.823	1.44	11.468
PL 23071 × LM 14	0.217	0.4	0.183	-3.092	-2.217	0.4	-0.404	-0.695	-0.266	-0.823	-1.44	-11.468
PL 23077 × CML 451	0.283	0.1	-0.183	12.342	4.717	0.1	1.404	0.970*	0.966	1.573	0.99	15.267
PL 23077 × LM 14	-0.283	-0.1	0.183	-12.342	-4.717	-0.1	-1.404	-0.970*	-0.966	-1.573	-0.99	-15.267
PL 23078 × CML 451	-1.217**	-0.65	0.567*	2.342	-0.783	-0.65	0.029	0.195	0.566	0.373	0.54	7.843

Cont...

Table 4. Estimates of specific combining ability (*sca*) effects of crosses for grain yield and its contributing traits in maize

Crosses	Days to 50% anthesis	Days to 50% silking	Anthesis silking interval	Plant height	Ear height	Days to maturity	Ear length	Ear girth	Kernel rows ear^{-1}	Number of kernels row^{-1}	100 kernel weight	Grain yield $plant^{-1}$
PL 23078 × LM 14	1.217**	0.65	-0.567*	-2.342	0.783	0.65	-0.029	-0.195	-0.566	-0.373	-0.54	-7.843
PL 23079 × CML 451	-0.967*	-0.4	0.567*	5.092	4.467	-0.4	-0.321	-0.63	-0.034	-3.103	-1.76	5.493
PL 23079 × LM 14	0.967*	0.4	-0.567*	-5.092	-4.467	0.4	0.321	0.63	0.034	3.103	1.76	-5.493
PL 23082 × CML 451	-0.467	-0.15	0.317	3.092	0.717	-0.15	-0.296	0.32	0.566	-0.677	-0.535	-0.157
PL 23082 × LM 14	0.467	0.15	-0.317	-3.092	-0.717	0.15	0.296	-0.32	-0.566	0.677	0.535	0.157
PL 23084 × CML 451	0.033	-0.15	-0.183	5.842	11.217*	-0.15	0.729	-0.255	0.091	0.347	-3.31	-7.257
PL 23084 × LM 14	-0.033	0.15	0.183	-5.842	-11.217*	0.15	-0.729	0.255	-0.091	-0.347	3.31	7.257
PL 23085 × CML 451	-1.217**	-1.150**	0.067	-2.658	1.217	-1.150**	-0.821	-0.355	-0.034	-0.927	-1.91	-10.058
PL 23085 × LM 14	1.217**	1.150**	-0.067	2.658	-1.217	1.150**	0.821	0.355	0.034	0.927	1.91	10.058
PL 23090 × CML 451	1.533**	1.600**	0.067	23.342**	8.467	1.600**	3.004**	0.42	-0.034	7.373**	1.665	34.542**
PL 23090 × LM 14	-1.533**	-1.600**	-0.067	-23.342**	-8.467	-1.600**	-3.004**	-0.42	0.034	-7.373**	-1.665	-34.542**
PL 23095 × CML 451	0.783*	1.100**	0.317	-11.158	-4.533	1.100**	0.579	-0.055	0.266	0.573	-0.51	3.642
PL 23095 × LM 14	-0.783*	-1.100**	-0.317	11.158	4.533	-1.100**	-0.579	0.055	-0.266	-0.573	0.51	-3.642
PL 23100 × CML 451	0.283	0.1	-0.183	-24.658**	-11.533*	0.1	-1.796	-0.980*	-0.134	-4.428*	-3.135	-38.533**
PL 23100 × LM 14	-0.283	-0.1	0.183	24.658**	11.533*	-0.1	1.796	0.980*	0.134	4.428*	3.135	38.533**
PL 23102 × CML 451	0.033	0.6	0.567*	-7.908	-5.033	0.6	-0.121	0.145	1.666**	-0.728	0.265	13.693
PL 23102 × LM 14	-0.033	-0.6	-0.567*	7.908	5.033	-0.6	0.121	-0.145	-1.666**	0.728	-0.265	-13.693
PL 23105 × CML 451	1.533**	1.100**	-0.433	-4.658	-1.783	1.100**	-2.496*	-0.805	-1.134*	-5.377*	1.34	-4.207
PL 23105 × LM 14	-1.533**	-1.100**	0.433	4.658	1.783	-1.100**	2.496*	0.805	1.134*	5.377*	-1.34	4.207
PL 23107 × CML 451	0.283	0.1	-0.183	-8.908	3.217	0.1	-0.146	-0.28	-0.434	-1.727	-0.185	-2.507
PL 23107 × LM 14	-0.283	-0.1	0.183	8.908	-3.217	-0.1	0.146	0.28	0.434	1.727	0.185	2.507
PL 23108 × CML 451	-0.717	-0.4	0.317	3.092	0.717	-0.4	-0.271	0.145	-0.134	0.722	-0.26	7.942
PL 23108 × LM 14	0.717	0.4	-0.317	-3.092	-0.717	0.4	0.271	-0.145	0.134	-0.722	0.26	-7.942
PL 23109 × CML 451	1.033*	0.6	-0.433	3.592	0.967	0.6	-1.721	-0.155	0.966	-3.227	-1.16	-12.407
PL 23109 × LM 14	-1.033*	-0.6	0.433	-3.592	-0.967	-0.6	1.721	0.155	-0.966	3.227	1.16	12.407
PL 23110 × CML 451	-0.967*	-1.400**	-0.433	1.592	-0.033	-1.400**	-0.171	0.02	-0.334	0.522	1.59	13.343
PL 23110 × LM 14	0.967*	1.400**	0.433	-1.592	0.033	1.400**	0.171	-0.02	0.334	-0.522	-1.59	-13.343
SE (s_{ij})	**0.3891**	**0.3847**	**0.2582**	**7.4981**	**5.1253**	**0.3902**	**1.0150**	**0.4497**	**0.5010**	**2.0584**	**1.7230**	**12.7893**
CD at 5%	**0.7786**	**0.7699**	**0.5167**	**15.0036**	**10.2556**	**0.7808**	**2.0311**	**0.8998**	**1.0025**	**4.1188**	**3.4477**	**25.5913**
CD at 1%	**1.0357**	**1.0241**	**0.6873**	**19.9580**	**13.6422**	**1.0386**	**2.7018**	**1.1969**	**1.3336**	**5.4789**	**4.5862**	**34.0419**

*, ** Significant at 5% ($p \leq 0.05$), 1% ($p \leq 0.01$) respectively

Table 5. Top 5 hybrids based on *per se* performance, *sca* and *gca* effects for grain yield and its contributing traits

S. No.	Character	*per se* performance of lines	*gca effects*	*per se* and *gca* effects	*per se* performance of crosses	*sca* effects	*per se* and *sca* effects
1.	Days to 50% anthesis	PL 23066 PL 23090 PL 23041 PL 23050A PL 23065	PL 230109 PL 230640 PL 23077 PL 23045	PL 23050A	PL 23109 × LM14 PL 23050 × LM14 PL 23050A × LM14 PL 23090 × LM14 PL 23043 × CML451	PL 23050 × LM14 PL 23090 × LM14 PL 23105 × LM14 PL 23043 × CML451 PL 23078 × CML451	PL 23050 × LM14 PL 23090 × LM14 PL 23043 × CML451
2.	Days to 50% silking	PL 23090 PL 23066 PL 23050A PL 23065 PL 23095	PL 23050A PL 23109 PL 23045 PL 23077	PL 23050A PL 23090	PL 23050A × LM14 PL 23090 × LM14 PL 23043 × CML451 PL 23109 × LM14 PL 23045 × CML451	PL 23043 × CML451 PL 23090 × LM14 PL 23110 × CML451 PL 23065 × CML451 PL 23085 × CML451	PL 23043 × CML451 PL 23090 × LM14
3.	Anthesis-silking interval	PL 23065 PL 23090 PL 23107 PL 23050A PL 23095	PL 23105 PL 23107 PL 23090 PL 23067 PL 23085	PL 23107 PL 23090	PL 23105 × CML451 PL 23107 × CML451 PL 23050A × LM14 PL 23090 × LM14 PL 23043 × CML451	PL 23050A × LM14 PL 23078 × LM14 PL 23079 × LM14 PL 23102 × LM14	PL 23050A × LM14
4.	Plant height	PL 23066 PL 23110 PL 23071 PL 23067 PL 23043	PL 23041 PL 23066 PL 23110 PL 23071 PL 23107	PL 23066 PL 23110 PL 23071	PL 23107 × LM14 PL 23066 × LM14 PL 23041 × LM14 PL 23040 × LM14 PL 23102 × LM14	PL 23100 × LM14 PL 23090 × CML451	-
5.	Ear height	PL 23066 PL 23110 PL 23071 PL 23067 PL 23078	PL 23041 PL 23107 PL 23066 PL 23110 PL 23043	PL 23066 PL 23110	PL 23041 × LM14 PL 23084 × CML451 PL 23066 × LM14 PL 23100 × LM14 PL 23065 × LM14	PL 23100 × LM14 PL 23084 × CML451	PL 23100 × LM14 PL 23084 × CML451
6.	Days to maturity	PL 23090 PL 23166 PL 23065 PL 23095 PL 23050A	PL 23050A PL 23109 PL 23045 PL 23077 PL 23099	PL 23050A	PL 23050A × LM14 PL 23090 × LM14 PL 23043 × CML451 PL 23110 × CML451 PL 23085 × CML451	PL 23090 × LM14 PL 23043 × CML451 PL 23110 × CML451 PL 23085 × CML451 PL 23065 × CML451	PL 23090 × LM14 PL 23043 × CML451 PL 23110 × CML451 PL 23085 × CML451

Cont...

Table 5. Top 5 hybrids based on *per se* performance, *sca* and *gca* effects for grain yield and its contributing traits

S. No.	Character	*per se* performance of lines	*gca effects*	*per se* and *gca* effects	*per se* performance of crosses	*sca* effects	*per se* and *sca* effects
7.	Ear length	PL 23065 PL 23071 PL 23095 PL 23105 PL 23066	PL 23043 PL 23084	-	PL 23105 × LM14 PL 23084 × CML451 PL 23085 × LM14 PL 23043 × LM14 PL 23043 × CML451	PL 23105 × LM14 PL 23050 × CML451 PL 23090 × CML451	PL 23105 × LM14
8.	Ear girth	PL 23065 PL 23095 PL 23071 PL 23105 PL 23066	PL 23107 PL 23084 PL 23065	PL 23065	PL 23107 × LM14 PL 23077 × CML451 PL 23107 × CML451 PL 23084 × LM14 PL 23065 × CML451	PL 23100 × LM14 PL 23077 × CML451	PL 23077 × CML451
9.	Kernel rows cob^{-1}	PL 23066 PL 23105 PL 23100 PL 23095 PL 23059	PL 23107 PL 23178 PL 23105 PL 23102 PL 23077	PL 23105	PL 23102 × CML451 PL 23078 × CML451 PL 23107 × LM14 PL 23077 × CML451 PL 23105 × LM14	PL 23102 × CML451 PL 23041 × LM14 PL 23105 × LM14	PL 23102 × CML451 PL 23105 × LM14
10.	Number of kernels row^{-1}	PL 23065 PL 23105 PL 23071 PL 23066 PL 23095	PL 23047 PL 23085 PL 23043 PL 23077 PL 23084	-	PL 23105 × LM14 PL 23077 × CML451 PL 23085 × LM14 PL 23100 × LM14 PL 23047 × CML451	PL 23090 × CML451 PL 23050 × CML451 PL 23105 × LM14 PL 23100 × LM14	PL 23100 × LM14 PL 23105 × LM14
11.	100 Kernel weight	PL 23071 PL 23095 PL 23066 PL 23043 PL 23077	PL 23043 PL 23184 PL 23071 PL 23067 PL 23040	PL 23071	PL 23041 × CML451 PL 23043 × CML451 PL 23184 × LM14 PL 23071 × CML451 PL 23048 × CML451	PL 23041 × CML451 PL 23056 × LM14	PL 23041 × CML451
12.	Grain yield plant^{-1}	PL 23065 PL 23071 PL 23095 PL 23110 PL 23066	PL 23043 PL 23047 PL 23105 PL 23107 PL 23110	PL 23110	PL 23110 × CML451 PL 23043 × CML451 PL 23043 × LM14 PL 23077 × CML451 PL 23047 × CML451	PL 23100 × LM14 PL 23090 × CML451 PL 23059 × LM14	-

× LM 14 were exhibited significant positive *sca* effects for grain yield (Table 4). Among these three hybrids, the hybrid PL 23100 × LM 14 (poor × poor) and also PL 23059 × LM 14 (poor × poor) registered desirable and significant *sca* effects for other yield contributing traits. Hence, these hybrids could be considered after confirming from heterotic studies for further testing in multi-location trails (Table 5).

Similar results on combining ability *i.e.,* significant positive *gca* and *sca* effects in desirable direction were obtained by Ahmad and Ansari (2017) and Sandesh *et al.* (2018), Rajesh *et al.* (2018), Sabitha *et al.* (2021) and Keerthana *et al.* (2023).

Among 60 hybrids, two crosses PL 23100 × LM 14 and PL 23059 × LM 14 were identified based on the *per se* performance and *sca* effects for grain yield. These crosses could be useful in development of high yielding hybrids in maize (Table 5).

Based on *per se* performance, the lines PL 23065 and PL 23095, PL 23066 and the crosses PL 23110 × CML 451 and PL 23043 × CML 451 exhibited higher grain yield coupled with earliness that indicates the usefulness of these crosses for earliness, so, they can be used in the development of the potential hybris with high yield and short duration that are useful in drought areas or low rainfall regions. Based on GCA effects, PL 23110 and PL 23105 were identified as the best parents for grain yield and most of its contributing characters. Hence, these parents could be utilized in the development of the high yielding and early maturing hybrids and also utilized in developing superior recombinants in further selection programmes for the improvement of yield parameters in maize. Based on SCA effects, two crosses PL 23100 × LM 14 and PL 23059 × LM 14 were identified based on the *per se* performance and *sca* effects for grain yield. These crosses could be useful in development of high yielding hybrids in maize. These hybrids need to be further evaluated across locations and over seasons to select best hybrids for commercial exploitation.

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APHIDOPHAGOUS COCCINELLID FAUNA ASSOCIATED WITH PULSES AND OILSEED CROP ECOSYSTEMS IN TAMIL NADU

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ABSTRACT

A field survey was conducted in Madurai and Virudhunagar districts of Tamil Nadu for the collection of aphidophagous coccinellids associated with pulses and oilseed crop ecosystems. A total of ten coccinellids were identified from both pulses and oilseed crop ecosystems. Out of which eight species *viz., Coccinella septempunctata* (Linnaeus), *Coccinella transversalis* (Fabricius), *Cheilomenes sexmaculata* (Fabricius), *Scymnus nubulis* (Mulsant), *Illeis cincta* (Fabricius), *Micraspis discolor* (Fabricius), *Anegleis cardoni* (Weise), *Harmonia octomaculata* (Fabricius) were identified from pulse crop ecosystems and ten species *viz., Coccinella septempunctata* (Linnaeus), *Coccinella transversalis* (Fabricius), *Cheilomenes sexmaculata* (Fabricius), *Scymnus nubulis* (Mulsant), *Illeis cincta* (Fabricius), *Micraspis discolor* (Fabricius), *Anegleis cardoni* (Weise), *Harmonia octomaculata* (Fabricius), *Brumoides suturalis* (Fabricius) and Paraexochomus nigripennis (Erichson) were identified from oilseed crop ecosystems. Out of this, Paraexochomus nigripennis was reported for the first time from Tamil Nadu.

KEYWORDS: Aphidophagous, coccinellids, pulses, oilseeds.

INTRODUCTION

Ladybird beetles (family Coccinellidae) belong to the superfamily Cucujoidea, suborder Polyphaga and order Coleoptera. The family Coccinellidae comprises of several subfamilies, *viz.,* Chilocorinae, Coccinellinae, Coccidulinae, Scymninae, Sticholotidinae, and Epilachninae. Of these, all except Epilachninae are predominantly predatory, while Epilachninae is phytophagous. Approximately 6,000 species of coccinellids are recorded worldwide (Vandenberg, 2000). Nearly 90 per cent of the species are insect predators, mainly targeting members of Sternorrhyncha. Tribes *viz.,* Scymnini, Hyperaspini, and Aspidimerini specialize in aphid predation. The subfamily Coccinellinae are largely aphidophagous, though some feed on coccids and each taxonomic group shows prey specificity. Studying the diversity of coccinellids in any crop ecosystem offers insights into sustainable insect pest management. The present study focused on documenting the aphidophagous coccinellid diversity in pulse and oilseed crop ecosystems of Tamil Nadu.

MATERIAL AND METHODS

The present investigation was undertaken during 2024–25 at the Department of Entomology, S.V. Agricultural College, Tirupati. Systematic surveys were conducted in Madurai and Virudhunagar districts of Tamil Nadu to collect coccinellid beetles from pulse and oilseed crops. Specimens were collected by using sweep net and hand picking methods. The collected beetles were euthanized using ethyl acetate and subsequently dried in a hot air oven at 45–50°C for 5–6 hours. Dried specimens were preserved in screw-capped glass vials with appropriate labels indicating crop and date of collection.

Coccinellid specimens were placed dorsally on a China clay block, and abdomens were separated under a binocular microscope. The abdomens were treated with freshly prepared 10 per cent KOH to digest soft tissues, either overnight at room temperature or heated at 50–60°C. Digestion time varied with specimen condition. Post-digestion, abdomens were washed in distilled water and softened tissues were removed using blunt needles. Cleared abdomens were mounted in glycerin for dissection. Male genitalia were dissected and examined under a Stereozoom binocular microscope for detailed observation. Morphological characterization was carried out following the terminology proposed by Sasaji (1971) and Poorani (2002).

RESULTS AND DISCUSSION

A total of 10 coccinellid species belonging to 9 genera under 3 tribes of family Coccinellidae were identified from the pulses and oilseeds crop ecosystems

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in Tamil Nadu. The coccinellid species *viz., Coccinella septempunctata* (Linnaeus), *Coccinella transversalis* (Fabricius), *Cheilomenes sexmaculata* (Fabricius), *Scymnus nubulis* (Mulsant), *Illeis cincta* (Fabricius), *Micraspis discolor* (Fabricius), *Anegleis cardoni* (Weise), *Harmonia octomaculata* (Fabricius) were identified from pulse crop ecosystems and the species *viz., Coccinella septempunctata* (Linnaeus), *Coccinella transversalis* (Fabricius), *Cheilomenes sexmaculata* (Fabricius), *Scymnus nubulis* (Mulsant), *Illeis cincta* (Fabricius), *Micraspis discolor* (Fabricius), *Anegleis cardoni* (Weise), *Harmonia octomaculata* (Fabricius), *Brumoides suturalis* (Fabricius) and *Paraexochomus nigripennis* (Erichson) were identified from oilseed crop ecosystems.

Key taxonomic and morphological features of the identified species are summarized below for confirmation.

The following two species are belongs to the **Subfamily: Chilocorinae; Tribe: Chilocorini**

***Paraexochonus nigripennis* (Erichson) (Plate 1: A, B)**

Body oval, dorsum moderately convex and glabrous. Head and pronotum yellowish; elytra black, shiny. Tegmen asymmetrical, parameres elongate and apically incurved. Aedeagus broad basally, tapering to a pointed apex. Sipho slender, slightly curved; spermatheca sclerotized, bulbous at base with coiled duct.

***Brumoides suturalis* (Fabricius) (Plate 2: A, B)**

Head, antennae, pronotum, and thorax reddish brown; eyes black. Elytra yellowish brown with two longitudinal black stripes. Legs brown; venter brown to dark brown. Ninth abdominal apophysis broad basally, bifid apically. Sipho curved, T-shaped basally, with broadened apex. Siphonal capsule elongate, quadrate, with slender inner process. Spermatheca robust, strongly curved, with a distinct W-shaped inner margin.

The following 7 species belongs to **Subfamily: Coccinellinae; Tribe: Coccinellini**

***Coccinella septempunctata* (Linnaeus) (Plate 3: A, B)**

Head black with brown eyes, yellow spots near eye margins; antennae dark brown. Pronotum black with yellow lateral spots; elytra with seven black spots. Legs black, simple; tarsi cryptotetramerous; claws paired. Sipho short with bilobed membranous apex; tegmen short with tapered median lobe. Spermatheca strongly hooked with distinct nodulus and ramus; infundibulum elongate.

***Coccinella transversalis* (Fabricius) (Plate 4: A, B)**

Body oval, glabrous, dorsum moderately convex. Head black with yellow spots; pronotum black with yellow-orange anterolateral areas. Elytra with variable black markings and black commissural line; venter and legs black. Tegmen asymmetrical; parameres elongate, apically incurved. Aedeagus broad at base, tapering; sipho slender, curved; spermatheca sclerotized with coiled duct.

***Harmonia octomaculata* (Fabricius) (Plate 5: A, B)**

Head orange to pale brown; eyes black; antennae and mouthparts reddish brown. Pronotum and elytra reddish brown with black posterior maculae; venter dark brown with whitish abdominal spots. Tegmen with short lateral lobes and shorter, distinct median lobe. Sipho basally curved, apically straight with spoon-shaped membranous apex; capsule processes hooked and broadened. Spermatheca broadly V-shaped with uniform width.

***Illeis cincta* (Fabricius) (Plate 6: A, B)**

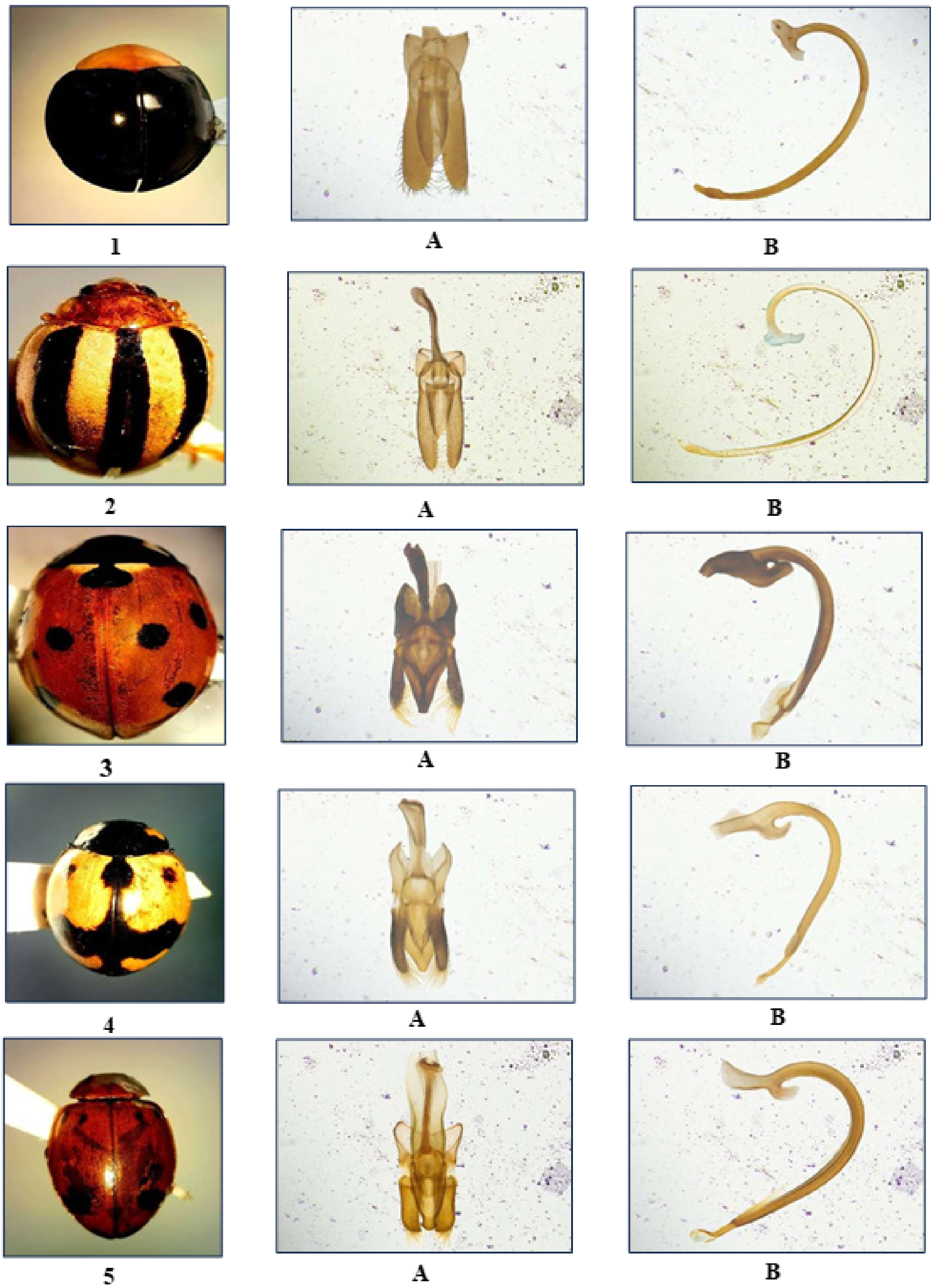
Head yellowish with black eyes; antennae and mouthparts yellowish to brown. Pronotum transparent yellow with black posterior spots; elytra pale yellow, shiny. Venter brown; legs yellowish to brown. Tegmen with elongate, densely setose lateral lobes; median lobe longer. Sipho C-shaped with spatulate apex; spermatheca long, strongly curved.

***Micraspis discolor* (Fabricius) (Plate 7: A, B)**

Head yellow; eyes black; mouthparts and antennae brown. Pronotum pale yellow with basal black markings; elytra orange with black commissural line. Female bright orange, male paler with half-moon black marking on pronotum. Tegmen with elongate setose lateral lobes; median lobe shorter, apically pointed. Sipho curved basally with hooked capsule processes; spermatheca C-shaped with Y-shaped infundibulum.

***Cheilomenes sexmaculata* (Fabricius) (Plate 8: A, B)**

Head pale yellow with possible black triangular mark on frons; eyes black; antennae and mouthparts brown. Pronotum yellow to orange with black markings; elytra with variable black zigzag patterns and a posterior spot. Sipho basally curved, thread-like apically; capsule



Plates: 1) *P. nigripennis* 2) *B. suturalis* 3) *B. septempunctata* 4) *C. transversalis* 5) *H. octomaculata*

A) Tegmen of male; B) Sipho of male

Plates: 6) *I. cincta* 7) *M. discolor* 8) *C. sexumaculata* 9) *A. cardoni* 10) *S. nubilus*
A) Tegmen of male B) Sipho of male

with rounded inner and pointed outer processes. Tegmen with broad median lobe; lateral lobes setose, equal in length. Spermatheca short, stout, kidney-shaped, joined to infundibulum by thread-like process.

***Anegleis cardoni* (Weise) (Plate 9: A, B)**

Head yellowish brown; eyes black; mouthparts dark brown. Pronotum orange-yellow with two discal spots and posterior black band; elytra orange-yellow with J-shaped stripes and piceous margins. Venter and legs brown. Sipho slightly curved, with bilobed membranous apex and curved inner process. Tegmen with long lateral lobes; median lobe flattened, broadened apically. Spermatheca finger-like, broad at base.

***Scymnus nubulis* (Mulsant) (Plate 10: A, B) Subfamily: Scyminae; Tribe: Scymini**

Body very small. Head and pronotum dark brown; pronotum with W-shaped posterior margin, punctate and pubescent; elytra dark brown with black commissural patch, densely pubescent. Venter dark brown; legs brown. Tegmen with short median lobe; lateral lobes elongate, sparsely setose. Sipho basally curved, thread-like apically; capsule with narrow inner and broad outer processes. Spermatheca curved, digitiform.

A comprehensive attempt to aphidophagous coccinellids associated with pulses and oilseed crop ecosystems in Tamil Nadu was not made so far.

Goswami *et al*. (2016) reported three species *viz., M. sexmaculatus* and *C.septempunctata* from pulse crop ecosystems in Sabour. Rani (2016) reported *viz., C. sexmaculata*, C. *transversalis*, H. *octomaculata*, *M. discolor, Scymnus coccivora*, and *B. suturalis* from pulse crop ecosystem in Guntur district of Andhra Pradesh and concluded that the above coccinellids play an important role in management of aphids, which also supports present research findings.

The results obtained are in compliance with the Vasista *et al.,* 2019 who reported 10 species of coccinellids from pulses and groundnut crop ecosystem in Andhra Pradesh. Sudharani *et al.* (2017) reported 6 species of Coccinellids *viz., C. sexmaculata, C. transversalis, H. octomaculata, B. suturalis, M. discolor* and *Scymnus* (Pullus) *coccivora* (Ayyar) from pulse crop ecosystems. Rekha *et al.* (2009) reported three species *viz., C. transversalis, M. sexmaculatus* , and *B. suturalis* from pulse crop ecosystems in Madurai district of Tamil Nadu. These findings are also is in accordance with the present findings.

A total of ten coccinellids belonging to 9 genera under the 3 tribes of family Coccinellidae were identified from the pulses and oilseed crop ecosystems which are found predacious on aphids in Tamil Nadu. Out of which eight species of Coccinellids *viz., C. septempunctata, C. transversalis, C. sexmaculata, S. nubulis, I. cincta, M. discolor, A. cardoni and H. octomaculata* were identified from pulse crop ecosystems. Ten species of Coccinellids *viz., C. septempunctata, C. transversalis, C. sexmaculata, S. nubulis, I. cincta, M. discolor, A. cardoni, H. octomaculata, B. suturalis* and *P. nigripennis* were identified from oilseed crop ecosystems. Among these *P. nigripennis* was reported for the first time from Tamil Nadu.

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A STUDY ON PROFILE OF FARMERS ON DRONE TECHNOLOGY APPLICATION IN AGRICULTURE OF RAYALASEEMA REGION OF ANDHRA PRADESH

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ABSTRACT

The present study was carried out to assess the profile of farmers utilizing drone technology application in Anantapuramu and Nandyal districts of Rayalaseema region of Andhra Pradesh over a randomly drawn sample of 120 respondents. The results revealed that majority of farmers were in the middle age (61.67%), completed high school (33.33%), had small farm size (33.33%), medium level of annual income (79.17%), social participation (55.83%), extension contact (53.33%), mass media exposure (70.00%), innovativeness (64.17%) and scientific orientation (67.50%).

KEYWORDS: Profile, drone technology application.

INTRODUCTION

Drones also known as Unmanned aerial vehicles (UAVs) have emerged as transformative tools in agriculture revolutionizing traditional farming practices by offering precision farming solutions. Drones have been considered to be part of the industry 4.0 ecosystem in India. According to industry estimates, currently over 3000 drones are being utilized in the Indian agriculture sector, which is expected to rise over 7000 by 2025. The Indian agricultural drone market is anticipated to achieve a value of US$ 14,237.6 million by 2033, with a market growth rate of 14.10 per cent CAGR during the forecasted period (Source: Fortune Business Insight, 2023) As agriculture faces challenges like climate change, labour shortage and increased food demand, there is need for incorporating novel technologies such as smart farming and precision agriculture. This study aims to investigate the profile of farmers in utilizing or adoption of drone technology application in agriculture.

MATERIAL AND METHODS

The present study was conducted by following exploratory research design. Two districts *viz.,* Anantapuramu and Nandyal districts of Rayalaseema region of Andhra Pradesh were selected based on the frequency and availability of drones. Two mandals were selected from each district thus making a total of four mandals *i.e.,* Bukkarayasamudram, Singanmala, Banaganapalli and Nandikotkur where significant number of sprayings had been carried out by farmers in these areas. From each of the selected mandals three villages were selected through simple random sampling procedure thus making a total of twelve villages from two districts. From the twelve villages selected, 10 drone users from each village were selected by simple random sampling procedure thus making a total of 120 drone users. After a thorough review of literature and consultations with experts a set of 9 variables were selected. The data was collected through a structured interview schedule and analyzed using mean and standard deviation for drawing meaningful interpretations.

RESULTS AND DISCUSSION

The respondents were distributed based on their selected profile characteristics and the results were presented in the Table.

Age

The data in Table shows that the majority (61.67%) of drone users were from the middle age group, followed by old age (37.50%) and only a small proportion (0.83%) from the young age group. This trend can be attributed to middle-aged farmers' greater experience, familiarity with technology and better access to resources, which help them make informed decisions about adopting drone technology. While some older farmers were open to new technologies, others faced challenges such as limited technological familiarity or resistance to change and some had already handed over their land to successors. The low percentage of young farmers may be due to their pursuit of diverse career opportunities

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outside agriculture. These findings align with those of Manjunath (2014).

Education

It could be inferred from Table that (33.33%) of drone users were educated up to high school, followed by illiterate (28.33%), middle school (19.17%), college level and above (10.83%), primary school (7.50%) and functionally literate (0.83%). The table indicates that most of the respondents had attained high school education, with fewer pursuing college education. This trend may be attributed to improved educational facilities, better transport and increased access to schools in villages, enabling more individuals to pursue higher levels of education. Those with higher education are generally better equipped to understand and adopt advanced technologies like drones, as their background aids in grasping drone operations and integrating them into farming. Similar findings were reported by Manjunath (2014).

Farm size

An outlook from the Table inferred that 33.33 per cent of the drone users had small farm size followed by marginal (20.00%), large (20.00%), semi medium (15.00%) and medium farm size (11.66%). This trend likely occurred because small farmers (2.5 to 5 acres) represented a middle ground where land size was sufficient to benefit from drone use, yet still manageable for individual investment, especially if supported by affordable services or government schemes. Both marginal farmers (up to 2.5 acres) and large farmers (above 10 acres) each made up 20.00 drone users of drone users, but their motivations differed. Similar findings were reported by Kamaraddi (2011) and Bharatkumar *et al.* (2024).

Annual income

It is evident from the Table that 79.17 per cent of the drone users had medium annual income followed by low (10.83%) and high (10.00%). The predominance of medium-income farmers suggests a relatively stable financial base among respondents, likely supported by diversified income sources such as crop cultivation, livestock and off-farm employment. This group typically has moderate landholdings, better access to agricultural inputs and active market participation, allowing them to meet household needs and invest modestly in their operations. Similar findings were reported by Gabriel (2014).

Social participation

An overview of Table indicated that 55.83 per cent of the drone users had medium level of social participation, followed by low (25.00%) and high (19.17%) levels of social participation. The table shows that social participation among drone users varies significantly, with over half falling into the medium category, indicating moderate involvement in community activities and benefiting from networking and information exchange. Less than one-third have low social participation, likely due to socio-economic constraints or limited interest in joining groups, with only a few involved in self-help groups or the gram panchayat. These results were in accordance with Puri *et al.* (2017) and Omega (2020).

Extension contact

It was clearly evident from Table that 53.33 per cent of the drone users had medium level of extension contact followed by high (24.17%) and low (22.50%) levels of extension contact. According to the data, most farmers (53.33%) reported a moderate level of contact with extension services, typically through occasional visits from extension officers and village agricultural assistants, as well as informal interactions with input dealers and peers. A smaller group (24.17%) had high extension contact, marked by active engagement, strong institutional connections and regular participation in activities at Krishi Vigyan Kendras. The results were in congruence with the findings of Thangaraja *et al.* (2008), Rakesh (2010) and Satish (2010).

Mass media exposure

It was clearly evident from Table that 70.00 per cent of the drone users had medium level of mass media exposure followed by low (18.33%) and high (11.67%) levels of mass media exposure. The study considered farmers' exposure to various mass media sources such as radio, newspapers, television, farm publications and the internet. The majority (70.00%) of farmers had a medium level of mass media exposure, largely due to widespread smartphone ownership and active use of platforms like YouTube for agricultural information. Some continued to use traditional media like radio. Farmers with high mass media exposure (11.67%) typically had better resources, higher education, larger landholdings and greater access

Table. Distribution of farmers according to their profile (n=120)

S. No.	Variables	Category	Frequency (f)	Percentage (%)	Mean	S.D.
1.	**Age**	Young (<35 years)	01	00.83		
		Middle (36-55) years	74	61.67	-	-
		Old (>56 years)	45	37.50		
		Total	**120**	**100.00**		
2.	**Education**	Illiterate	34	28.33		
		Functionally literate	01	0.83		
		Primary school	09	7.50		
		Middle school	23	19.18	-	-
		High school	40	33.33		
		College level and above	13	10.83		
		Total	**120**	**100.00**		
3.	**Farm size**	Marginal (Up to 2.5 acres)	24	20.00		
		Small (2.5 to 5 acres)	40	33.33		
		Semi medium (5 to 7.5 acres)	18	15.00	-	-
		Medium (7.5 to 10 acres)	14	11.67		
		Large (> 10 acres)	24	20.00		
		Total	**120**	**100.00**		
4.	**Annual income**	Low annual income	13	10.83		
		Medium annual income	95	79.17	**228375**	**180770.017**
		High annual income	12	10.00		
		Total	**120**	**100.00**		
5.	**Social participation**	Low social participation	30	25.00		
		Medium social participation	67	55.83	**2.03**	**1.85**
		High social participation	23	19.17		
		Total	**120**	**100.00**		
6.	**Extension contact**	Low extension contact	27	22.50		
		Medium extension contact	64	53.33	**10.51**	**1.47**
		High extension contact	29	24.17		
		Total	**120**	**100.00**		
7.	**Mass media exposure**	Low mass media exposure	22	18.33		
		Medium mass media exposure	84	70.00	**13.85**	**2.34**
		High mass media exposure	14	11.67		
		Total	**120**	**100.00**		
8.	**Innovativeness**	Low innovativeness	19	15.83		
		Medium innovativeness	77	64.17	**35.59**	**3.36**
		High innovativeness	24	20.00		
		Total	**120**	**100.00**		
9.	**Scientific orientation**	Low scientific orientation	11	9.17		
		Medium scientific orientation	81	67.50	**25.89**	**2.93**
		High scientific orientation	28	23.33		
		Total	**120**	**100.00**		

to digital platforms and extension services, enabling them to adopt modern practices more readily. Similar findings were reported by Kamaraddi (2011).

Innovativeness

An overview of Table indicated that 64.17 per cent of the drone users had medium level of innovativeness, followed by high (20.00%) and low (15.83%) levels of innovativeness respectively. The study found that most drone users demonstrated a medium level of innovativeness, indicating moderate openness to new technologies, willingness to take calculated risks and the ability to update their knowledge and skills. This was likely due to their exposure to information, moderate social participation, and ability to balance traditional and modern practices. A smaller group of highly innovative farmers were early adopters, eager to use drone technology to improve their farming, while those with low innovativeness were often limited by insufficient resources, lack of awareness or low risk tolerance, making them less likely to adopt new technologies. Some users remained resistant to change, preferring traditional methods over new innovations. This finding was in agreement with the findings of Manjunath (2014).

Scientific orientation

An overview of Table indicated that 67.50 per cent of the drone users had medium level of scientific orientation, followed by high (23.33%) and low (9.17%) levels of scientific orientation respectively. Table shows that over half of the drone users had a medium level of scientific orientation, likely due to their educational background. This moderate scientific mindset, supported by exposure to innovations through Krishi Vigyan Kendras (KVKs), private agencies and peer networks, helped farmers adopt drone technology and improve productivity. Similar findings were reported by Puri *et al.* (2017) and Akhila (2023

The results revealed that the majority of the variables belonged to the middle to high-level category, indicating a moderate level of exposure to various factors that could influence adoption, utilization and also further promotion. Specifically, the study showed that most farmers were middle-aged, had attained a moderate level of education and possessed small to medium-sized farms. Moreover, the farmers exhibited medium levels of annual income, social participation, extension contact, mass media exposure, innovativeness and scientific orientation. These findings suggested that the farmers in the study area had a considerable potential for adopting drone technology application but required further training and support to enhance their skills and knowledge. To facilitate effective adoption the government support is crucial including subsidies for drone technology acquisition, practical demonstrations, hands-on training offer realistic and context-specific guidance on integrating drone technology application into existing agricultural practices and implement promotional initiatives to raise awareness about the benefits and potential of drone technology in agriculture.

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CORRELATION ANALYSIS AMONG YIELD AND ITS COMPONENT TRAITS IN F_2 POPULATION OF GROUNDNUT (*Arachis hypogaea* L.) DERIVED FROM TCGS 1694 × ICGV 201179

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ABSTRACT

Groundnut (*Arachis hypogaea* L.) is a vital oilseed crop cultivated extensively for its economic and nutritional value. Enhancing pod yield remains a key objective in groundnut breeding programs. In the present study, F_2 population derived from the cross TCGS 1694 × ICGV 201179 was evaluated at the Regional Agricultural Research Station (RARS), Acharya N.G. Ranga Agricultural University (ANGRAU), Tirupati, Andhra Pradesh, during the *kharif* 2024. The analysis revealed that pod yield per plant exhibited a highly significant positive correlation with seed yield per plant, followed by number of pods per plant, number of seeds per plant, hundred pod weight, hundred seed weight, and shelling out-turn percentage. These findings suggest that these traits are closely associated with pod yield and can be effectively utilized as indirect selection indices in the advancement of high-yielding groundnut genotypes.

KEYWORDS: Groundnut, correlation, yield and yield-attributing traits.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is the major oilseed crop of India. It belongs to subfamily Papilionaceae of family Leguminosae and is highly self-pollinated due to cleistogamous flowers. It is an important cash crop for the farmers of the arid and semi-arid tropics, where most of the peanut cultivation is concentrated (Janila *et al.,* 2016). Groundnut is a significant source of oil (45 to 50%), carbohydrates (20%), fibre, magnesium, zinc, folacin, potassium, calcium, phosphorus, iron, vitamins and three forms of fat-soluble tocopherols (α, γ and δ) hence, it is called "poor man's almond" and play a key role in combating malnutrition (Mukri *et al.,* 2014).

In India Groundnut is grown in an area of 5.396 M ha with a production of 11.31 Mt and productivity of 2,097 kg ha^{-1} and in Andhra Pradesh, it is grown in an area of 0.346 Mha and producing 0.360 Mt and the productivity on average is 1041 kg ha^{-1} (INDIASTAT, 2024-2025). Obtaining high yielding groundnut varieties is of prime importance to ensure food security needs.

Yield is a complex trait governed by many component characters with considerable degree of association in both positive and negative directions. Determining the relationship between yield and its constituent traits is extremely valuable since it serves as the foundation for selection. correlation is the biometrical technique that can be used to assess how strongly the character pairs are associated and to identify potential selection criteria for a breeding program. The present investigation was carried out to assess the nature and magnitude associations between pod yield and its component characters in F_2 generation of groundnut.

MATERIAL AND METHODS

The experimental material comprised 244 F_2 plants derived from the cross TCGS 1694 × ICGV 201179, developed and provided by Groundnut Breeding Department, Regional Agricultural Research Station (RARS), ANGRAU, Tirupati. The field experiment was conducted at the Dryland Farm of RARS, ANGRAU, Tirupati, Andhra Pradesh, during the *kharif* 2024 and the F_2 material was sown on 1st August 2024. The parental lines, TCGS 1694 and ICGV 201179, were sown on either side of the F_2 population.

The F_2 population was sown in rows of 4 meters in length, with a spacing of 30 cm between rows and 10 cm between plants within the row. Standard agronomic practices were followed throughout the crop growth period to ensure optimal plant development.

Phenotypic observations were recorded on all 244 individual F_2 plants for the following traits: number of pods per plant, number of seeds per plant, shelling out-turn (%), hundred pod weight (g), hundred seed weight (g), seed yield per plant (g) and pod yield per plant (g). Correlation analysis among these traits was

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Table. 1 Pearson correlation coefficients among yield and yield-attributing traits in the F_2 population of the cross TCGS 1694 × ICGV 201179

	NPP	NSP	SOT	HPW	HSW	SYP	PYP
NPP	1.000	0.929**	0.011	0.119	0.0390	0.867**	0.940**
NSP		1.000	0.215**	0.251**	-0.014	0.923**	0.931**
SOT			1.000	0.392**	0.392**	0.374**	0.131*
HPW				1.000	0.657**	0.442**	0.392**
HSW					1.000	0.297**	0.225**
SYP						1.000	0.954**
PYP							1.000

*= Significance at 5% level; **= Significance at 1% level

NPP: Number of pods plant^{-1}, **NSP:** Number of seeds plant^{-1}, **SOT:** Shelling out-turn (%), **HPW:** Hundred pod weight (g), **HSW:** Hundred seed weight (g), **SYP:** Seed yield plant^{-1} (g), **PYP:** Pod yield plant^{-1} (g).

performed using OPSTAT statistical software to identify relationships contributing to yield improvement.

RESULTS AND DISCUSSION

Correlation coefficients among yield and yield-related traits in the F_2 population of the cross TCGS 1694 × ICGV 201179 were computed and presented in Table 1. The analysis revealed that pod yield per plant exhibited a highly significant and strong positive correlation with several key traits, including seed yield per plant (r = 0.954**), number of pods per plant (r = 0.940**), number of seeds per plant (r = 0.931**), hundred pod weight (r = 0.392**), hundred seed weight (r = 0.225**), and shelling out-turn (r = 0.131*). These associations suggest that these traits are directly and mutually associated with pod yield, making them important selection criteria for enhancing productivity in groundnut. Similar findings were reported by Prabhu *et al.* (2015), Devi *et al.* (2018), Wadikar et al. (2018), Kumar *et al.* (2019), Khan *et al.* (2022), Yadav *et al.* (2023), and Vaghasiya *et al.* (2025). The positive correlation of pod yield with hundred pod weight aligns with results from Adlak (2019) and Vargheese *et al.* (2024), while its association with shelling out-turn is consistent with Saritha *et al.* (2018).

The number of pods per plant showed a strong positive and highly significant correlation with number of seeds per plant (r = 0.929**) and seed yield per plant (r = 0.867**), reinforcing their collective importance in yield improvement. These results corroborate previous findings by Anitha *et al.* (2014), Jain *et al.* (2016), Reddy *et al.* (2017), Hampannavar *et al.* (2018), Wadikar *et al.* (2018), Khan *et al.* (2022), Gali *et al.* (2023), Yadav *et al.* (2023), and Vaghasiya *et al.* (2025). However, number of pods per plant showed a non-significant and weak positive association with hundred pod weight (r = 0.119), hundred seed weight (r = 0.039), and shelling out-turn (r = 0.011). Similar trends were reported by Sravanthi *et al.* (2024) and Vaghasiya *et al.* (2025).

The number of seeds per plant showed a highly significant positive correlation with seed yield per plant (r = 0.923**), hundred seed weight (r = 0.251**), and shelling out-turn (r = 0.215**), whereas a non-significant negative correlation was observed with hundred pod weight (r = -0.014).

The seed yield per plant had a strong positive and highly significant association with hundred seed weight (r = 0.442**), shelling out-turn (r = 0.375**), and hundred pod weight (r = 0.297**). These findings are supported by Prabhu *et al.* (2015), Reddy *et al.* (2017), Khan *et al.* (2022), and Vaghasiya *et al.* (2025) for hundred seed weight; by Anitha *et al.* (2014), Jain *et al.* (2016), Hampannavar *et al.* (2018), Khan *et al.* (2022), and Yadav *et al.* (2023) for shelling out-turn; and by Kumari and Sasidharan (2020) for hundred seed weight.

Shelling out-turn exhibited a moderate but highly significant positive correlation with hundred pod weight (r = 0.392**) and hundred seed weight (r = 0.391**). These results are consistent with Suvarna (2020), Prabhu *et al.* (2015), Kannappan *et al.* (2022), and Kumar (2023).

Lastly, a highly significant positive association was observed between hundred pod weight and hundred seed weight (r = 0.657**), which is in agreement with findings of Anitha *et al.* (2014), Prabhu *et al.* (2015), Kumar *et al.* (2019), Kannappan *et al.* (2022), Kumar (2023), and Sravanthi *et al.* (2024).

These interrelationships highlight the importance of pod and seed traits in yield improvement and provide a robust basis for the selection of promising segregants in early generations.

The present investigation on the F_2 population derived from the cross TCGS 1694 × ICGV 201179 revealed significant genetic variability and strong positive correlations among key yield and yield-attributing traits. Pod yield per plant showed highly significant and positive associations with seed yield per plant, number of pods per plant, number of seeds per plant, hundred pod weight, hundred seed weight, and shelling out-turn, indicating their direct contribution to yield improvement. These traits can thus serve as effective selection indices in early-generation breeding for enhancing productivity in groundnut. The identified relationships provide valuable insights for groundnut breeders to formulate effective selection strategies and accelerate the development of high-yielding genotypes through phenotypic selection.

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COMPARATIVE ANALYSIS OF PEST PATTERN IN RICE AMONG VARIOUS DISTRICTS OF ANDHRA PRADESH

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ABSTRACT

Rice (*Oryza sativa, f*: Gramineae) is an important food crop among the cereals that is majorly affected by insect pests. More than 70 insect species are associated with the rice crop at one stage or the other, and 20 are pests of major economic significance. Among the sucking pests, Yellow Stem Borer (YSB) and Rice Leaf Folder (RLF) cause a severe threat to rice production. There is a need to understand the similarity of pest patterns among various locations in Andhra Pradesh before fixing the type of forewarning advisory, either at the district level or location-specific. In this context, Primary data on major insect catches in rice were collected from solar light traps installed at Farmer's open Rice fields under the Sree PVF Project running from S.V. Agricultural College, ANGRAU, Tirupati in Eight districts of Andhra Pradesh during and *Kharif* seasons. The pest patterns were compared using Pettit's test and Buishand Range test for two major pests of Rice in eight districts *viz.,* Nandyala, SPS Nellore, Anantapur, Annamayya, Chittoor, YSR Kadapa, Krishna and East Godavari. The study concludes that effective management of pest patterns is crucial for sustainable rice production and explores essential information for location-specific pest management strategies.

KEYWORDS: Solar light traps, insect catches in rice, pest pattern and non-parametric approach.

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important cereal crop and symbol of both cultural identity and global unity. The year 2004 was declared the International Year of Rice because rice is the staple food for more than half of the world's population. A sustainable increase in rice production will reduce hunger and poverty and contribute to environmental conservation and a better life for present and future generations for whom Rice is Life. Of the more than 70 species recorded as pests of rice, about 20 have major significance. However, in commercial production, rice productivity and quality are adversely affected by many biotic stresses, particularly insect pests. Insect pests damage the rice crop at different stages of its growth. Yield losses in global rice output due to pests (diseases, animal pests, and weeds), range from up to 20 per cent to at least 30 per cent of the attainable yield (Savary, *et al.,* 2000). Out of these, oAnly a few are potential threats. Yellow Stem Borer (YSB), Brown Plant Hopper (BPH), Rice Leaf Folder (RLF), Gall Midge (GM), *etc.,* cause damage to rice fields. This study is taken up to compare the major pest patterns in rice among several districts of Andhra Pradesh to know the need for location-specific advisory for effective pest management.

Study area

Solar light traps were installed at Nandyala, SPS Nellore, Anantapur, Annamayya, Chittoor, YSR Kadapa, Krishna and East Godavari districts of Andhra Pradesh under an externally funded project sponsored by Sree Padmavathi Venkateswara Foundation, Vijayawada which is being run from S.V. Agricultural College, ANGRAU, Tirupati. Insect count data on major pests in rice *viz..,* Yellow Stemborer (YSB) and Rice Leaf Folder (RLF) on a daily basis for *Rabi* and *Kharif* seasons for the year 2022-23 was collected from farmers' rice fields.

MATERIAL AND METHODS

Descriptive statistics

Descriptive or summary statistics play a vital role in data analysis and it is used to summarize, describe and present data in a meaningful and interpretable manner.

Pettit's test

This statistical test is a non-parametric rank test, widely used for evaluating the presence of abrupt changes in the time series of the climatic data, given by Pettit (1979). This test application can be found in Buragohain, *et al.,* 2023 and Dubey, *et al.,* 2023. This test can identify the significant change in the mean of a time series when

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the exact time of the shift is not known. In this test, the ranks r_1, r_2, r_3, … rn, of the series Y_1, Y_2, Y_3, … Yn, is used for the calculation of the statistics (Zarenistanak *et al.* 2014):

$$X_k = 2\sum ri - k(n+1) \quad k = 1 \ldots \ldots \ldots n \text{ ---------------- (1)}$$

$$X_E = \max |X_k| \text{ for } 1 \leq k \leq n \text{ ---------------- (2)}$$

Kumar, T *et.al.,* 2022 utilised this test for Trend Analysis of Groundwater Level, Rainfall and Area under Groundwater Irrigation in Ropar district of Punjab

Buishand range test

Buishand (1982) developed this statistical test. The application of this test can be found in Polisetty, *et al.,* 2023, Yildirim, G and Rahman, A 2022. Rabab, *et.al.,* 2024 utilised both Pettit's test and Buishand test for rainfall trend detection. In this test the adjusted partial sum, which is the cumulative deviation from the mean for kth observation of series x_1, x_2, x_3, …, xn with a mean $(\overline{x})$ can be calculated as,

$$S_0^* = 0 \text{ and } S_k^* = \sum_{i=1}^{k}(\mathrm{Yi} - \mathrm{Y}) \quad k = 1,2, \ldots \ldots, n \text{ ---- (3)}$$

The statistical significance test of the realized shift is tested with the "rescaled adjusted range (R)", the difference between the maximum and minimum of S_K^* values scaled by sample standard deviation:

$$R = \frac{(\max S_k^* - \min S_K^*)}{S} \text{ ------------------ (4)}$$

Both Pettit's and Buishand's range test can be observed in Oganja, Y.H, *et.al.,* 2024 and Mohammadi, H, *et.al.,* 2024.

RESULTS AND DISCUSSION

Descriptive statistics

Tables 1 and 2 present the mean, standard deviation and coefficient of variance (CV%) computed for the insect pest counts of Yellow Stem Borer and Rice Leaf Folder in six districts during *Kharif* and in eight districts during *Rabi*, in Andhra Pradesh. During *Kharif,* the CV% ranged between 39.65 per cent to 168.9 per cent for YSB and for RLF was between 48.9 per cent to 243.5 per cent indicating high level inconsistency. Whereas during *Rabi*, the CV% of YSB ranged between 35.5 per cent to 793.7 per cent, and RLF ranged between 40.72 per cent to 204.3 per cent indicating that the data under consideration is highly heterogeneous among various districts.

Pettit's test for yellow stem borer and rice leaf folder during *rabi* and *kharif*

Pettitt's test is a non-parametric statistical test used to detect a single change point or shift in a time series. This test can be observed in Hurtado, *et.al.,* 2020 and Laasya, *et.al.,* 2024. The test statistic (U*) measures the magnitude of the change detected in the time series based on the ranks of observations before and after the potential change points. A significant p-value indicates the presence of a change point or shift at time (K) in the time series data.

From Table-3, it is noticed that, during *Kharif* season, there was no change in the pattern of the Yellow Stem Borer and Rice Leaf Folder among all districts.

From Table-4, it is noticed that, during *Rabi* season, there was a change in the pattern of Yellow Stem Borer in Krishna district as the p-value is <0.05 concluded that a change point exists in the time series and for the remaining districts there is no change point as they are non-significant and there was no change point or pattern of Rice Leaf Folder in all districts.

Buishand's range test for yellow stem borer and rice leaf folder during *rabi* and *kharif* seasons

The Buishand's Range test is used to identify a single change point suddenly rather than gradual trends where the shift is at mean level. The test statistics (R) measures the range of cumulative deviations from the mean. An application of this test can be observed in Gaddikeri, V., *et.al.,* 2024.

The Buishand's Range test results during *Kharif* are presented in Table-5. From the results, Yellow Stem Borer (YSB) showed the change point at time K for the districts Nandyala, SPS Nellore, Anantapur, Annamayya, Chittoor and YSR Kadapa are at 44, 35, 10, 33, 33 and 87 respectively. As the p-values of Annamayya and Chittoor districts are <0.05 indicating significant change points exist in the time series whereas for the remaining districts there is no change point. For Rice Leaf Folder (RLF), the change point at time K for the districts Nandyala, SPS Nellore, Anantapur, Annamayya, Chittoor and YSR Kadapa are at 58, 43, 47, 19, 38 and 55 respectively. As the p-value for all the districts is >0.05 indicates no change point as it is non-significant.

Table 1. Descriptive statistics of yellow stem borer (YSB) and rice leaf folder (RLF) incidence during *kharif* season

District	Yellow stem borer in kharif			Rice leaf folder (RLF) in kharif		
	Mean	SD	CV%	Mean	SD	CV%
Nandyala	8	4.75	168.9	14	5.67	243.5
SPS Nellore	1	0.89	104.1	1	1.01	107.2
Anantapur	21	8.13	39.65	5	3.5	75.19
Annamayya	2	1.30	62.8	3	1.58	56.4
Chittoor	1	0.81	168.8	1	0.70	140.3
YSR Kadapa	1	0.95	95.5	4	1.65	48.9

Table 2. Descriptive statistics of yellow stem borer (YSB) and rice leaf folder (RLF) during *rabi* season

District	Yellow stem borer in rabi			Rice leaf folder in rabi		
	Mean	SD	CV%	Mean	SD	CV%
Nandyala	7	4.71	69.44	14	5.80	40.72
SPS Nellore	1	0.69	140.96	1	0.62	142.68
Anantapur	2	1.14	62.35	2	1.05	77.72
Annamayya	3	0.86	35.50	3	1.23	58.40
Chittoor	1	0.62	220.50	3	1.92	73.10
YSR Kadapa	1	0.75	300.80	1	1.38	204.30
Krishna	1	0.12	793.70	1	0.94	131.20
East Godavari	2	1.51	131.20	2	1.40	120.90

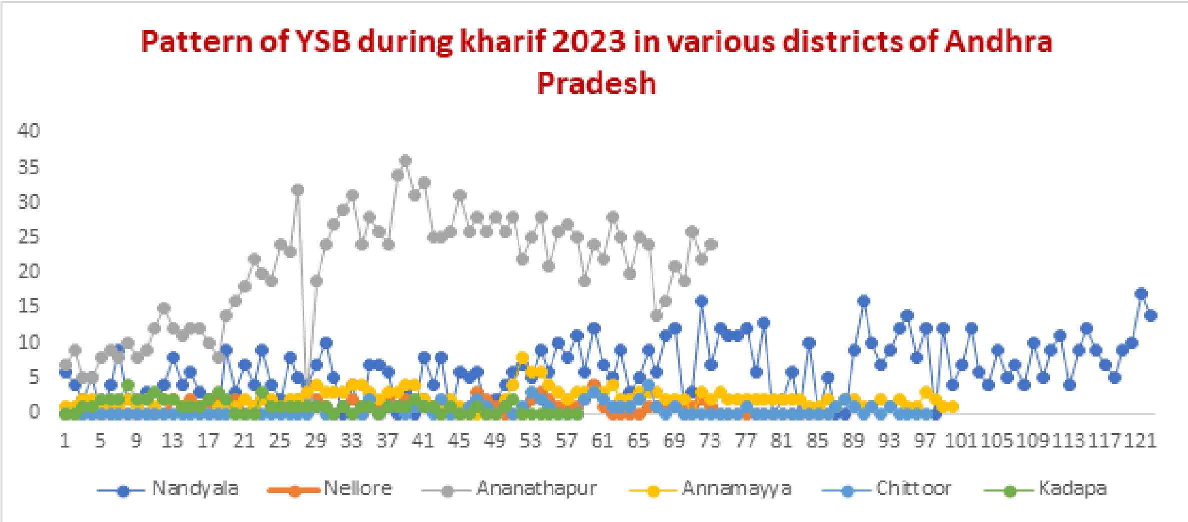

Fig.1. Pattern of yellow stem borer during *kharif* 2023 in various district of Andhra Pradesh

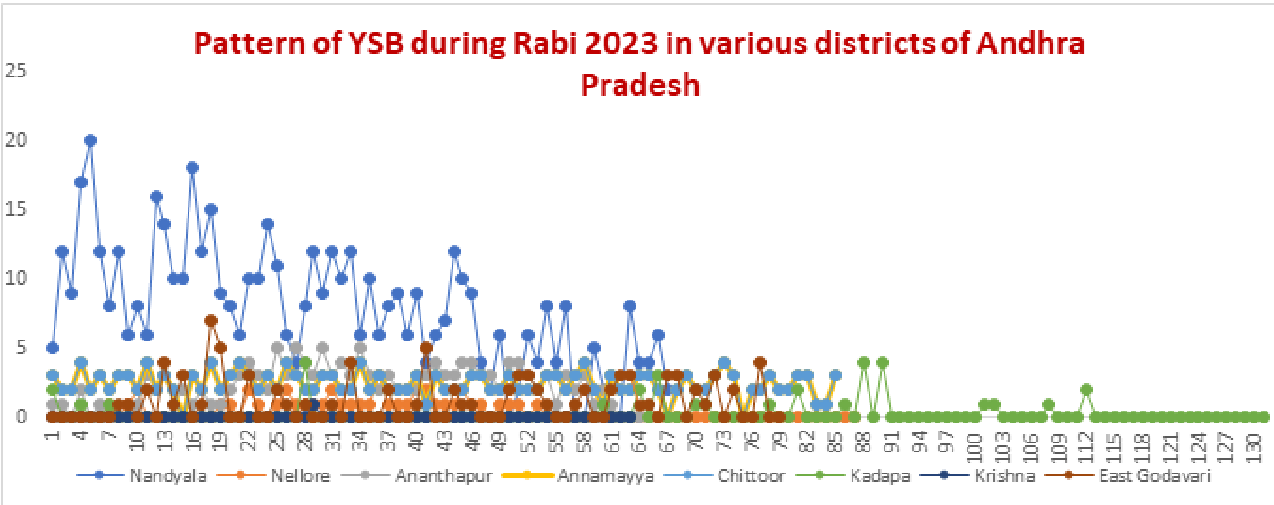

Fig.2. Pattern of yellow stem borer during *rabi* 2023 in various district of Andhra Pradesh

The Buishand's Range test results during *Rabi* are presented in Table -6. From the results, Yellow Stem Borer (YSB) showed the change point at time K for the districts Nandyala, SPS Nellore, Anantapur, Annamayya, Chittoor, YSR Kadapa, Krishna and East Godavari at 39,47,30,27,59,60,32 and 7 respectively. There was a change in the pattern of Yellow Stem Borer in the Anantapur district as the p-value is <0.05 concluded that a change point exists in the time series and for the remaining districts there is no change point as they are non-significant. For Rice Leaf Folder (RLF), the change point at time K for the districts Nandyala, SPS Nellore, Anantapur, Annamayya, Chittoor, YSR Kadapa, Krishna and East Godavari are at 33, 57, 24, 38, 19, 84, 30 and 10 respectively and there was a change in the pattern of Rice Leaf Folder in the Nandyala district as the p-value is <0.05 and for the remaining districts there is no significant change point as they are non-significant.

Descriptive statistics revealed the heterogeneity in the insect pest count data and coefficient of variation (CV%) indicating significant variability in pest incidence in all districts during two seasons. Pettit's test identified a significant change or peak in the pattern of YSB in Krishna district during the *Rabi* season, whereas no significant changes or peaks were found in other districts for YSB. No significant peaks were found among all

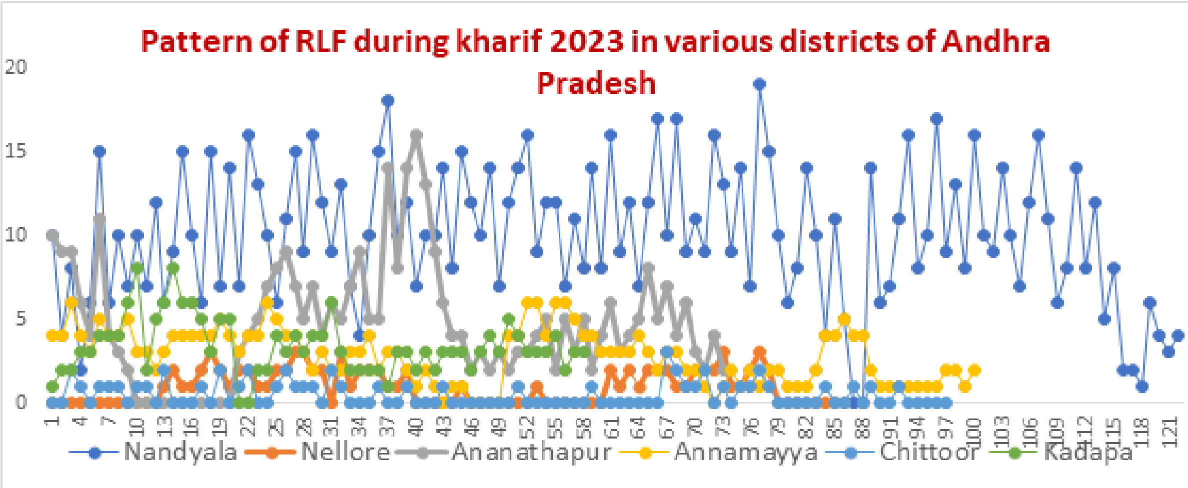

Fig.3. Pattern of rice leaf folder during *kharif* 2023 in various district of Andhra Pradesh

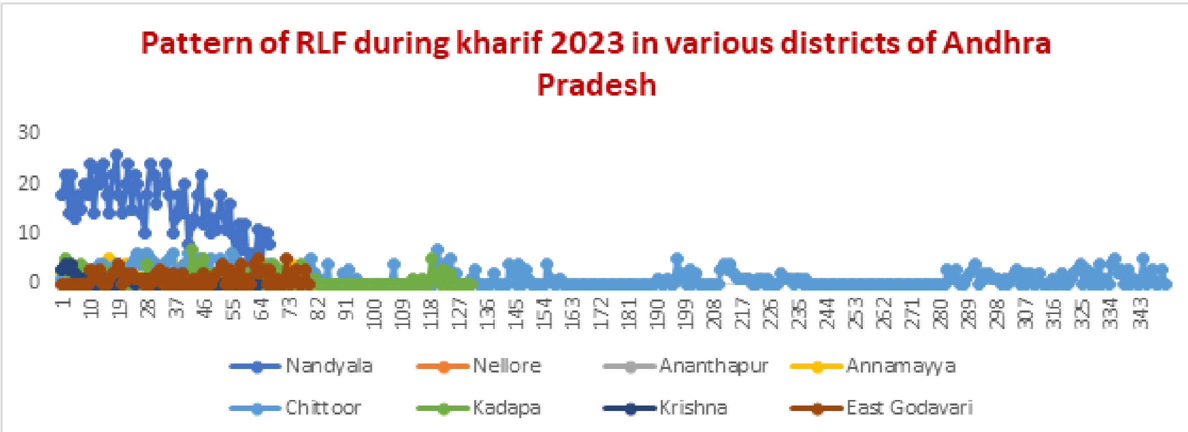

Fig.4. Pattern of rice leaf folder during *rabi* 2023 in various district of Andhra Pradesh

Table 3. Pettit's test for yellow stem borer and rice leaf folder during *kharif* season

District	Yellow stem borer			Rice leaf folder		
	U*	p-value	Changepoint	U*	p-value	Changepoint
Nandyala	363	1.00	111	819	0.22	57
Nellore	399	0.45	47	238	1.00	6
Anantapur	352	0.30	31	282	0.59	37
Annamayya	522	0.39	68	378	0.85	68
Chittoor	432	0.59	77	260	1.00	14
Kadapa	270	1.00	56	466	0.73	60

Table 4. Pettit's test for yellow stem borer and rice leaf folder during *rabi* season

District	Yellow stem borer			Rice leaf folder		
	U*	p-value	Changepoint	U*	p-value	Changepoint
Nandyala	240	0.64	39	372	0.13	27
Nellore	288	0.94	50	310	0.84	57
Anantapur	248	0.53	56	324	0.20	24
Annamayya	224	1.00	27	418	0.37	38
Chittoor	395	0.28	59	233	1.00	67
Kadapa	666	0.61	60	584	0.81	84
Krishna	394	**0.05**	35	248	0.46	30
East Godavari	350	0.94	7	354	0.44	24

districts in the patterns of RLF during the crop period in the *Rabi* season. Further, Buishand's Range test detected a significant change point for YSB in Ananthapur district during *Rabi* and for RLF, significant change points were observed in Annamayya and Chittoor districts during *Kharif.* Hence, the findings suggest that pest patterns vary across districts and seasons, which is essential information for location-specific pest management strategies.

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Research Note

Andhra Pradesh J Agril. Sci : 12(1): 65-69, 2026

YIELD AND ECONOMICS OF GREENGRAM VARIETIES UNDER VARIED SOWING WINDOWS DURING *RABI* SEASON

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ABSTRACT

A field experiment was conducted during late *rabi,* 2024-25 at dryland farm of S.V. Agricultural College, Tirupati to study the effect of sowing window and varieties on yield and economics of *rabi* greengram. The treatments comprised of three sowing windows *viz.,* II Fortnight of December (S_1), I Fortnight of January (S_2) and II Fortnight of January (S_3) allotted to main plots and four varieties *viz.,* LGG 607 (V_1), LGG 630 (V_2), LGG 574 (V_3) and IPM-2-14 (V_4) allotted to sub plots and replicated thrice. Hence, from the present study, it can be concluded that higher productivity and profitability of greengram can be realized from LGG 630 variety of greengram sown during II Fortnight of December (S_1) indicating its suitability for late sowing during *rabi* season on sandy loam soils of Southern Agro-Climatic Zone of Andhra Pradesh.

KEYWORDS: Greengram, late *rabi*, productivity, sowing window, varieties.

INTRODUCTION

Pulses are the edible seeds of leguminous plants that are harvested solely for their dry grain. They are not only affordable and versatile but also environmentally friendly, helping to improve soil health through nitrogen fixation. Pulses are primarily grown for their dry edible seeds, contributing significantly to food security, soil fertility and sustainable agriculture. Their cultivation is highly influenced by agro-climatic conditions, making the sowing window the optimal period for planting, a critical factor in achieving good yields and quality produce. Each pulse crop has a specific sowing time depending on the region, climate and variety.

There is also considerable diversity in varieties of pulses, developed through breeding programmes to enhance traits such as drought tolerance, disease resistance and early maturity. Selecting the right variety adapted to the local conditions and sowing window are key for maximizing the productivity. This paper explores the sowing window and varieties of greengram, highlighting their adaptability to Southern Agro-Climatic Zone of Andhra Pradesh and the role of varietal improvement in enhancing productivity of greengram.

MATERIAL AND METHODS

The field experiment was conducted during late *rabi*, 2024-25 at dryland farm of S.V. Agricultural College, Tirupati. The experimental soil was sandy loam in texture, neutral in reaction (pH 6.7), low in organic carbon (0.4 per cent) and available nitrogen (230 kg ha^{-1}), medium in available phosphorus (25 kg ha^{-1}) and available potassium (250 kg ha^{-1}). The experiment was laid out in a split-plot design with three main plots and four sub plots and replicated thrice.

The treatments comprised of three sowing windows *viz.,* II Fortnight of December (S_1), I Fortnight of January (S_2) and II Fortnight of January (S_3) assigned to main plots and four varieties *viz.,* LGG 607 (V_1), LGG 630 (V_2), LGG 574 (V_3) and IPM-2-14 (V_4) allotted to sub plots. The crop was supplied with recommended fertilizer dose of 20 kg N and 40 kg P_2O_5 through urea and single super phosphate, respectively to all the plots as basal *i.e.,* at the time of sowing.

2.1 Statistical analysis

The data was recorded on yield attributes and yield of greengram at harvest were statistically analysed following the analysis of variance procedure suggested by Panse and Sukhatme (1985). Statistical significance was tested by 'F' value at 5 per cent level of probability and wherever the 'F' value was found significant, critical difference (CD) was worked out at 5 per cent level of probability and the values were furnished. The treatment differences which were non-significant were denoted by "NS".

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Table 1. Seed and haulm yield (kg ha^{-1}) of greengram as influenced by sowing window and varieties

Treatments		Seed yield	Haulm yield
Main plots: Sowing window (3)			
S_1 : II Fortnight of December		874	2083
S_2 : I Fortnight of January		641	1517
S_3 : II Fortnight of January		454	1163
	SEm±	21.9	57.1
	CD (P=0.05)	86	230
Sub plots: Varieties (4)			
V_1 : LGG 607		720	1624
V_2 : LGG 630		819	1887
V_3 : LGG 574		475	1357
V_4 : IPM-2-14		610	1463
	SEm±	30.0	66.5
	CD (P=0.05)	89	199
Sowing window (S) × Varieties (V)			
S at V			
	SEm±	51.97	114.1
	CD (P=0.05)	NS	NS
V at S			
	SEm±	50.03	114.9
	CD (P=0.05)	NS	NS

Table 2. Economics (₹ ha^{-1}) of greengram as influenced by sowing window and varieties

Treatments	Gross returns	Net returns	Benefit-cost ratio
Main plots: Sowing window (3)			
S_1 : II Fortnight of December	82920	55220	2.9
S_2 : I Fortnight of January	48308	20608	1.7
S_3 : II Fortnight of January	35158	7458.0	1.3
SEm±	1403.0	1403.0	0.05
CD (P=0.05)	5509	5509	0.2
Sub plots: Varieties (4)			
V_1 : LGG 607	58796	31096	2.1
V_2 : LGG 630	66985	39285	2.4
V_3 : LGG 574	44250	16550	1.5
V_4 : IPM-2-14	51818	24110.0	1.8
SEm±	2000.4	2000.4	0.07
CD (P=0.05)	5943	5943	0.2
Sowing window (S) X Varieties (V)			
S at V			
SEm±	3464.8	3464.8	0.13
CD (P=0.05)	NS	NS	NS
V at S			
SEm±	3312.4	3312.4	0.12
CD (P=0.05)	NS	NS	NS

RESULTS AND DISCUSSION

Seed yield and haulm yield were significantly influenced by sowing window and varieties, while the interaction effect of sowing window and varieties was found to be non-significant.

Among the varied sowing windows, greengram sown during II Fortnight of December (S_1) recorded significantly higher seed and haulm yield over other sowing windows. The next best sowing window was with the crop sown during I Fortnight of January (S_2) and II Fortnight of January (S_3) in the order of descent with significant disparity between them. However, the latter sowing window recorded significantly lower seed and haulm yield (Table1).

Early sowing of greengram *i.e.,* II Fortnight of December (S_1) resulted in significantly higher seed and haulm yield. This increase in yield can be attributed to favourable environmental conditions during the vegetative and reproductive stages, lower pest and disease incidence and clear weather at maturity. These factors collectively minimized flower and pod drop, thereby contributing positively to the overall yield of the early-sown crop. These results were in conformity with the findings of Dhaka *et al*. (2018) and Bankar *et al.* (2020).

Pertaining to varieties, significantly higher seed and haulm yield of greengram was recorded with LGG 630 (V_2) which was significantly superior over LGG 607 (V_1) and IPM-2-14 (V_4). In contrast, significantly lower seed and haulm yield was obtained with LGG 574 (V_3). The yield-attributing characters of variety LGG 630 such as higher number of pods branch^{-1}, more number of seeds pod^{-1}, longer pods and greater pod weight have positively correlated with higher yield of greengram. Increase in seed yield during early sown crop might be due to the combination of genetic traits, disease resistance, agronomic advantages and better photosynthetic efficiency. Similar results were reported by Singh *et al*. (2011) and Niveditha *et al.* (2022).

The higher gross returns, net returns and benefit-cost ratio of greengram were obtained with the crop sown during II Fortnight of December (S_1), which was followed by the crop sown during I Fortnight of January (S_2) and II Fortnight of January (S_3), with significant disparity between them and the latter variety registered lower values of above parameters. Highest economic returns with early sown crop might be because of higher seed and haulm yield. These results were in line with the findings of Nagamani *et al.* (2020) and Ali *et al.* (2021).

With regard to varieties, LGG 630 (V_2) recorded significantly higher gross returns, net returns and benefit-cost ratio. Lower values of the above parameters were realized with LGG 574 (V_3). Higher gross returns with LGG 630 (V_2) variety of greengram might be because of higher yield attributing characters of that particular variety. Similar results were reported from the findings of Samant (2014) and Marthe *et al*. (2024).

Hence, it can be concluded that higher productivity and profitability of greengram can be realized from LGG 630 variety of greengram sown during II Fortnight of December (S_1) indicating its suitability for late sowing during *rabi* season on sandy loam soils of Southern Agro-Climatic Zone of Andhra Pradesh.

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PERCEPTION AND WILLINGNESS TO ADOPT DRONE TECHNOLOGY IN TIRUPATI DISTRICT - A STUDY ON FARMERS PROFILE

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ABSTRACT

The present study was conducted to assess the perception and willingness of farmers to adopt drone technology, with a specific focus on their socio-economic and psychological profiles in Tirupati district of Andhra Pradesh. A random sample of 120 farmers was selected for the study. The findings revealed that a majority (53.33%) of the farmers belonged to the middle-aged category, with 30.00 per cent having attained college-level education and above. Most farmers owned small-sized landholdings (33.33%) and had undergone training related to drone technology (65.83%). In terms of socio-psychological attributes, a significant proportion exhibited medium levels of annual income (84.17%), social participation (47.50%), and extension contact (66.67%), innovativeness (82.50%), achievement motivation (73.33%), economic orientation (76.67%), decision-making ability (85.00%), and scientific orientation (77.50%).

KEYWORDS: Adoption, drone technology, perception, profile and willingness.

INTRODUCTION

The agricultural sector is embracing a technological shift, with drones (UAVs) emerging as a key tool for enhancing precision, efficiency, and sustainability. As global food demand rises, traditional practices often lead to resource waste and reduced productivity. In contrast, drones equipped with multispectral sensors and AI analytics provide real-time data on crop and soil health, enabling targeted use of water, fertilizers, and pesticides. They assist in mapping, disease detection, irrigation monitoring and precision spraying, helping farmers increase yields while reducing costs and environmental impact.

MATERIAL AND METHODS

The study followed an exploratory research design to assess the profile of farmers adopting drone technology in Tirupati district, Andhra Pradesh, which was purposively selected as the researcher hails from the region. Among the 34 mandals, four with high drone usage were chosen purposively. From each mandal, two villages were selected, totaling eight villages. In each village, 15 farmers were selected using simple random sampling, resulting in a sample size of 120. Based on a literature review and expert input, 12 variables were identified. Data were collected through a structured interview schedule and analyzed using frequency, percentage, mean, and standard deviation for meaningful interpretation.

RESULTS AND DISCUSSION

The farmers were distributed into different categories based on their selected profile characteristics and the results were presented in the table 1.

Age

The results from table 1 revealed that majority (53.33%) of the drone farmers belonged to middle aged category followed by old aged (43.33%) and young age (3.34%) categories. The reason behind this was middle aged farmers have accumulated years of experience that allowed them to make informed decisions about technologies. This finding was in conformity with Burman *et al.* (2023).

Education

The findings from table 1 showed that 30.00 per cent of the drone farmers had completed their college level education followed by high school (25.00%), illiterate (18.33%), primary school (12.50%), middle school (7.50%) and functionally literate (6.67%). This trend may be due to better access to nearby schools, colleges, and transport facilities in villages. This finding was in conformity with Vecchio *et al.* (2020).

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Farm size

The results furnished in table 1 stated that majority (33.33%) of the farmers were small farmers followed by marginal and large (20.00%), semi medium (15.00%) and medium (11.67%) farmers. This indicates a balanced land size, suitable for drone use and manageable for individual investment if supported by affordable services or schemes. The result was in accordance with the finding of Manjunath (2014).

Annual income

From the table 1, it can be inferred that 84.17 per cent of the drone farmers had medium annual income followed by high (12.50%) and low (3.33%) levels of annual income. The predominance of medium-income farmers indicates a stable financial base, likely supported by diverse income sources, moderate landholdings, input access, and market participation. This finding was in conformity with Gabriel (2014).

Social participation

It could be understood from the table 1 that 47.50 per cent of the drone farmers had medium level of social participation followed by low (39.17%) and high (13.33%) levels of social participation. Few farmers were part of self-help groups or gram panchayats, while over half showed medium social participation. This reflects moderate community involvement, offering some benefits of networking, information exchange, and collective problem-solving. This finding was in conformity with Puri *et al.* (2017).

Training undergone

The results from the table 1 depicted that 65.83 per cent of the farmers had undergone training followed by 34.17 per cent of the farmers had not undergone training. The reason behind this was by the efforts of RASS-KVK officials, who conducted demonstrations on drone technology in various locations, thereby encouraging farmers to attend the training programs. The results were in line with the findings of Akhila (2023).

Innovativeness

The findings from the table 1 showed that majority (82.50%) of the farmers had medium level of innovativeness followed by low (13.33%) and high (4.17%) levels of innovativeness. This trend may be due to farmers' receptiveness to technological advancements for better returns, supported by their moderate education levels, enabling them to adopt innovations like drone technology. This finding was in conformity with Gogoi *et al.* (2016).

Extension contact

The findings on extension contact from table 1 projected that 66.67 per cent of the drone farmers had medium level of extension contact followed by low (20.00%) and high (13.33%) levels of extension contact. This moderate level of interaction is often due to periodic visits by extension personnel and village agricultural assistants, combined with a fair interest in agricultural advancements. The result was in accordance with the finding Kimani (2019).

Achievement motivation

It could be concluded from the table 1 that majority (73.33%) of the drone farmers had medium level of achievement motivation followed by high (17.50%) and low (9.17%) levels of achievement motivation The predominance of medium achievement motivation suggests that most of the drone farmers possess a fair degree of ambition and perseverance in their agricultural activities, which can contribute positively to productivity and openness to adopting new technologies. The result was in accordance with the finding Clothier *et al.* (2015).

Economic orientation

It could be observed from table 1 that 76.67 per cent of the drone farmers had medium economic orientation followed by high (13.33%) and low (10.00%) levels of economic orientation. Farmers involved in the study on drone technology were driven by a common desire to improve their socio-economic status and enhance their standard of living through increased income. The result was in accordance with the findings of Clothier *et al.* (2015) and Puri *et al.* (2017).

Decision-making ability

The results of the decision-making ability from table 1 showed that majority (85.00%) of the drone farmers had medium level of decision-making ability followed by high (10.00%) and low (5.00%) levels of decision-making ability. This suggests that many farmers adopted a balanced and thoughtful approach when making decisions related to drone technology. The findings of the present study were similar to that of Puri *et al.* (2017).

Table 1. Distribution of farmers according to their profile (n=120)

S. No.	Category	Frequency (f)	Percentage (%)
1. Age			
1	Young age (35 years and below)	04	03.34
2	Middle age (36 to 55 years)	64	53.33
3	Old age (56 years and above)	52	43.33
	Total	**120**	**100**
2. Education			
1	Illiterate/No schooling	22	18.33
2	Functionally literate	08	06.67
3	Primary school	15	12.50
4	Middle school	09	07.50
5	High school	30	25.00
6	College level and above	36	30.00
	Total	**120**	**100**
3. Farm size			
1	Marginal (Up to 2.5 acres)	24	20.00
2	Small (2.5 to 5 acres)	40	33.33
3	Semi medium (5 to 7.5 acres)	18	15.00
4	Medium (7.5 to 10 acres)	14	11.67
5	Large (>10 acres)	24	20.00
	Total	**120**	**100**
4. Annual income			
1	Low annual income (<50,000)	04	03.33
2	Medium annual income (50,000 to 2lakhs)	101	84.17
3	High annual income (>2lakhs)	15	12.50
	Total	**120**	**100**
		Mean= 119083.3	**SD=72679.75**
5. Social participation			
1	Low social participation	47	39.17
2	Medium social participation	57	47.50
3	High social participation	16	13.33
	Total	**120**	**100**
			Mean=1.39 SD=1.37
6. Training undergone			
1	Training undergone	79	65.83
2	Not training undergone	41	34.17
	Total	**120**	**100**
7. Innovativeness			
1	Low innovativeness	16	13.33
2	Medium innovativeness	99	82.50
3	High innovativeness	05	04.17
	Total	**120**	**100**
			Mean=35.26 SD=3.82

Cont...

Table 1. Distribution of farmers according to their profile (n=120)

S. No.	Category	Frequency (f)	Percentage (%)
8. Extension contact			
1	Low extension contact	24	20.00
2	Medium extension contact	80	66.67
3	High extension contact	16	13.33
	Total	**120**	**100**
			Mean= 9.87 SD=1.48
9. Achievement motivation			
1	Low achievement motivation	11	9.17
2	Medium achievement motivation	88	73.33
3	High achievement motivation	21	17.50
	Total	**120**	**100**
			Mean=28.11 SD=2.48
10. Economic orientation			
1	Low economic orientation	12	10.00
2	Medium economic orientation	92	76.67
3	High economic orientation	16	13.33
	Total	**120**	**100**
			Mean=26.43 SD=1.62
11. Decision-making ability			
1	Low decision-making ability	06	05.00
2	Medium decision-making ability	102	85.00
3	High decision-making ability	12	10.00
	Total	**120**	**100**
			Mean=5.55 SD=0.76
12. Scientific orientation			
1	Low scientific orientation	21	17.50
2	Medium scientific orientation	93	77.50
3	High scientific orientation	06	05.00
	Total	**120**	**100**
			Mean=26.26 SD=2.74

Scientific orientation

From the table 1, it could be interpreted that majority (77.50%) of the farmers had medium level of scientific orientation followed by low (17.50%) and high (5.00%) levels of scientific orientation. It reflects a moderate inclination towards acquiring new knowledge and embracing innovative farming practices. This moderate scientific mindset, supported by exposure to innovations through Krishi Vigyan Kendras (KVKs), private agencies and peer networks, helped farmers adopt drone technology and improve productivity. The findings of the present study was similar to that of Verma *et al.* (2023).

The present study was conducted in Tirupati district revealed that the majority of farmers belonged to the medium-to-high category for most of the variables *viz.,* middle-aged, had completed college or higher education, owned small to medium landholdings, and had undergone prior training. Most exhibited moderate levels of annual income, social participation, contact with extension services, innovativeness, achievement motivation, economic orientation, decision-making ability, and scientific mindset. These characteristics suggest a strong foundation and considerable potential for adopting drone technology. To realize the full potential of drone adoption by farmers, it is essential to establish hands-on training workshops, field demonstrations through Farmer Producer Organizations or custom hiring centers, streamline subsidy access, foster partnerships with ICAR, KVKs, and local agricultural universities, and expand digital literacy programs to build farmer confidence in drone applications. Integrating these measures with awareness campaigns, institutional support, and robust policy frameworks will help reduce costs, minimize input waste, enhance agricultural sustainability, and improve both productivity and farmer livelihoods.

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ASSESSING THE COST OF CULTIVATION OF GROUNDNUT CROP UNDER CLIMATE CHANGE IN KARNATAKA STATE IN INDIA

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ABSTRACT

Groundnut (*Arachis hypogaea* L.) is a major oilseed crop in Karnataka, largely cultivated under rainfed conditions. This study examines the impact of climatic variability on groundnut cost of cultivation using district-level panel data for 1990–2023. A dynamic Arellano–Bond Generalized Method of Moments (GMM) estimator was employed to address endogeneity. Results show that rainfall significantly reduces production costs, whereas temperature increases costs beyond a threshold level. Higher wet-day frequency and positive SPI values raise costs, while moderate cloud cover lowers them. The findings highlight the sensitivity of groundnut production costs to climate variability in semi-arid regions.

KEYWORDS: Climate change, groundnut, cost of cultivation, generalized method of moments (GMM).

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is an important oilseed crop in Karnataka which is predominantly grown in the northern dry regions of the State. In 2023, Karnataka contributed to around 5 percent of all production in India. Chitradurga, Tumkur, Raichur, Koppal and Yadgir are major producers in the region. Acreage in 2021-22 is around 4.5 lakh hectares in Karnataka. India is the world's second largest groundnut oil producer (19.8% in 2022-23). Price of groundnut varies between ₹3685 to ₹6800 per quintal. The state witnessed a decline of about 2.1 per cent in the growth rate of acreage between the year 2017-18 to 2022-23. However, the yields increased by about 34 per cent. Costs of production (A2) in Karnataka vary between ₹3622 and ₹3700 per quintal. The cost of production shows an increasing trend, rising by about 9 per cent from 2021-22 to 2022-23 as shown in Figure 1. Costs of production depend on agronomic, economic and climatic conditions. Climatic change can trigger changes in agronomic and economic factors besides directly influencing the production. Optimal combinations of inputs would differ and production technology could itself change in response to these climatic variations.

Climatic conditions such as rainfall and temperature exhibit changes in trends and patterns in Karnataka. Rainfall shows increasing variability over time since the year 2000 (Pandey and Ponnaluru, 2021). There were around eight long-term drought incidents in the span of 31 years with four significant drought periods in years of 1999-2005, 2011-2014, 2015-2018 and 2018-2020. The intensity of drought increased in the last decade compared to previous decades. Temperatures (daily average Maximum and minimum) also exhibit increasing trends. Summer (March, April, May) temperature increased by 0.18°C to 0.61°C. Winter (December, January, February) minimum temperatures increased by 0.3°C to 0.65°C. Given the climatic changes over the study region, it is highly desirable to quantify the impact of climatic changes on crop production costs. This study quantifies the climatic impacts on cost of production by utilizing generalized method of moments estimators.

The previous studies in the domain of agriculture economics and climate change by Bantilan *et al.* (2013), Rao *et al.* (2013) and Acharya *et al.* (2011) assessed the impact of temperature change on crop revenues. Groundnut yields decreased by 2.3 to 42 per cent across India in response to climatic changes (Kadiyala *et al.* 2021). Climatic variability is a significant determinant affecting total cost of cultivation (Kashyap *et al.* 2024). Various crops responded differently to rising temperatures and this difference in response does not affect the crop patterns (Birthal *et al*. 2021). Increase in temperature reduces the profitability of groundnut (Sembene 2023). ENSO and Indian Ocean sea surface temperatures affected yields of crops including groundnut (Krishna Kumar *et al.* 2004). Climate variability affected technical efficiency besides crop

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acreage, yield and profitability(Singh and Jyoti, 2009). Farmer's production decisions such as level of inputs, choice of crops etc depended on climatic variability and specific approaches are required for each crop (Gadgil *et al.* (2002). The climatic variables incorporated in this study are Temperature, Rainfall, Wet-Day Frequency, Cloud Cover and Precipitation levels.

MATERIAL AND METHODS

Agronomic Data used in this study was obtained from the Directorate of Economics and Statistics (DES) and the reports of Commission for Agricultural Costs and Prices (CACP). The data set utilized in the study is a state level panel covering all the districts of Karnataka spanning over 33 years from 1990 to 2023. ICRISAT DLD provides coverage on agronomic and weather variables from the year 1990 to 2015 and DES covers the rest of period. The Data on costs of cultivation is obtained from Directorate of Economics and Statistics, Government of India. The Indian Meteorological Department (IMD) provided Climate data spanning over 100 years from 1900 to 2002. Data from all these sources is collated and organized into a SAS Database. SAS SQL, SAS IML and Base SAS routines were utilized for analysis.

Dependent variable in the model is cost of production incurred from growing groundnut crop in a year. Revenue from a crop is calculated as a product of quantity produced in tons and the market price received in Rupees. Cost of cultivation is in Rupees and A2 component of cost is considered as per the CACP Methodology. A2 measures the costs of hired and owned labour(human, machine, bullock), value of seeds, pesticides, fertilizers, depreciation, irrigation charges, land revenues, Interest on working capital and miscellaneous expenses, and rent paid for leased in land. Figure 1 shows the trends and patterns in the cost of cultivation over time. An increasing trend can be observed over the study period. Cost varied between ₹849 per quintal in year 2000 and ₹3879 in 2015, with a standard deviation of ₹928. Cost data over time is presented in Table 1.

Climate data is constructed using weather data on each district. Climate normal for variables such as temperature, rainfall, and cloud cover are calculated as moving average of thirty years. For example, normal temperature for the year 2016 is an average of temperatures recorded for years 1986 through 2015. Similarly, normal temperature for the year 2017 is an average for the years 1987 through 2016. Period of thirty years is used for calculating climate normal from weather data as per the convention in the literature. Descriptive statistics for all the variables used in the estimation are presented in Table 2.

Climatic change (changes in temperature, rainfall, seasonality) increase the vulnerability of agriculture. Temperature and rainfall are specified as quadratic functions to capture the nonlinearity in the relation between costs realized and climate. Annual average temperatures (Maximum and Minimum) are considered. Summer temperature ranges between 23°C to 43 °C and winter varies 9°C to 27°C. Cloud cover is an important factor affecting production. Higher cloud cover with little rainfall could be disastrous for the crop. It could affect photosynthesis directly. Increased cloud cover in the early and mid-agricultural cropping season poses significant impacts on crop. Larger amount of cloud cover coupled with higher moisture levels could affect pest and disease incidence. An increase in cloud cover likely leads to vegetation growth. The Indian Meteorological Department reports cloud cover data in percentage units. Given the positive and negative impacts on crop growth, parameter estimate on cloud cover could be either positive or negative.

Southwest monsoon provides 80 per cent of annual rainfall and the rest is from Northeast Monsoon. Western ghats, coastal and southern Karnataka are on the windward side whereas the Kalyan Karnataka region is on the leeward side. This causes spatial variability in the rainfall across the districts. Given that the study area is predominantly semiarid and rainfed increase in rainfall could increase agricultural production and lower costs may be realized. Parameter estimate on rainfall is hypothesized to be negative. Wet-days are defined as the rainy days when the rainfall received is ≥2.5mm. The frequency of wet-days is measured in HPA (Heavy Precipitation Amount) units. Increase in wet-day frequency could lead to nonlinear increases crop growth. Parameter estimate on Wet-day frequency could either be positive or negative. Standardized Precipitation Index (SPI) captures the changes in the amount and variance of the rainfall during the crop growing season. SPI at various periodicity was calculated using monthly precipitation data. SPI values are measured in standard deviations and range between -3.0 (extremely dry) to 3.0(extremely wet condition). Significant correlation

Table 1. Cost of cultivation of *kharif* groundnut (₹/ha), 2015–16 to 2023–24

Year	CoC_A2	CoC_A2 + FL	Gross value added
2015-16	39168	48271	70015
2016-17	40153	49190	74240
2017-18	42122	51586	76112
2018-19	42415	51953	75337
2019-20	42708	52319	74561
2020-21	48222	57965	76183
2021-22	53768	64655	87138
2022-23	58662	70137	96963
2023-24	63788	76772	114789

CoC_A2: Cost of Cultivation (A2), FL: Family labour
Source: Data obtained from CACP

Table 2. Descriptive statistics of variables used in the study (1990–2023)

Variable	Brief description	Mean	Std Dev	Minimum	Maximum
Cost	Cost in ₹/quintal	1939.01	927.84	848.64	3879.56
Rainfall	Rainfall (mm)	1256.35	591.65	501.20	2673.94
Avg Temperature	Average Temperature °C	21.37	3.14	15.07	27.49
CCO	Cloud cover	35.43	7.52	19.81	50.90
Wetdayfreq	Wet-Day Frequency	4.66	1.66	1.85	8.34
SPI	Standardized Precipitation index	0.23	0.80	-1.02	2.85

Source: Author's analysis of data available from CACP, IMD.

Table 3. Parameter estimates from dynamic GMM panel estimation

Variable	Parameter estimates	Standard error	Pr > |t|
Cost lag1	-0.3348	0.0249	<.0001
Rainfall	-37.9067	13.1592	0.0042
Rainfall Sqr	-0.0010	0.0051	0.8406
Avg Temperature	7375.8870	1075.2000	<.0001
Avg Temperature Sqr	-273.6900	35.2720	<.0001
Cloud cover	-18535.1000	1625.0000	<.0001
Cloud cover Sqr	210.9975	15.1696	<.0001
Wetday Freq	91044.6900	15970.4000	<.0001
Wetday Freq Sqr	-4596.9800	1089.5000	<.0001
Standardized Precipitation Index	234.2880	19.8265	<.0001
Dependent Var: Cost			

Source: Author's analysis of data available from CACP, IMD.

between crop's irrigation demand and the change in SPI values across different time scales. This study estimated SPI in 12-month scale. Average of SPI values in the State for 28 years ranged from 0 to 0.52. Parameter estimate on SPI is hypothesized to be positive.

Estimation

$$Cost_{it} = \alpha Cost_{it-1} + \beta_1 Rain_{it} + \beta_2 Rain_{it}^2 + \beta_3 Temp_{it} + \beta_4 Temp_{it}^2 + \beta_5 Cloud_{it} + \beta_6 Cloud_{it}^2 + \beta_7 WetDay_{it} + \beta_8 WetDay_{it}^2 + \beta_9 SPI_{it} + \epsilon_{it}$$

The cost function was estimated within a dynamic panel framework using the Arellano–Bond Generalized Method of Moments estimator. PROC PANEL procedure of SAS was utilized for estimating the model under dynamic framework. Arellano Bond dynamic estimator under Generalized Method of Moments framework is employed. Dynamically lagged dependent variable has been included in the panel data model of production costs. Arellano Bond Estimator uses lagged values of the dependent variable as instruments to control for the endogeneity from the included lagged dependent variable. Suitability of these lags as instruments was verified by Sargan test.

RESULTS AND DISCUSSION

Results from the estimated model are presented in Table 3. Parameter estimate on lagged dependent variable is negative and statistically significant. Magnitude of the estimate (0.3348) is less than 1, indicating that the lagged effect dies down eventually. Parameter estimate on rainfall is negative and statistically significant (on linear

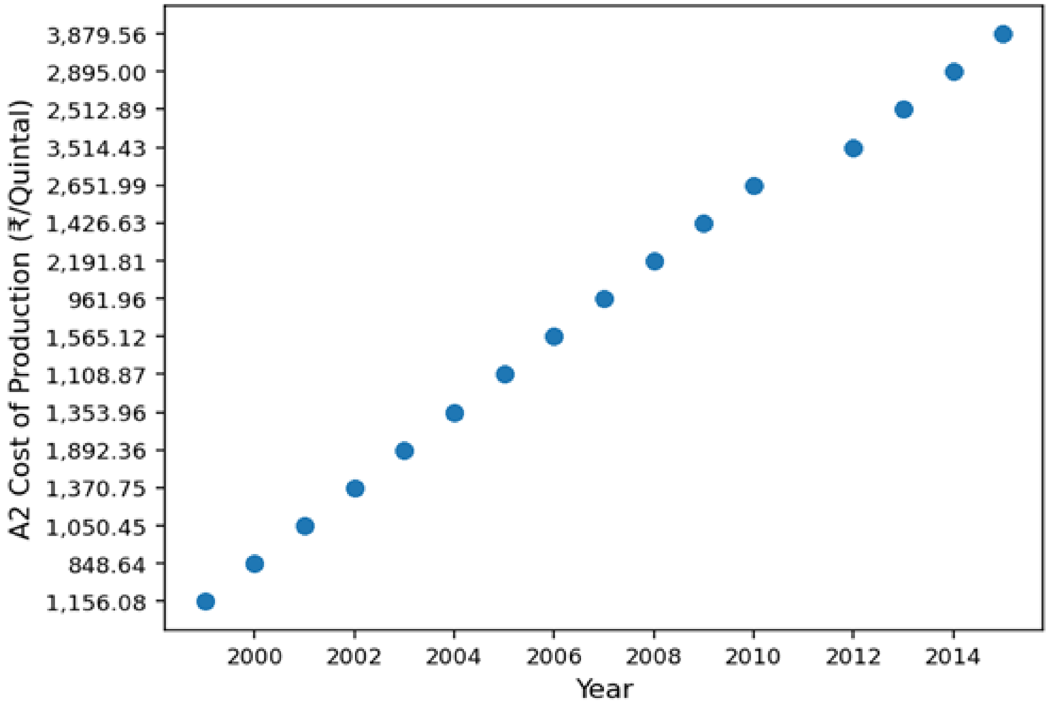

Figure.1. Trend in cost of groundnut production (₹/quintal), 1990–2023

term and insignificant on the quadratic term) indicating that the costs decrease with increase in rainfall. A 1per cent increase in rainfall results in a 26.23 per cent decrease in costs. Given the rain-fed nature of the farming this result is consistent with the literature. Parameter estimate on temperature is negative (-273.69) on the quadratic term and positive on the linear term indicating that costs increase with increase in temperature but at a decreasing rate. a 1 per cent increase in temperature leads to a 75.25 per cent rise in costs. Parameter estimate on cloud cover is significant and positive on quadratic term and negative on the linear term. It indicates that more cloud cover percentage lowers the costs incurred.

Parameter estimate for wet-day frequency is statistically significant and negative on quadratic term, positive on linear term indicating that with the higher frequency of rainy days are associated with higher costs. This might be due to increase in the incidence of pest and diseases with increased number of rainy days. Parameter estimate on SPI is statistically significant and positive. It implies that the frequent drought incidence increases costs of production.

This study estimates the impact of climate variability on groundnut production costs in Karnataka using a dynamic panel GMM framework for 1990–2023. Results indicate that temperature increases raise costs nonlinearly, while rainfall reduces costs in rainfed districts. Increased wet-day frequency and drought variability elevate production costs.

The dynamic nature of cost adjustment suggests that climatic shocks may have persistent effects. Adaptation strategies such as improved irrigation infrastructure, climate-resilient varieties and integrated pest management may help stabilize production costs.

Future research may incorporate spatial dependence across districts and explore climate–technology interaction effects.

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FACTORS INFLUENCING TRIBAL WOMEN PARTICIPATION IN VAN DHAN VIKAS KENDRA IN ALLURI SITARAMA RAJU DISTRICT IN ANDHRA PRADESH

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ABSTRACT

This study investigates the factors that influence tribal women participation in Van Dhan Vikas Kendras (VDVKs) in Alluri Sitarama Raju district, Andhra Pradesh. A primary survey was conducted in the ASR district with a sample size of 160 members, comprising 80 VDVK beneficiaries and 80 non-beneficiaries. Binary logit regression analysis was used to examine the socio-economic characteristics of sample SHG women. The analysis revealed that awareness, extension services and distance to VDVK centre showed a positive influence on tribal women beneficiaries to participate, while age has shown a significantly negative impact on women's participation at 1% level of significance. The female-headed families showed a significantly positive impact on women's participation at 5% level of significance. The findings also recorded that women engaged in VDVKs have improved income, skills and empowerment over the years. Therefore, the socio-economic characteristics enhance SHG participation and the overall effectiveness of the VDVK model.

KEYWORDS: Binary logistic regression, self-help group, tribal women, van dhan vikas kendras.

INTRODUCTION

Van Dhan Vikas Kendras (VDVKs) provides entrepreneurship activities and income support through marketing of value addition to minor forest products. It works under the Pradhan Mantri Van Dhan Yojana scheme (PMVDVY) with the main aim to empower tribal women through marketing of Minor Forest Produce (MFP). Minor Forest Produce (MFP) refers to non-timber forest produce which includes bamboo, brushwood, stumps, canes, tusser, cocoon, honey, waxes, lac, medicinal plants and herbs. Each Kendra includes around 15 SHGs with 300 members and acts as hub for training, processing and skill development for tribal women. The Ministry of Tribal Affairs serves as the central nodal department while Tribal Cooperative Marketing Federation of India (TRIFED) acts as the national nodal agency for this initiative during the year 2018 at nation level. In Andhra Pradesh there are 6225 VDVK SHGs, 415 VDVK Clusters and 123758 gatherers across 8 districts (TRIFED, 2024). Van Dhan Vikas Kendras helps in providing training, machinery, implements and processing units for minor forest products and helps them to fetch high price on their marketed processed products. It also supports tribal women in providing packing and branding. It aims to enhance the livelihoods of tribal communities residing in forest areas. As a whole, it provides entrepreneurship activities and income support through marketing of value addition to minor forest products. The entry of VDVKs eventually empowered tribal women to become micro-entrepreneurs by improving their livelihood with fair profits on sold products (TRIFED, 2024).

The Paderu Revenue Division in Alluri Sitharama Raju district, Andhra Pradesh which comprises 11 mandals and has a population of 604,047 with 576,026 living in rural areas and 28,021 in urban areas. Scheduled Tribes make up 90.71 percent (547,951 individuals) of the population while Scheduled Castes constitute 0.69 percent (4,154 individuals). Major tribal groups include the Bhagatha, Konda Dora, Koyya Dora, Valmiki, Khond, Koya, Gadaba and Porja speaking Telugu, Odia and Kuvi languages. Minor forest products are a crucial income source for these tribal populations, contributing between 20 to 40 percent of their annual earnings. Notably, women play a vital role in collecting and marketing these products, making this activity a key factor in promoting women's economic empowerment (IBEF, 2021). Van Dhan Vikas Kendras are functioning in 6 mandals in ASR district namely Paderu, Gudem Kotha Veedi, Chintapalli, Koyyuru, G. Madugula and Peddabayalu. The centers provide skill development, infrastructure and market access to beneficiary Self-help group which enable women to market value added minor

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forest produce. Empowering women is a key to uplifting tribal communities (Dhanasree K., 2014).

The research focuses on analyzing key aspects of Van Dhan Vikas Kendra in promoting tribal women entrepreneurship through the training and marketing of Minor Forest Natural Produce in Alluri Sitarama Raju district. It aims to assess the status and performance of VDVKs' in enabling effective marketing, evaluate their impact on income generation and empowerment of tribal women. Further, the research tries to explore the factors influencing the participation of women SHGs in VDVK. As a whole, the study intends to find out VDVK contribution towards livelihood opportunities, economic and social empowerment of tribal women in the Alluri Sita Rama Raju district.

MATERIAL AND METHODS

The prime objective of the study is to examine the various socio-economic and institutional factors that influence the participation of women Self-Help Group members in VDVK activities. A sample of 160 respondents was selected consisting of 80 VDVK beneficiaries and 80 non-beneficiaries from three mandals Paderu, Chintapalli and G. Madugula. Data was collected and analyzed using binary logistic regression. Information was gathered on socio-economic characteristics which influence the tribal women participation in VDVK.

Binary Logit Model

A Binary Logit Model was employed to analyse the factors influencing tribal women's participation in VDVKs through SHGs. The dependent variable was binary:

1 = VDVK beneficiary (SHG member participate in VDVK)

0 = VDVK Non-Beneficiary

The general logit model is specified as:

$$\ln\left(\frac{p}{1-p}\right) = \beta_0 + \sum_{i=1}^{n} \beta_i X_i$$

Where:

p = probability of being a VDVK beneficiary

1-p = probability of VDVK non-beneficiary

X_i = vector of explanatory variables

β_0, β_i= regression coefficients

RESULTS AND DISCUSSION

Socio economic profile of VDVK beneficiaries and non-beneficiaries in ASR district

Age plays a crucial role in determining their involvement in entrepreneurial activities. As shown in the table 1, the average age of women is 35 for beneficiaries and 38 for non-beneficiaries. Education signifies the formal or informal learning acquired by individuals that shapes their awareness, communication ability and confidence in engaging with external systems. The average literacy years of beneficiary women are 6 years, while the average literacy years for non-beneficiary women are 4 years. Higher education levels usually result in better decision-making and leadership within SHGs and VDVKs. Land holding size reflects the extent of agricultural or forest-based land resources available to a household, influencing their economic stability and production capacity. In tribal regions, larger land holdings often enable better participation in value addition and processing of Minor Forest Produce (MFP), while marginal or landless households rely more on forest gathering. Understanding land size distribution is essential for planning support interventions, credit linkage and capacity-building efforts under schemes like PMVDVY. The land less households are 17.2 per cent in beneficiaries, while it is 35.7 per cent in non-beneficiaries. Female-headed families represent households where women serve as primary decision-makers and breadwinners. The female headed families among beneficiaries are of 78.75 per cent, while only 56.25 per cent among non-beneficiaries. In tribal societies, such families often face dual responsibilities of income generation and family care, making them more vulnerable but also potentially more responsive to empowerment initiatives. Their participation in Self-Help Groups (SHGs) and Van Dhan Vikas Kendras (VDVKs) often signals a higher level of resilience, leadership and motivation for collective entrepreneurship. The average family size of beneficiaries is 6.05, while it is 6.85 for non-beneficiaries. Family size determines the labour availability within a household and impacts income needs, dependency ratios and participation in livelihood activities. For tribal women, managing larger households can either limit or encourage group participation depending on support systems, making it a key variable in analyzing their engagement with development programmes and MFP-based enterprises. About 72.5 per cent of VDVK beneficiaries are aware while only 43.75 per cent of non-beneficiaries are aware regarding the schemes of the Government. Awareness regarding Government schemes refers to the level of knowledge tribal women have about various government programs aimed at improving their livelihoods, health, education and economic status. In the context of VDVKs, better awareness helps women access available support, participate actively and benefit from development initiatives. Assessing this factor highlights how effectively information about such schemes reaches the target community. Extension services involve the delivery of technical support, training and awareness-building efforts to rural and tribal populations. About 81.25 per cent of beneficiaries are exposed to the extension services, while only 21.25 per cent of non-beneficiaries are exposed. The frequency of these services indicates how regularly tribal women are engaged by government officials or field-level facilitators. In the PMVDY framework, consistent extension contacts help ensure proper implementation, builds trust and enhances the capacity of SHG members within the VDVKs. Distance from VDVK centre denotes the physical gap between production clusters and their nearest trading centres. The average distance from VDVK for beneficiaries is predominantly within 0-15km, with 43.75 per cent residing 0-5km away, 33.75 per cent within 6-10km and 22.5 per cent within 11-15km. For non-beneficiaries, only 1% are within 6-10km, 30% within 11-15km, 41.25 per cent within 16-20km and 18.75 per cent within 21-30km. The non-beneficiaries are more engaged in agricultural labour (31.25%) and farm households (22.5%), while beneficiaries show higher involvement in non-farm activities (65%). A small share from both groups works in the organized sector, with beneficiaries slightly higher in size (3.75%). Beneficiaries recorded higher employment with 310 man-days per year and income of Rs. 59,912.55 per year against non-beneficiaries with 220 man-days and Rs. 45,286.52 per year. Their annual consumption expenditure was also greater, with food consumption at Rs. 37,200 and non-food at Rs. 24,800, while non-beneficiaries spent Rs. 26,400 and Rs. 17,600 respectively. Asset ownership shows that beneficiaries had higher housing (56.25%) and LPG connections (65.5%), whereas non-beneficiaries reported more livestock (60%) and material assets (32.5%). Importantly, VDVKs contributed 210 man-days exclusively to beneficiary households, strengthening their employment base.

Factors influencing tribal women participation in Van Dhan Vikas Kendra in Alluri Sitarama Raju district

To assess the determinants influencing tribal women's participation in Van Dhan Vikas Kendras (VDVKs), a binary logistic regression model was employed. This model helped to identify key socio-economic, institutional and market-related factors that significantly impact the likelihood of women joining VDVKs. The model results include coefficient value, standard errors, significance levels and odds ratios, as presented in Table-2. The model demonstrated strong explanatory power, with a pseudo-R^2 value of 0.7650, indicating that 76.5 per cent of the variation in membership decisions could be explained by the included variables. The regression results are presented in Table-2, identifying the significant determinants of VDVK participation.

Discussion of significant determinants

Age is statistically significant at the 1 percent level, an increase in age was associated with a lower probability of VDVK membership. The odds ratio of 0.711 suggests that the younger individuals are more likely to participate in the VDVK. This confirms that younger tribal women are more likely to engage in organized value-addition activities compared to older women. Significant at the 5 percent level, female-headed families showed a strong positive influence, with an odds ratio of 12.160. This indicates that women from female-headed households were over twelve times more likely to be VDVK members compared to those from male-headed families, reflecting their greater motivation to seek support systems and enhance household income through collective enterprise. Awareness was significant at the 1 percent level and positively influenced VDVK participation. With an odds ratio of 2.042, women who were aware of the scheme were nearly twice as likely to join. This finding underscores the importance of effective information dissemination and village-level sensitization campaigns. Extension Services were the most influential factor in the model, showing significance at the 1 percent level. The odds ratio of 6.115 indicates that access to extension services increased the likelihood of joining a VDVK by more than six times. This result demonstrates the importance of institutional outreach and technical handholding in mobilizing tribal women for enterprise development. Distance was found to have a positive and significant effect at the 10 percent level. With an odds ratio of 1.683, the model suggests that distance is also one of a

Table 1. Socio-economic characteristics of VDVK beneficiary and non- beneficiary (n = 160)

Particulars	Beneficiary N=80	Non-Beneficiary N=80
A. Socio economic characters		
Average family Size	6.05	6.85
Average Age of Women	35	38
18-25	2	-
26-40	32	28
41-50	46	52
51-60	-	-
More than 60	-	-
Average Literacy of women (No of years)	6	4
Illiterate	45	48
Primary school	12	12
High school	10	10
Inter/Diploma	11	10
Degree	2	-
Percentage of schedule tribes to total Members (%)	100	100
Percentage of female headed families (%)	78.75	56.25
Land less households (%)	17.2	35.7
Awareness regarding Government schemes (%)	72.5	43.75
Extension services (%)	81.25	21.25
Distance from VDVK (%)		
0-5 km	43.75	-
6-10 km	33.75	1.0
11-15 km	22.5	30.0
16-20 km	-	41.25
21-30 km	-	18.75
B. Occupation classification		
Particulars (%)	**Beneficiary**	**Non-Beneficiary**
Agricultural Labour households	18.75	31.25
Non- farm households	65	43.75
Farm households	12.5	22.5
Households engaged in organised sector employment	3.75	2.5
C. Employment details		
Particulars (man-days/yr)	**Beneficiary**	**Non-Beneficiary**
Off farm employments (MGNREGA, Sericulture, Livestock)	40	140
VDVKs	210	-
Agriculture	60	80
Total man-days/year	310	220

Table 1. Socio-economic characteristics of VDVK beneficiary and non- beneficiary (n = 160)

Particulars	Beneficiary N=80	Non-Beneficiary N=80
D. Mean employment and income		
Particulars	**Beneficiary**	**Non-Beneficiary**
Employment man-days /Year	310	220
Income (Rs/year)	59912.55	45286.52
E. Consumption Expenditure per year		
Particulars	**Beneficiary**	**Non-Beneficiary**
Food consumption	37200	26400
Non-food consumption	24800	17600
F. Asset ownership in households		
Particulars (%)	**Beneficiary**	**Non-Beneficiary**
Livestock	47.5	60
Housing	56.25	33.75
Material assets	27.5	32.5
LPG Gas Connection	65.5	66.25

Author's calculations

Table 2. Logit model estimates and marginal effects for determinants of VDVK membership

S. No	VDVK membership	Coefficient value	Standard error	P > |z|	Odds ratio
1.	Age	-0.3403***	0.0829	0.000	0.711
2.	Education	0.2353	0.3582	0.511	1.265
3.	Land holding Size	0.6080	0.4752	0.201	1.836
4.	Female headed families	2.4982**	1.2136	0.040	12.160
5.	Family size	0.1104	0.5265	0.834	1.116
6.	Awareness	0.7142***	0.2623	0.006	2.042
7.	Extension service	1.8107***	0.4766	0.000	6.115
8.	Distance to VDVK Centre	0.5207**	0.3150	0.098	1.683
	Number of observations	160			
	Pseudo R^2	0.7650			

*** 1%, ** 5%, *10% at level of significance; calculations were done by the author.

key factor for the women to join the VDVKs in the study area. Variables such as education level, landholding size and family size were found to be statistically insignificant ($p > 0.05$), indicating they did not substantially affect the likelihood of VDVK membership in the study area.

The results show that, Younger tribal women are more likely to join VDVKs, while female-headed households show a strong positive influence on membership. Awareness of the scheme and access to extension services significantly boost participation, with extension services being the most impactful factor. Distance is also a significant factor for participation in the VDVKs. However, education, landholding size and family size do not significantly affect membership. These findings highlight the key roles of motivation, awareness and support over socio-economic traits in driving VDVK participation. The findings resonate with studies by Joshi (2019), Shah and Panigrahi (2015) and Sukhdeve (2011), which also reported that female headship, awareness and extension support significantly influence women's involvement in collective enterprise activities. These studies affirm the relevance of targeted institutional support, capacity building and effective communication in enhancing women's economic empowerment in tribal regions.

The study presents a comprehensive evaluation of the Van Dhan Vikas Kendra (VDVK) scheme in Alluri Sitarama Raju (ASR) district of Andhra Pradesh. The socio-economic profile of VDVK beneficiaries compared to non-beneficiaries reveals significant improvements in livelihood, awareness and empowerment among the former. Beneficiaries had greater access to extension services (81.25%) and higher awareness of government schemes (72.5%) compared to only 21.25 per cent and 43.75 per cent among non-beneficiaries, respectively. This indicates more effective outreach and capacity-building interventions for VDVK participants. A notable 78.75 per cent of beneficiary households were female-headed, reflecting enhanced leadership and women's empowerment. The findings reaffirm the scheme's significant role in transforming the socio-economic landscape of tribal communities by fostering value addition, entrepreneurship and institutional linkages in the Minor Forest Produce (MFP) sector.

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CONSTRAINTS IN PRODUCTION AND MARKETING OF COIR PRODUCTS IN WEST GODAVARI DISTRICT OF ANDHRA PRADESH

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ABSTRACT

This study investigates the problems faced by coir industries in Andhra Pradesh, focusing on production, manufacturing, and marketing of coir fibre. The research explores constraints perceived by farmers and analyses their suggestions to address these issues and revive the coir industry. Ten respondents, selected through a random sampling procedure, provided insights into 10 identified problems categorized under production, manufacturing, marketing of coir fiber. Garrett's ranking technique was employed to prioritize constraints in coir marketing. Inadequate/unavailability of raw material was identified as key concern with Garrett Mean Score of 78.2 followed by, shortage of labour (71.2), lack of finance (65.6) and lack of Government support (56.8). The least concerns were lack of training /motivation (26.6), lack of credit facilities by banks (23.5) and less adaptability of technology, heavy transportation cost, and lack of product innovation were also identified as prominent issues in coir industries. In coir marketing, inadequate prices were identified as key concerns. The study concludes with valuable suggestions from coir producers, marketers and manufacturers, emphasizing mechanization, technical guidance, and improved market information dissemination for sustainable development in the coconut and coir industries.

KEYWORDS: Coir fibre, rural industries, sustainability, constraints in production & marketing.

INTRODUCTION

In India about two-third of rural income is now generated in non-agricultural activities through various small and micro level enterprises in rural areas. The fact that India is a country of villages and that about 70 per cent of its people reside in rural regions is well known in India can only set itself on the intended developmental road through a progressive, expanding and active rural society. In the unique environment of India, small-scale rural industries hold significant importance. About half of the gross value of production that originates in the manufacturing sector is contributed by them. Right now, it employs 14 million people and accounts for 40 per cent of the nation's export earnings (Department of Science & Industrial Research).

Industrialization in rural areas plays a crucial role in balanced regional development by fulfilling several economic and social needs of rural areas by increasing employment opportunities, diversifying rural occupations, raising living standards besides reducing exodus to urban centres (Roy B. C, 1997). Hence, it is crucial to support and grow rural industry while taking into account its importance for the nation's socio-economic landscape. Sustainable economic growth is significantly impacted by the rural or traditional industry, which is a sub-sector of small-scale industry (Nagesh A. R, 1990).

The coir industry in India has made progress in domestic as well as in international markets because of its eco-friendly and biodegradable products. The coir industry in India is one of the largest employments generated especially in rural areas across the coconut producing states. It is one of the few traditional or rural businesses that turn the waste material that is coconut husk into money (Chillar M, 2004). One of the unique features of the coir sector is that it offers agricultural labourers part-time work options and full-time employment to unskilled individuals. One way to help the impoverished in rural areas find gainful employment and money turnover through the industrialization of coir (Jeya B. J, 1989).

The major coconut-growing states and Union Territories rely heavily on the coir industry, a cottage industry of considerable importance. In this industry, almost 5.5 lakh people find work, primarily in part-time positions. This industry exports goods worth of about Rs.70 crores. The primary raw material used to make coir goods is coconut husk. Coir goods are made from

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around half of the available coir husk (Kumaraswamy Pillai M, 2005). Therefore, there is room for the coir industry to expand. For female artisans, specialised training programmes have been created. To boost employment and income, skilled women craftspeople will receive improved, contemporary treadle machines (Nair B, 1997). A focus has been placed on creating tools, machinery and equipment through research and development in order to lessen drudgery and increase coir worker's output. The current development plans have their goals, the diversification of goods, quality enhancement and revitalization of coir cooperatives (Malik I. R, 1988). Additionally, efforts were made to investigate potential export markets for coir and its derivatives.

Andhra Pradesh occupies third position with 600 number of coir industries. But in terms of growth percentage Karnataka was the top position with 40.01 per cent growth. West Godavari District of A.P has more number of coir-based product manufacturing units. The units has a mixed past and is a traditional one with traditions and sometimes antiquated methods. The majority of coir labourers come from economically and socially disadvantaged backgrounds. Cooperatives, commercial, public, government, and unorganized production units are the main players in the coir industry (Senthil Kumar R, 2015). There observed a deceleration of coir industry especially after COVID because of reduced indents and exports with this backdrop the present research article is intended to identify the major constrains faced by the coir units and to analyse this suggestions put forth by the respondents.

METHODOLOGY

The study randomly was conducted in West Godavari district of Andhra Pradesh. Ten coir units which were established more than 5 years ago were selected randomly as the sample from four mandals. Marketing intermediaries were also taken as the sample to understand the existing marketing channel. The collected data was analysed with a range of tools and techniques.

Garrett Ranking Technique

The constraints of coir fibre industry problems were measured by applying Garrett ranking procedure. The order of merit given by the respondents was converted into rank by using the formula. To find out the most significant factor that associated with the respondent, Garrett's ranking technique was used. As per this method, respondents have been asked to assign the rank for all factors and the outcomes of such ranking have been converted into score value with the help of the following formula:

$$\text{Per cent position} = \frac{100(R_{ij} - 0.5)}{N_{.}}$$

R_{ij} = Rank given for the i^{th} variable by j^{th} respondents

N_j = Number of varibales ranked by j^{th} respondents

With the help of Garrett's table, the per cent position estimated was converted into scores. Then for each factor, the scores of everyone were added and then total value of scores and mean values of score was calculated. The components having highest mean value was the most important factor.

RESULTS AND DISCUSSION

The identified problems were ranked by using the Garrett ranking technique and are presented in Table 2. Results revealed that, unavailability of raw material was identified as the major constraint faced by the manufacturers with a Garrett mean score as 78.2, which was attributed to uneven supply and increased competition for raw materials. This happened due to climate change and occurrence of diseases affecting coconut palm that lead to fluctuations in coconut production. The non availability of labour was ranked second with a Garrett score as 71.2. As labour is utilised during husk processing and manufacturing of coir in to various products and now-a-days due to shortage of labour automated technology is using. The absence of financing facilities was ranked third with 65.6 Garrett score. As credit allocation is entirely determined by the bank. A bank would never want to take a chance by approving a loan for a small business like the coir industry. These tiny village industries also experience high bank interest rates.

Lack of government support was identified as the fourth constraint with a Garrett mean score as 56.8. This can be attributed to the inappropriate government policies, as the proprietors of coir units stated that the main causes of their concerns were excessive taxes and export levies. The low adoption of technology (51.3) is the fifth constraint that can be described to expensive initial investment cost and a workforce that is primarily unorganized as this industry heavily relies

Table 1. Selection of district, mandals and respondents

State	District	Mandals	No. of respondents
Andhra Pradesh	West Godavari	Chintaparu	5
		Iragavaram	2
		Yelamanchali	1
		Achanta	2
Total		**4 mandals**	**10 respondents**

on conventional methods for converting husk into fibre. This is because there is a lack of information regarding the use of technology. Sixth constraint is the coir sector is greatly impacted by high transportation costs with a Garrett means score as 51.3, which has an effect on market dynamics and production. Due to its bulk and weight, coconut husk is difficult to transport, and the expense is increased by the fact that coir processing facilities are usually located in remote areas with sample raw materials.

Exporters rejection due to low quality was ranked seventh with 44.8 score. Occasionally the quality of coir fibre may be inadequate, resulting in exporters rejecting it as inappropriate retting. A fluctuation in the fibre's moisture content was caused by inconsistent drying techniques, which will lower the quality. Coir fibre must adhere to certain specifications set by exporters, such as consistency in length, colour, and strength. The results are in line with the results of Gunasekarane J, 2006 .The coir sector has historically seen little in the way of new product innovation throughout time. Due to a lack of funding for research and development, a dearth of technological advancements, and a cautious approach to embracing new market trends, the industry has struggled to diversify its product line and modernise its production technology as it relates to sustainable and environmentally friendly materials. Hence, lack of product innovation was ranked eight with a Garrett means score (36.6). The lack of proper training for many workers in this industry about contemporary techniques and equipment results in inefficiencies and decreased output. Access to educational resources and development programmes catered to the unique requirements of the coir business is typically restricted, which exacerbates this training deficit. Garrett means score (26.6) revealed it as ninth constraint. Lack of credit facilities from banks, was ranked as 10th constraint because many coir firms are informal and there are perceived risks connected with changeable market conditions, banks are reluctant to provide loans to these businesses. As a result, the lack of operating capital causes coir manufacturers to suffer and restricts their ability to make investments in new equipment, raw materials, and employee growth. The livelihoods of those reliant on this traditional business are also impacted by this financial constraint, in addition to the productivity and profitability of coir enterprises. The results are in consistent with the results of Mohamed C, 2005 and Poornimadevi S, 2017).

1. Availability of raw material: Encourage the use of high-yielding coconut cultivars that yield more husks, which will increase the supply of coir. Establish well-run collection points where farmers can readily sell the husks of coconuts. As a result, there will be less waste and a consistent supply of raw materials. To increase productivity and efficiency, provide instruction on contemporary farming practices, pest management strategies, and coir extraction processes.

2. Automated machines: Introduce machines that are fully or partially automated for tasks including matting, spinning, weaving, and defibering. As a result, efficiency is increased and less physical labour is required. Develop multitasking skills in current employees to create a flexible workforce who can move to where they are most required. Invest in training programs that will improve employees' abilities to operate sophisticated machinery and make sure they can handle more advanced equipment.

3. Providing institution finance liberally: Make the most use of the resources and raw materials that are available. Use inventory control strategies to cut down

Table 2. Constraints in manufacturing of coir products

S. No	Factors	Garrett mean score	Rank
1.	Non-remunerative prices & Unavailability of raw material	78.2	I
2.	Non-Availability /Shortage of labour	71.2	II
3.	Lack of Finance	65.6	III
4.	Lack of Government support or Government policies	56.8	IV
5.	Less Adaptability of Technology	51.3	V
6.	Heavy Transportation Cost	45.4	VI
7.	Less Quality of Coir fibre /Rejection based on quality at exporter	44.8	VII
8.	Lack of Product Innovation	36.6	VIII
9.	Lack of Training /Motivation	26.6	IX
10.	Lack of Credit facilities by banks	23.5	X

The suggestions put forth by the respondents for the betterment of coir units are presented below

Table 3. Suggestions to improve the manufacturing of coir products

S. No	Factors	Garrett mean score	Rank
1.	Raw material availability	65.6	I
2.	Automated machines	56.8	II
3.	Providing credit/Institution finance should be provided liberally	51.3	III
4.	Favourable Government policies	45.4	IV
5.	Training and providing motivation for technology adoption	44.8	V
6.	Huge cost of transport may be curtailed	36.6	VI
7.	Following the export quality norms	26.6	VII
8.	New coir products should be encouraged	23.5	VIII

on waste and material expenses. Use lean manufacturing strategies to cut expenses, simplify operations, and get rid of waste. Get rid of stages that don't offer value and concentrate on those that do process find inefficiencies and bottlenecks in your production processes to continuously improve them and cut costs without making a large financial commitment.

4. Favourable government policies: Investigate alternative product lines to coir ropes and mats. This could include furniture made of coir, environmentally friendly packaging, geotextiles, and bio-composite. To make coir goods more robust, long-lasting, and aesthetically pleasing, spend money on research and development. In this sense, cooperation with academic institutions or commercial research facilities may be beneficial. In order to guarantee consistency and high standards in product manufacture, implement contemporary quality control systems. Adopt green production techniques to lessen your influence on the environment and attract environmentally sensitive customers.

5. Training and providing motivation for technology adoption: Create devices that are simple to use and maintain, especially for people with little experience in technology. Include clear instructions and user-friendly interfaces. Provide employees specialised training to enable them to comprehend and utilise new technology. Incorporate practical experience and ongoing assistance. Improve workers' digital literacy to aid in their understanding of and ability to adjust to technology, particularly in rural locations.

6. Huge cost of transport may be curtailed: Create a number of smaller production facilities in closer proximity to important markets or sources of raw materials. This lowers the distance that coir goods must travel, resulting in lower transportation expenses. Make goods that can be put together when they get there. This enables more compact packaging, perhaps saving money on transportation. Utilise IoT to track shipments in real time and monitor conditions, which can improve planning and cut down on pointless travel.

7. Following the export quality norms: Start by locating husks in areas renowned for their superior coir fibre production. Build enduring connections with vendors who can reliably supply high-quality raw materials. At various production phases, do routine quality checks to identify flaws early on. When feasible, use automated systems to minimise human mistake.

8. New coir products should be encouraged: Invest in research and development to generate novel coir composites or blends with other natural or synthetic materials to produce goods with improved qualities (such as greater water resistance or durability). Provide coir goods that can be customised to meet unique customer needs, such as mats with custom designs or sizes for industrial applications. Obtain eco-certifications in order to attract customers who care about the environment. Make coir goods' sustainability and biodegradability a major selling point.

9. Lack of training/motivation: Organise frequent workshops that cover both fundamental and sophisticated coir fabrication methods. Encourage employees to become familiar with various jobs in the manufacturing process as this can boost adaptability and cut down on downtime. Conduction of certification programs that allow employees who meet specific skill levels to be recognised and possibly advance in their careers. Establish an incentive program whereby employees receive bonuses or other rewards for meeting targets, being productive, or producing high-quality work.

10. Lack of credit facilities by banks: Coir producers can have more negotiating leverage if they organise cooperative societies or join existing ones. Cooperative groups are frequently granted credit by banks more readily than individual firms. Encouraging coir workers to form Self-Help Groups (SHGs) can facilitate resource pooling, microcredit access, and financial literacy enhancement. Make use of government programs that provide financing without requiring collateral, such as the financing Guarantee Fund Trust for Micro and Small Enterprises (CGTMSE). Spread the word about the Coir Udyami Yojana and other government grants and subsidies that are expressly intended for the coir business, and offer assistance in applying for them.

Problems in manufacturing and marketing of coir products have been studied. In manufacturing related constraints unavailability of raw material secured highest Ranking Based Quotient score of (78.2) Non availability of labour, lack of credit facility /finance, non-supportive Government policies, Less adaptability of technology, high transportation cost, poor quality of raw material are other problems faced by farmers in production of coir products in decreasing order of their importance. Among other restrictions connected to marketing, traders with intense competition had the highest R.B.Q. The following list of obstacles farmers face in the production of coir products is ranked in decreasing order of significance: high price fluctuations, long distance to markets, demand fluctuations, lack of coordination among market channel members, strict delivery deadlines, non-availability of credit, rejection based on quality, and recovery of credit.

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SEGREGATION DISTORTION IMPLICATIONS AND ANALYSIS IN CROP BREEDING

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ABSTRACT

Mendel's law of segregation assumes equal transmission of alleles from parent to offspring. However, real-world genetic studies frequently reveal deviations from this expected pattern, a phenomenon known as segregation distortion (SD). This refers to the unequal inheritance of alleles during the formation of gametes or the development of zygotes. Such distortion is commonly observed in segregating populations, including F_2 generations, backcrosses, and recombinant inbred lines (RILs). Initially, researchers attributed these deviations are due to technical errors in genotyping or experimental design. However, it is now widely accepted that segregation distortion is often a result of underlying biological mechanisms. These include gametic selection, zygotic selection, meiotic drive, chromosomal rearrangements, and genetic incompatibility. In plant breeding, segregation distortion pose both challenges and opportunities. It may disrupt the accuracy of marker-assisted selection (MAS), QTL mapping, and genetic linkage analysis, potentially leading to the misidentification of desirable traits. However, if properly identified and analyzed, distorted markers can help uncover important genomic regions involved in reproductive barriers or trait inheritance. Advanced statistical methods such as chi-square analysis, likelihood ratio tests and bayesian models as well as specialized mapping tools can assist in detecting and interpreting segregation distortion. Understanding these patterns enables plant breeders to refine selection strategies and accelerate the development of improved crop cultivars.

KEYWORDS: Gametic selection, genomic regions, meiotic drive, marker-assisted selection (MAS), segregation distortion, zygotic selection.

INTRODUCTION

Deviation of the observed genotypic frequencies from the expected mendelian ratios indicates a violation of the law of segregation. Such deviation is referred to as segregation distortion (SD) which was first reported by Mangelsdorf and Jones in 1926 in Maize. SD act as an evolutionary force by influencing the frequency of alleles by manipulating the transmission of alleles during the meiosis. It can increase the frequency of heterozygous alleles through the process called Transmission Ratio Distortion (Huang *et al.,* 2013). It occurs when the genetic distortion affects the transmission of alleles from one generation to the next generation, leading to unequal ratio of different alleles in the offspring. So it is also called as Biased Transmission Distortion. Under normal segregation, the ratio of male (XY) to female (XX) offspring is expected to be 1:1.

Under distorted segregation, due to the presence of a segregation distorter (SD) linked to the FcRAN1 locus, the transmission of the Y chromosome is favored, resulting in a skewed ratio of male (XY^+): female (XX) = 178:7. Colored bars represent homologous chromosomes carrying the FcRAN1 locus, with red and blue indicating normal alleles and yellow showing the distorted allele carrying SD (Figure:1) (Ikegami *et al.,* 2021). The FcRAN1 genotype shows a strong association with the sex phenotype, such genotypic distortion may affect the evolution of sexual reproduction and sex chromosomes in multiple ways (Kozielska *et al.,* 2010). This is due to SD acts on Y chromosome increasing its transmission to the offspring. The Y chromosome is transmitted to the offspring more frequently than the X. As a result, the frequency of the XY genotype increases in the next generation. By the selfish genetic elements present on the chromosome can manipulate the segregation of chromosomes during meiosis, leading to an increase in their own frequency in the population. It can complicate genetic mapping, QTL analysis and breeding programmes. In Figure 1, the X and Y chromosomes are homomorphic, showing no significant molecular structural differences (Storey, 1975).

Reasons of segregation distortion

Marker-associated factors

SD can result from errors at specific marker loci, leading to incorrect genotyping and biased segregation patterns. Marker genotyping errors, such as

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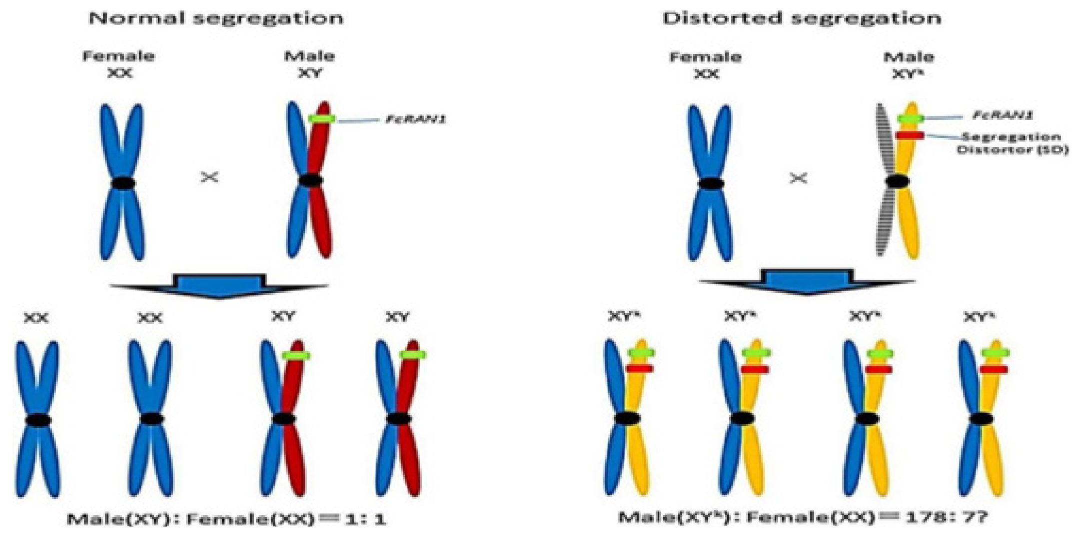


Fig.1. Schematic illustration of normal and distorted segregation of the sex-determining locus (FcRAN1) in Fig (*Ficus carica)*

contamination, incomplete DNA digestion, or technical failures, as well as the use of inappropriate statistical tests, can produce inaccurate allele scoring and artificially distorted segregation patterns (Diouf & Mergeai, 2012). Residual heterozygosity in parental lines may also contribute to SD when multiple alleles exist at a locus, leading to deviations in the progeny (Diouf & Mergeai, 2012). Additionally, mutations within the primer binding sites of molecular markers can prevent amplification of specific alleles. For instance, a heterozygous plant (A/B) may appear homozygous (A/A) if the B allele fails to amplify, resulting in segregation distortion (Diouf & Mergeai, 2012).

Gametic selection

Selective processes during gamete formation or fertilization can also produce SD. Certain alleles may cause pollen abortion, reducing the frequency of affected alleles in functional pollen and skewing segregation ratios in the progeny (Xu *et al.,* 2013). Alleles that influence the rate of pollen tube growth can affect fertilization success, as faster-growing pollen tubes are more likely to reach and fertilize the ovule, leading to unequal representation of alleles. Similarly, comparative fertilization, where interactions between pollen and pistil tissues preferentially favor certain genotypes, can further contribute to SD (Kim *et al.,* 2014).

Zygotic Selection

Post-fertilization mechanisms can also induce SD. Certain zygotes may be selectively eliminated or favored, causing deviations from expected Mendelian ratios (Garavello & Pardo, 2020). Additionally, asymmetric chromosome movement during meiosis, such as preferential segregation of specific alleles, can result in SD in the progeny.

Mechanisms of segregation distortion

Killer protector system

In this system, gametes carrying a killer gene survive only if they also harbor a linked protector gene; gametes lacking the protector are selectively eliminated. A classical example is the S5 locus in rice, which comprises three tightly linked genes—ORF3, ORF4, and ORF5—that interact to determine gamete viability. In Indica rice, ORF3+ (protector) counteracts the toxic effect of ORF5+ (killer), whereas in Japonica, the absence of ORF3+ leads to programmed cell death of gametes containing only the killer gene, resulting in SD. The evolutionary origin of such systems often involves multiple sequential steps, where the balance between killer and protector genes may be established or disrupted, as observed in ancestral populations of the S5 complex under the parallel-sequential divergence model (Ouyang and Zhang, 2013, Ouyang, 2019; Du *et al.,* 2011; Mi *et al.,* 2020). Over evolutionary time, suppressor genes may arise that mitigate the killer's effect, temporarily restoring Mendelian segregation, before new cycles of distortion emerge. These dynamic interactions illustrate how linked genetic elements can bias allele transmission, influence hybrid sterility, and shape population genetics.

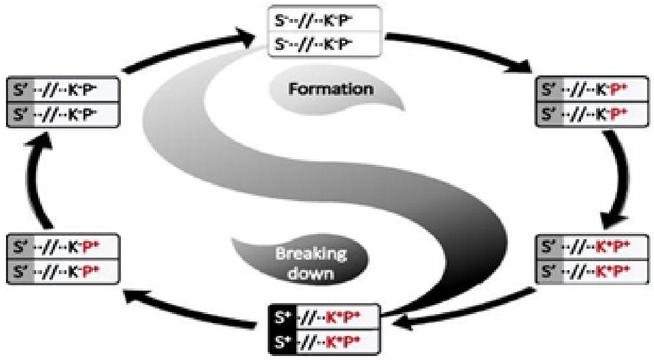


Fig. 2. Evolutionary origin of SD occurs through a recurrent cycle of killer–protector formation, suppression, breakdown and reformation and maintaining dynamic genetic imbalance over time.

The molecular and evolutionary dynamics of killer–protector systems have been investigated in rice and other species, highlighting their importance in reproductive isolation and breeding strategies (Yang *et al.,* 2012; Xia *et al.,* 2020; Mi *et al.,* 2020).

Meiotic drive

A meiotic driver is a selfish genetic element that manipulates the segregation process to ensure its preferential inclusion in functional gametes of heterozygotes, thereby reducing the transmission of the competing allele. Two ways to be over-represented: gamete killing in males (disruption of alternative sperm) and gonotaxis in females (preferential transmission into the ovule). During spermatogenesis, the driver prevents the formation of functional sperm that do not have a copy of itself. This efficient strategy is referred to as 'interference'.

Biased chromosome segregation

Asymmetry of female meiosis where not all meiotic products become gamete. In females, during meiosis where it produces only one large egg cell and small polar bodies that don't become eggs. Here, one with red have a driver act as a competitor.

Meiotic drivers can act more aggressively during meiosis by sabotaging the ability of competing alleles to complete meiosis. This mechanism is a bit more aggressive. The driver gene (on red chromosome) doesn't just ensure its own smooth ride. It actively interferes with it's competitor. Meiosis 1:- occur normally Meiosis 2: Here's where the, Sabotage happens! the driver gene on the red chromosome disrupts the proper segregation of the competing blue chromosome. It might cause it to break, not sort Correctly.

Post meiotic gamete killing

This is most direct & more aggressive form of meiotic drive. The chromosomes actually segregate(normal). The driver gene then activates a "kill switch". Driver disrupts gametogenesis and destroy developing gametes carrying the competing allele. This means that after the gametes are formed, any gamete that happen to contain the blue chromosome is actively destroyed.

Fate and evolutionary consequences of gene duplication in the context of segregation distortion

Gene duplication represents a fundamental process driving genome evolution and functional diversification. The evolutionary fate of a newly duplicated gene generally follows two major trajectories depending on whether it benefits the host organism. When the duplicated gene confers a host benefit, it may be retained through neofunctionalization, where the duplicate acquires a novel function distinct from the ancestral copy, or through subfunctionalization, in which ancestral functions are partitioned between the two paralogs (Ohno, 1970; Lynch and Conery, 2000). In some cases, the duplicated copy evolves into a driver gene (figure:4 (a)), a selfish genetic element that distorts Mendelian segregation to favor its own transmission, as reported in Drosophila and Neurospora (Larracuente and Presgraves, 2012). Alternatively, if the new copy provides no host advantage, it typically experiences relaxed selection pressure, leading to degenerative mutations and pseudogenization (Zhang, 2003). However, occasionally such a non-beneficial duplicate may evolve selfish properties, initiating conflict between the host genome and the driver element.

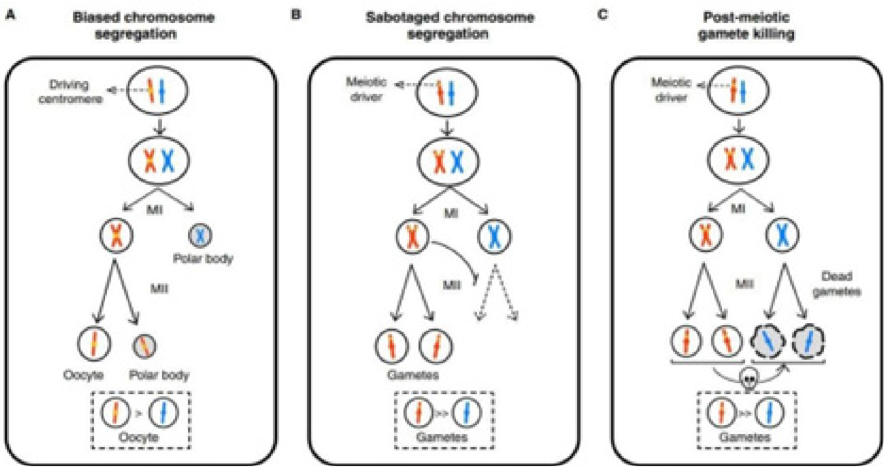
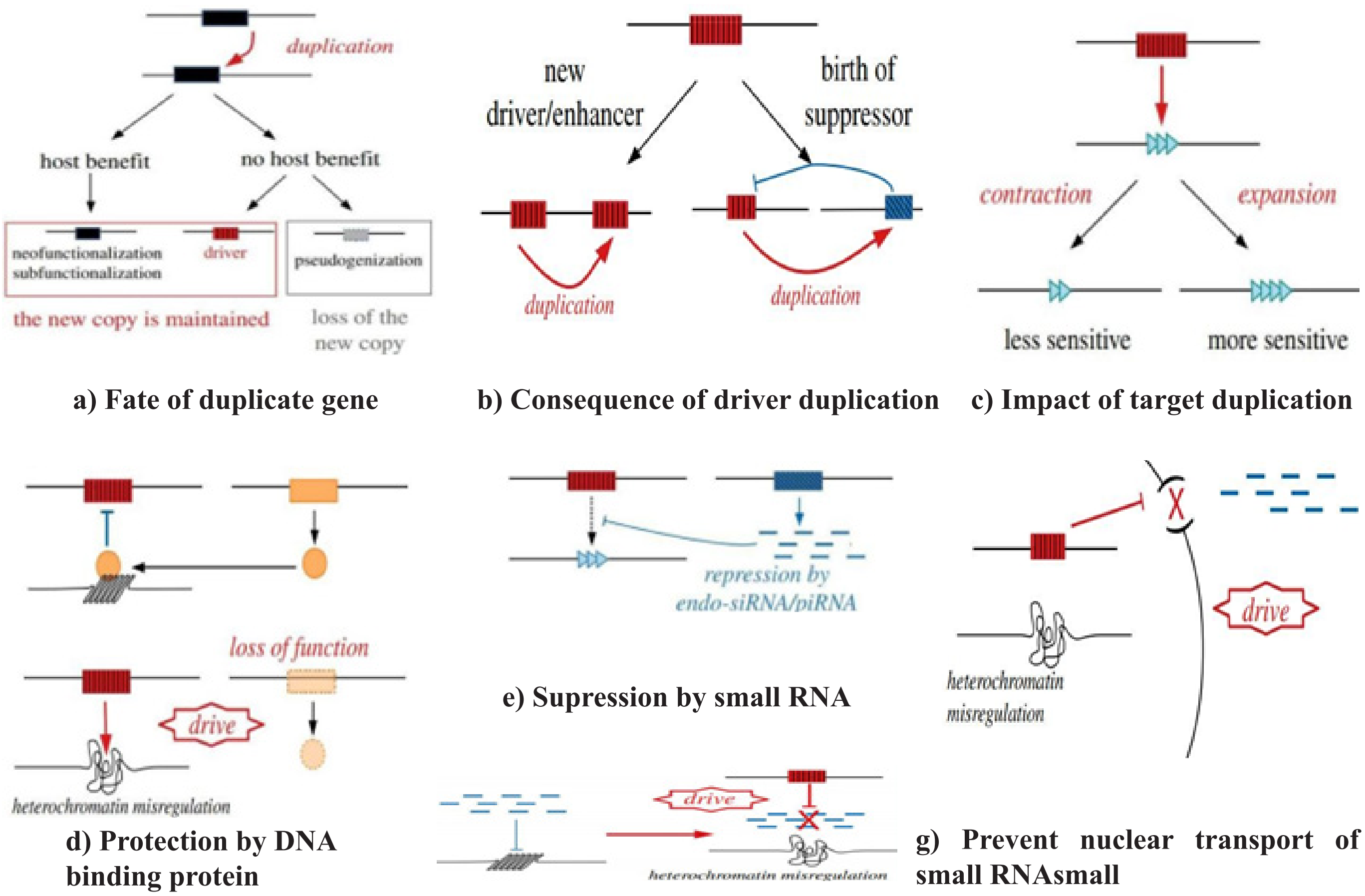


Fig. 3. Schematic representation of meiotic drive mechanisms showing (A) biased chromosome segregation, (B) sabotaged chromosome segregation, and (C) post-meiotic gamete killing, each leading to non-Mendelian allele transmission



a) Fate of duplicate gene

b) Consequence of driver duplication

c) Impact of target duplication

d) Protection by DNA binding protein

e) Supression by small RNA

f) Inhibition of small RNA production

g) Prevent nuclear transport of small RNAsmall

Fig.4. Schematic representation illustrating the evolutionary dynamics of gene duplication and segregation distortion

Consequences of driver duplication

When a duplicated driver element further amplifies itself, its segregation distortion activity can intensify, but excessive drive is often deleterious to host fitness. To counterbalance this, the host evolves suppressor genes that mitigate the driver's effects, restoring fair meiosis. Interestingly, these suppressor genes may themselves arise through secondary duplication events, representing an evolutionary arms race between the driver and its suppressors (Courret *et al.,* 2019; Wedell *et al.,* 2019) (figure: 4(b)).

Impact of target duplication

The interaction between a driver and its target gene can further influence this dynamic. If the target locus becomes less sensitive to the driver's influence, a contraction in driver prevalence occurs. Conversely, target expansion—through duplication or increased susceptibility—can enhance the driver's spread (Helleu *et al.,* 2016). Thus, changes in target gene architecture can shape the persistence or decline of segregation distorters (figure: 4(c)).

Host defense mechanisms

Hosts have evolved multiple defense strategies to protect genomic integrity from driver activity. One mechanism involves DNA-binding proteins (figure: 4(d)) that recognize and bind to driver-associated sequences, preventing access to essential chromosomal regions and blocking the driver's manipulative effects. Another critical mechanism is small RNA-mediated suppression. Host organisms produce endo-siRNAs or piRNAs (figure: 4(e)) that recognize driver transcripts and silence them either transcriptionally or post-transcriptionally (Aravin *et al.,* 2007). However, drivers may counteract this repression by inducing heterochromatin misregulation, (figure: 4(f)) disrupting the host's small RNA biogenesis and creating a self-reinforcing feedback loop that complicates suppression (Chakraborty *et al.,* 2022). In some cases, the driver induces chromatin barriers that impede nuclear transport of small RNAs, preventing them from entering the nucleus where the driver operates (figure:4 (g)). This spatial barrier enables the driver to escape silencing, perpetuating the genomic conflict.

Ab10 chromosomal meiotic drive in maize: The Rhoades Model

The Abnormal chromosome 10 (Ab10) system in maize (Zea mays) represents one of the most well-characterized examples of chromosomal meiotic drive, first described by Rhoades (1952). The Ab10 haplotype carries large heterochromatic regions, known as knobs, composed primarily of Knob180 and TR-1 tandem repeats. A key component of the drive mechanism is a novel kinesin motor protein, encoded by the Kindr gene, which is essential for activating these knob sequences (Dawe *et al.,* 2018). Upon activation, Kindr binds specifically to the Knob180 and TR-1 repeats, converting them into neocentromeres—additional microtubule attachment sites capable of generating poleward movement during meiosis (Yu *et al.,* 1997; Swentowsky *et al.,* 2020). During anaphase I of meiosis, the Ab10 chromosome exhibits enhanced traction as it is pulled towards the pole by both its primary centromere and the neocentromeric knobs. In contrast, the normal chromosome 10 (N10) lacks these activated knob regions and thus experiences weaker spindle attachment (Hiatt and Dawe, 2003). This differential movement leads to biased segregation, where the Ab10 chromosome is preferentially transmitted to more than 50 per cent of gametes, violating Mendelian expectations. In asymmetric female meiosis, this bias is particularly evident, as the Ab10-bearing chromatid is more frequently incorporated into the functional egg cell rather than the polar bodies, resulting in unequal gamete distribution. Collectively, the Rhoades model demonstrates how structural and molecular innovations—specifically neocentromere formation driven by the Kindr kinesin—allow Ab10 to manipulate the meiotic process for its own transmission advantage (Rhoades, 1952; Dawe *et al.,* 2018; Swentowsky *et al.,* 2020).

Chromosomal abnormalities and their role in segregation distortion

Chromosomal abnormalities represent key structural or numerical alterations that can significantly affect meiotic behavior and genetic transmission. Deletions involve the loss of a chromosomal segment, often including the centromere, which results in the formation of acentric fragments that fail to attach to spindle fibers and are subsequently lost during meiosis (Griffiths *et al.,* 2000; Brown, 2002). In contrast, duplications lead to the doubling of a chromosomal segment, increasing gene dosage and sometimes generating driver loci capable of distorting normal segregation patterns during gametogenesis (Larracuente and Presgraves, 2012). Inversions, which occur when a chromosomal segment is excised and reinserted in the reverse orientation, can interfere with recombination; the resulting acentric and dicentric fragments often fail to segregate properly, leading to gametic loss or sterility (Kirkpatrick, 2010).

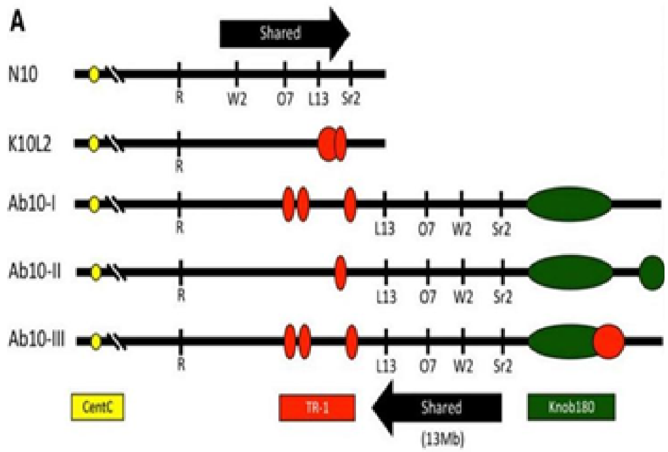


Fig. 5(A). The abnormal chromosome 10 (Ab10)

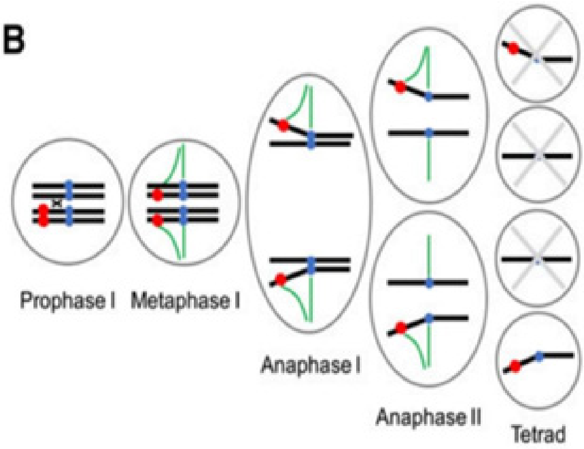
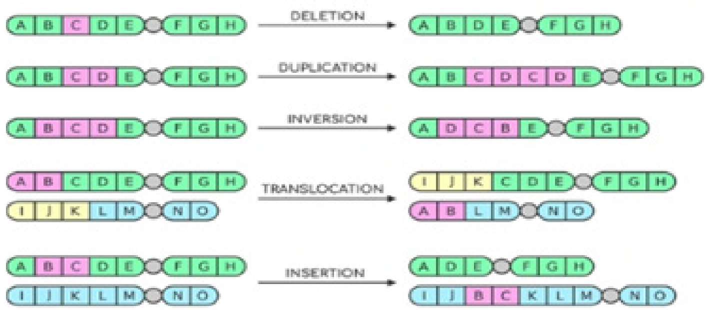


Fig. 5(B). The Rhoades model of neocentromere



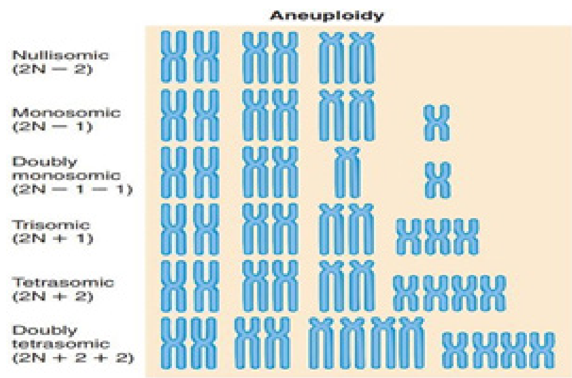


Fig. 6. Chromosome abnormalities

Translocations, involving the relocation of chromosomal segments or entire gene blocks to new positions within the genome, disrupt normal pairing and segregation during meiosis and can consequently influence fertility and segregation ratios (Kumari and Kumar, 2015). Numerical chromosomal changes, including aneuploidy, arise from errors in chromosome segregation, such as nondisjunction, leading to the gain or loss of specific chromosomes.

Such irregularities can result in gametes with unbalanced chromosome numbers—trisomic or monosomic—which, when involved in fertilization, produce offspring with abnormal karyotypes. These numerical anomalies disturb normal Mendelian segregation and contribute to segregation distortion or meiotic drive phenomena, where certain alleles or chromosomes are preferentially transmitted to the next generation (Pardo-Manuel de Villena and Sapienza, 2001; Fishman and Saunders, 2008). Thus, both structural and numerical chromosomal abnormalities play a significant role in shaping genome evolution and reproductive outcomes through their effects on meiotic segregation.

Gametic selection: The t-Haplotype and meiotic drive in mice

The t-haplotype in Mus musculus represents one of the most well-studied examples of a naturally occurring meiotic drive system. It is a large chromosomal region, approximately 40 megabases in length, located on chromosome 17, and encompasses a set of tightly linked genes that collectively promote biased transmission of the t allele (Amaral and Herrmann, 2021). Male mice heterozygous for the t-haplotype (T/t) normally would transmit either the wild-type (T) or t allele to their offspring in equal proportions. However, due to the action of this meiotic drive system, the t allele is transmitted to more than 50% of progeny, demonstrating a clear deviation from Mendelian segregation (Herrmann *et al.,* 1999; Lyon, 2003). The t-haplotype contains multiple genes classified as distorters and a single responder, which function together to manipulate sperm motility.

The distorter genes—such as Tagap, Fgd2, Nme3, and Tiam2—disrupt the normal regulation of the SMOK (Sperm Motility Kinase) protein, a critical component in controlling the directional motility of sperm flagella (Bauer *et al.,* 2012; Herrmann and Bauer, 2012). This disruption impairs the motility of sperm carrying the wild-type T allele, effectively crippling their ability to swim towards the egg. In contrast, sperm carrying the t-haplotype remain functional because of the t-responder (SmokTcr), which compensates for the distorter-induced defects and restores proper motility (Herrmann *et al.,* 1999; Amaral and Herrmann, 2021). This intricate interaction between distorters and the responder within the t-haplotype creates a "selfish" genetic element that biases sperm function and inheritance in its favor, ensuring that t-bearing sperm are more likely to fertilize the egg. Consequently, this mechanism exemplifies how genetic conflicts within the genome can drive evolutionary processes by promoting non-Mendelian inheritance patterns.

Pollen competition and zygotic selection

Pollen competition and zygotic selection represent key post-meiotic mechanisms contributing to segregation distortion in plants. Unilateral incompatibility often requirements of pollen tube growth frequently exceed the pollen's intrinsic reserves. Furthermore, successful fertilization depends on species-specific signaling between the pollen and the ovule, highlighting the intricate molecular communication underlying reproductive compatibility and selection. Zygotic selection, on the other hand, occurs through the nonrandom loss of diploid zygotes after fertilization. This process can take place during various stages of development, including embryo or seed maturation within the maternal tissue, early germination, or during later juvenile stages (Fishman *et al.,* 2019). Maternal plants that mature only a subset of fertilized eggs can selectively replace less viable zygotes with those carrying more adaptive genotypes, promoting offspring fitness. Two major factors contributing to zygotic selection include environmental selection, where specific germination or growth conditions favor one parental genotype, and inbreeding depression, which promotes segregation distortion at single loci through the expression of lethal or deleterious recessive alleles in homozygous individuals. Collectively, these mechanisms demonstrate how post-fertilization processes can shape genetic transmission patterns and influence evolutionary outcomes in plant populations.

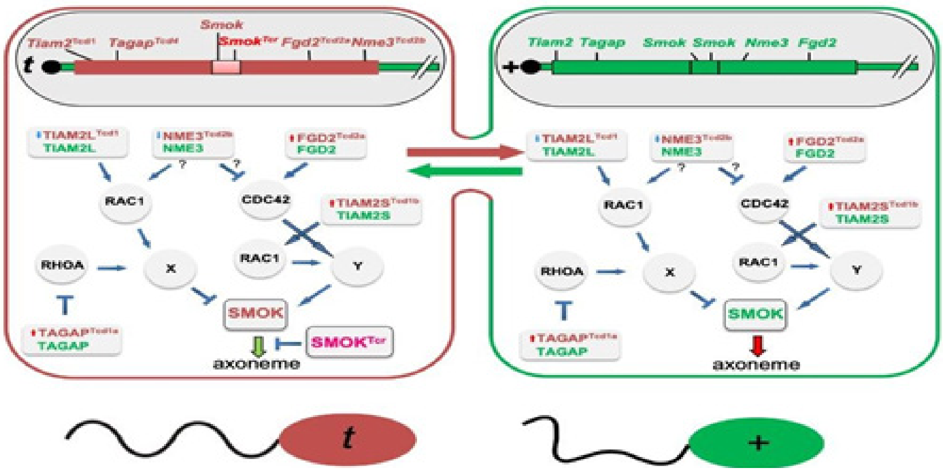


Fig. 7. t-haplotype meiotic drive mechanism

leads to the stylar rejection of pollen grains carrying incompatible or mismatched genotypes, thereby generating pollen-specific, style-dependent segregation distortion (SD) (Fishman *et al.,* 2019). Pollen tube performance and successful fertilization are highly influenced by interactions between the male gametophyte and female reproductive tissues, as the energetic

Implications of segregation distortion in crop breeding

Segregation distortion (SD) poses significant challenges and opportunities in modern crop breeding programs by influencing the predictable transmission of alleles. Since SD results in the non-Mendelian inheritance of certain alleles, it complicates the prediction of offspring genotypes and the selection of desirable traits, as alleles may be passed on at frequencies deviating from the expected 1:1 ratio (Liu *et al.,* 2010; Xu, 2008). This distortion directly affects marker-assisted selection (MAS), where molecular markers are used to track genes or quantitative trait loci (QTLs). Skewed allele transmission can weaken or misrepresent marker–trait associations, leading to unreliable identification of genomic regions controlling agronomically important traits (Tao *et al.,* 2002). In genetic mapping, the presence of SD interferes with the accuracy of linkage analysis by distorting recombination frequency estimates, there by reducing the precision of QTL mapping and fine-mapping efforts (Xu, 2008). Moreover, if the distorted segregation pattern disproportionately favors undesirable alleles, breeding efficiency declines, increasing the time and resources required to achieve breeding objectives such as enhanced yield, stress tolerance, or disease resistance. Despite these challenges, segregation distortion also offers valuable biological insights into the mechanisms of gametic selection, meiotic drive, and reproductive incompatibility—processes that, once understood, can be exploited to manipulate genetic inheritance and improve breeding outcomes (Fishman and Saunders, 2008; McDermott and Noor, 2010).

Furthermore, SD influences gene flow and population structure by altering allele frequencies among breeding lines or populations, potentially reducing genetic diversity or causing unintended introgression effects in hybrid programs (Lu *et al.,* 2002). Therefore, recognizing and managing segregation distortion is essential for breeders to refine selection strategies, maintain genetic balance, and better utilize the full genetic potential of crop germplasm.

Approaches for the Analysis of segregation distortion

Segregation distortion (SD) refers to the deviation of observed genotypic ratios from the expected Mendelian inheritance patterns. To understand and quantify this deviation, several statistical and computational methods have been developed, ranging from classical hypothesis-testing procedures to advanced probabilistic and mixed-model approaches (Xu, 2008). The Chi-square test is the most widely used and straightforward statistical method for detecting segregation distortion. It evaluates whether the observed frequencies of alleles or genotypes conform to the expected Mendelian ratios. Under the null hypothesis (H_0), segregation follows Mendelian expectations, while under the alternative hypothesis (H_1), significant deviation occurs. The Chi-square statistic is computed and compared to the critical value (3.84 at $p = 0.05$, $df = 1$). If the calculated value exceeds this threshold, the null hypothesis is rejected, indicating significant segregation distortion in the analyzed population. The Likelihood Ratio Test (LRT) provides a more powerful and flexible alternative to the Chi-square approach, particularly when dealing with small sample sizes or complex inheritance patterns. It compares the likelihood of the observed data under both null and alternative hypotheses to determine the presence of distortion. The test statistic follows a Chi-square distribution, and a significant result suggests deviation from Mendelian segregation (Li *et al.,* 2007).

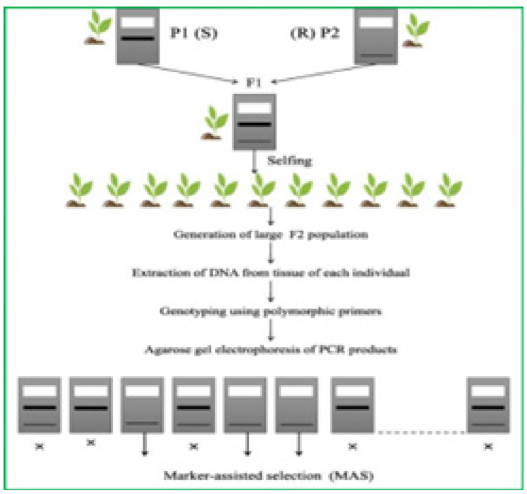


Fig. 8. Marker assisted selection(MAS)

The LRT is especially useful in mapping populations where segregation distortion may vary among loci or chromosomes.

The Bayesian segregation ratio analysis extends traditional inference by incorporating prior information with observed data to estimate posterior probabilities of segregation ratios. This approach uses Bayes' theorem to update prior expectations—typically the Mendelian 3:1 or 1:2:1 ratios—based on observed genotype frequencies. If the posterior probability strongly supports a non-Mendelian ratio, it indicates segregation distortion. Bayesian approaches are advantageous in accounting for uncertainty, small sample sizes, and incomplete datasets (Wang *et al.,* 2019).

Beyond these classical tests, advanced statistical frameworks such as the Expectation–Maximization (EM) algorithm and Generalized Linear Mixed Models (GLMMs) are applied to improve parameter estimation under complex segregation patterns. The EM algorithm iteratively estimates missing or hidden genotypic data, providing more accurate detection of distortion, while GLMMs allow the incorporation of random effects and complex experimental designs (Xu 2008). Quantitative Trait Locus (QTL) mapping is another key analytical approach, used to locate chromosomal regions associated with segregation distortion or traits influenced by distorted loci. QTL mapping involves the selection of an appropriate mapping population, measurement of target traits, genotyping using molecular markers, and statistical association analysis between marker loci and trait variation. This approach helps identify genomic regions showing distortion and their potential impact on quantitative traits (Zhao *et al.,* 2013; Li *et al.,* 2007). A variety of bioinformatics tools and software packages have been developed to facilitate segregation distortion and QTL analysis. Widely used programs include JoinMap, MapQTL, MSTMap, R/qtl, TASSEL, PLINK, PolymapR, GATK, and the CIMMYT Fieldbook. These platforms support data visualization, statistical testing, and marker-trait association studies, offering integrated workflows for segregation and linkage analysis (Van Ooijen, 2011). Together, these statistical, Bayesian, and computational frameworks provide a comprehensive foundation for studying segregation distortion and its genetic consequences in plant breeding and genomics.

A phenomenon known as segregation distortion (SD) refers to the unequal inheritance of alleles during the formation of gametes or the development of zygotes which is commonly observed in segregating populations, including F_2 generations, backcrosses, and recombinant inbred lines (RILs). At the molecular level, the S1TPR locus demonstrates dual roles as both a segregation distorter and protector, a mechanism distinct from conventional killer–protector systems. The S1TPR gene rescues S1-g gametes while selectively eliminating S1-s gametes lacking the protective allele, thereby ensuring biased transmission in favor of the functional allele. In practical breeding applications, incorporating distorted markers has proven beneficial for improving linkage map accuracy and genome coverage. These markers facilitate better grouping of loci within chromosomes and enhance consistency between linkage and physical maps (Xu, 2008). Understanding and accounting for SD in quantitative trait locus (QTL) mapping and marker-assisted selection (MAS) can thus prevent the loss of desirable alleles and improve breeding precision. Ultimately, the success of modern crop breeding programs depends on a thorough understanding of segregation distortion mechanisms. By identifying and managing segregation distortion loci (SDLs), breeders can optimize parent selection, minimize transmission bias, and achieve greater control over the inheritance of favorable traits. This knowledge provides an invaluable foundation for advancing crop genetic improvement and ensuring sustainable breeding outcomes.

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