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ID : RA0526

Rooftop rainwater harvesting as a water conservation strategy for sustainable agriculture in the semi-arid region of North Gujarat: A case study at the Dry Farming Research Station

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ABSTRACT

Water scarcity and erratic rainfall are major challenges to sustainable crop production in the semi-arid region of North Gujarat. The present study evaluated the potential of rooftop rainwater harvesting as a water conservation strategy at the Dry Farming Research Station, Radhanpur. Rainwater from a 1000 m² reinforced cement concrete rooftop was collected through a pipe network and stored in a farm pond with a capacity of 15.60 lakh litres. Based on annual rainfall of 527.7 mm in 2024 and 736.8 mm in 2025, the estimated harvestable runoff was 474.93 m³ (4,74,930 L) and 663.12 m³ (6,63,120 L), respectively. The stored water was utilized through an automated drip irrigation system to provide supplemental irrigation during critical crop growth stages, thereby reducing moisture stress and improving water-use efficiency. The study demonstrated that rooftop rainwater harvesting is a simple, cost-effective and sustainable approach for enhancing water availability, reducing dependence on groundwater and improving agricultural resilience in semi-arid regions. Technology has significant potential for wider adoption in water-scarce areas of North Gujarat and similar agro-climatic regions.

Keywords: Rooftop rainwater harvesting, rainfed agriculture, farm pond, water conservation

INTRODUCTION

India ranks first in rainfed agriculture globally in both area (86 M ha) and the value of produce. Rainfed regions in India contribute substantially toward food grain production including 44% of rice, 87% of coarse cereals (sorghum bicolor), pearl millet (*Pennisetum glaucum*), maize (*Zea mays*) and 85% of food legumes, 72% of oilseeds, 65% of cotton and 90% of minor millets. Overall, the rainfed areas produce 40% of the food grains, support two-thirds of the livestock population and are critical to food security, equity and sustainability (Venkateswarlu *et al.*, 2015). In India, about 75–80% of annual rainfall is received through the southwest monsoon during June to September and Gujarat region receives maximum rainfall i.e. 96% of its annual rainfall in southwest monsoon (Indian meteorological department, 2022). The distribution of rainfall is highly variable both spatially and temporally which creating challenges for sustainable crop production particularly in dryland regions.

Gujarat state is in the western part of India and comprises diverse agro-climatic zones but predominantly falls under semi-arid to arid regions. Particularly, North Gujarat experiences low and erratic rainfall (400–800 mm) with

uneven distribution. In addition, high evapotranspiration, declining groundwater levels and salinity problems are major issues in crop production in this region. Crop production in such environments is largely dependent on stored soil moisture and limited irrigation resources. Frequent dry spells during crop growth stages cause moisture stress, resulting in reduced yield and instability in production. Therefore, efficient management and conservation of available water resources are essential for sustaining agricultural production in these regions.

Rooftop rainwater harvesting refers to the collection of rainwater from rooftops for future utilization. It reduces dependency on groundwater resources and provides an additional source of water for irrigation, domestic purposes, livestock and groundwater recharge. Rooftop rainwater harvesting has gained importance due to its simplicity, low operational cost and high runoff collection efficiency. In this system, rainfall received on rooftop surfaces is collected through drainage networks and stored in suitable structures such as farm ponds, tanks or recharge systems. The stored water can subsequently be used for supplemental irrigation during critical crop growth stages when rainfall is insufficient.

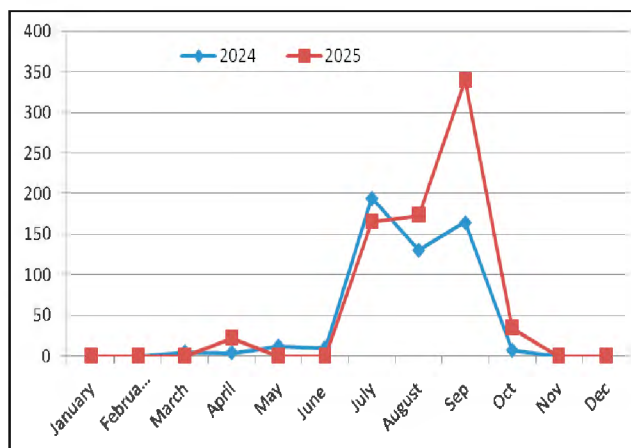
Gujarat has considerable potential for rooftop rainwater

harvesting due to its climatic conditions and seasonal rainfall pattern. Such systems can contribute significantly to water conservation, particularly in arid and semi-arid areas where rainfall occurs mainly during a short monsoon period. Patan district where the study location is situated, receives substantial monsoon rainfall, indicating considerable scope for harvesting and utilizing rainwater for agricultural purposes.

MATERIALS AND METHODS

Study area and rainfall

The study was conducted at Dry Farming Research Station, Sardarkrushinagar Dantiwada Agricultural University, Radhanpur, which represents the arid to semi-arid region of North Gujarat. The area receives low and erratic rainfall (300–700 mm annually) with high evapotranspiration, light-textured soils and frequent moisture stress conditions. An automatic weather station has been installed at the centre and the daily rainfall data are recorded and utilized for analysis purposes and shown in Graph 1.



During year 2024, the station received a total rainfall of 527.7 mm, whereas during year 2025, the annual rainfall was 736.8 mm. The rainfall distribution showed a strong concentration during the southwest monsoon period, particularly from July to September. The uneven distribution of rainfall resulted in inadequate moisture availability during crop growth periods highlighting the importance of efficient rainwater harvesting and storage systems (Anonymous, 2026).

The rainfall data have been presented graphically to visualize seasonal trends and distribution patterns and its variability emphasizes the need for effective rainwater harvesting and storage systems for sustainable crop production. The major crops cultivated at the station include blackgram, greengram, sorghum and mothbean during the

kharif season while cumin, dill seed and chickpea are cultivated during the *rabi* season. These crops generally require approximately 250–400 mm water during their crop growth period. Since rainfall does not always coincide with crop water demand, supplemental irrigation becomes essential for achieving stable productivity.

Rooftop rainwater harvesting system design

The rooftop rainwater harvesting system is divided into three primary components: catchment, conveyance and storage structures.

1. Catchment

The office building of DFRS serves as the catchment area for the rooftop rainwater harvesting system. The building has an approximate rooftop area of 1000 m², including the main terrace and adjoining paved surfaces. The terrace is constructed of reinforced cement concrete (RCC) with a sloping design that facilitates efficient runoff collection. This slope ensures that rainwater flows naturally toward designated collection points, minimizing water stagnation and losses. Thus, the entire rooftop catchment area effectively contributes to the collection and channelling of rainwater into the harvesting system.



2. Conveyance (Pipe System)

Rainwater collected from the rooftop is conveyed to the storage structure through a well-designed network of downpipes. The system consisted of Downpipes of 110 mm diameter and Main conveyance pipeline of 140 mm diameter. The pipe network was installed with an appropriate slope to facilitate gravity flow and minimize water losses during transportation. Collection points were connected to the main conveyance pipeline, which transported harvested runoff directly to the farm pond. The pipeline system included covered ventilation openings to maintain smooth water flow and prevent interruption caused by air locking.



3. Storage structure (Farm pond)

The harvested rooftop runoff was stored in a farm pond constructed near the office building. The farm pond dimensions were:

Bottom size: 42 m × 14.5 m

Upper surface size: 46 m × 17.5 m

Depth: approximately 3–4 m

The pond had a gradual slope, with a depth of about 3 m at the inlet side and increasing to approximately 4 m toward the outlet side. This design improved sediment deposition, storage efficiency, and water retention capacity. The total storage capacity of the farm pond was 15.60 lakh litres. The stored water was later utilized for supplemental irrigation through an automated drip irrigation system.



Estimation of rainwater harvesting potential

The potential quantity of harvested rainwater was estimated using rooftop catchment area, annual rainfall, and runoff coefficient.

The standard equation used was:

$$R = A \times P \times C$$

Where,

R = Annual runoff (m³)

A = Catchment area (m²)

P = Annual rainfall (m)

C = Runoff coefficient

A runoff coefficient of 0.90 was considered for RCC rooftop surfaces due to their high runoff efficiency and minimal infiltration losses (Biswas and Mandal, 2014).

RESULTS AND DISCUSSION

Rainfall Variability and Crop Water Requirement

The rainfall pattern at Dry Farming Research Station, Radhanpur showed considerable year-to-year variability. During 2024–25, the station received only 527.7 mm rainfall, whereas rainfall during 2025–26 increased to 736.8 mm. The rainfall was mainly concentrated during the monsoon months (July–September) and resulting in uneven availability of water throughout the crop growing season.

The major crops grown at DFRS include blackgram, greengram, sorghum and mothbean during *kharif* season and cumin, dill seed and chickpea during *rabi* season. These crops require approximately 250–400 mm water during their growth period. Under dry farming conditions, rainfall alone is often inadequate to meet crop evapotranspiration demand, particularly during prolonged dry spells. Therefore, supplemental irrigation from harvested rainwater plays an important role in sustaining crop growth and improving production stability.

Rooftop Rainwater Harvesting Potential

The rooftop rainwater harvesting system effectively collected runoff from the 1000 m² rooftop catchment area. Based on an annual rainfall of 527.7 mm and 736.8 mm during the year 2024 and 2025, respectively and a runoff coefficient of 0.90 the estimated annual harvestable runoff was:

For year 2024,

$$R = 1000 \text{ m}^2 \times 0.5277 \text{ m} \times 0.90 = 474.93 \text{ m}^3 \\ = 4,74,930 \text{ litre water}$$

For year 2025,

$$R = 1000 \text{ m}^2 \times 0.7368 \text{ m} \times 0.90 = 663.12 \text{ m}^3 \\ = 6,63,120 \text{ litre water}$$

The designed farm pond capacity of 15.60 lakh litres was higher than the estimated annual rooftop runoff volume. This additional storage capacity provides flexibility for storing runoff from future expansion of catchment areas and possible integration with field runoff harvesting systems. The combination of rooftop collection and farm pond storage ensured conservation of rainfall that would otherwise be lost as surface runoff.

Utilization of Harvested Water for Crop Production

The harvested rainwater provided supplemental irrigation during critical crop growth stages when rainfall was inadequate, thereby reducing moisture stress in *kharif*

season crop. The stored water was subsequently used for supplemental irrigation of *rabi* crops, particularly cumin and dill seed through an automated drip irrigation system. Drip irrigation ensured efficient application of stored water directly to the crop root zone, reducing evaporation losses and improving water-use efficiency. The harvested water reduced crop moisture stress, improved crop establishment, promoted better growth and development, and enhanced production stability under dry farming conditions. The system transformed the production environment from a completely rain-dependent system to a partially irrigated system thereby improving resilience to rainfall variability.

Role of Rooftop Rainwater Harvesting in Semi-Arid Agriculture

The results demonstrate that rooftop rainwater harvesting is a practical water conservation strategy for semi-arid regions. Unlike conventional irrigation sources, harvested rainwater provides locally available water without additional energy requirements for extraction. Integration of rainwater harvesting with efficient irrigation systems such as drip irrigation can significantly improve water productivity. Similar findings have been reported by Biswas and Mandal (2014), who highlighted the effectiveness of rainwater harvesting systems for improving water availability in water-scarce regions. The approach is particularly relevant for North Gujarat, where groundwater depletion, salinity problems and rainfall uncertainty limit agricultural sustainability.

CONCLUSION

The study demonstrated that rooftop rainwater harvesting is an effective and sustainable water conservation strategy for

the semi-arid region of North Gujarat. The system successfully harvested 4.75–6.63 lakh litres of rainwater annually from a 1000 m² rooftop catchment, providing a reliable source of supplemental irrigation during critical crop growth stages. Integration of harvested rainwater storage with drip irrigation improved water-use efficiency, reduced dependence on groundwater and enhanced crop resilience under variable rainfall conditions. The findings indicate that rooftop rainwater harvesting coupled with farm pond storage can contribute significantly to sustainable water resource management and agricultural productivity in dryland regions. Adoption of this technology at research farms and by farming communities can strengthen climate resilience and support sustainable agriculture in water-scarce areas.

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ID : RA1026

Studies on key bioactive compounds in volatile and fixed oil of cardamom (*Elettaria cardamomum* L.)

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ABSTRACT

Experiment was conducted in Cardamom (*Elettaria cardamomum* L.) with extraction of the volatile and fixed oil to analysing the major bioactive compounds and fatty acids detection. The major whole dry green pod like structures called as capsule and is used as flavouring in Tea and many foods preparation and pan masala too. It is also known as “Elaichi”. By using the rotary evaporator apparatus 2% oils were extracted. These oils were utilized after the making FAME and injected in autosampler of GC MS for detection of compounds with untargeted approaches and compared with RT and score of NIST library. The experimental results shown the 54 compounds identified in cardamom oils out of them 51 were unique. More than 60% area were detected in the analysis of volatile compounds of Cardamom viz., Eucalyptol (25.79%), 3-Cyclohexene-1-methanol, α ,4-trimethyl-, acetate (37.05%). Thirteen compounds were in the range of 1 to 5% and 39 compounds were detected in the range of 0.02 to 0.92% in volatile oils of cardamom. In Fatty acids profiling showed 18 fatty acids including SFA (Saturated Fatty acids) 7.17%, MUFA (Monounsaturated Fatty acids) 69.71%, PUFA (Poly Unsaturated Fatty acids) 23.12%, MUFA/PUFA ratio showed 3.015% and UnsFA/SFA (Unsaturated Fatty acids/SFA) ratio indicated 12.95% area in Cardamom

Keywords : Cardamom, GC MS, fixed oil, volatile oil

INTRODUCTION

Elettaria cardamomum (L.) Maton, also known as Indian cardamom, green cardamom botanically is a herbaceous perennial plant belonging to *Zingiberaceae* family also reported as “Queen of spices”. The essential oil of cardamom capsules is a high-value ingredient in foods, beverages, perfumery and traditional medicines. It is responsible for the characteristic aroma of cardamom and variability in volatile contents of this capsule (Ashokkumar *et al.* 2021) As the scientist already know that phytochemicals and bioactive compounds in medicinal plants significantly benefit human health as Cardamom essential oil exhibits potential as a broad-spectrum antimicrobial and anticancer agent and proven test with cardamom essential oils and identify the inhibition zone. *Staphylococcus aureus* (ATCC 6538) and *Bacillus cereus* (ATCC6629) are two examples of Gram-positive bacteria against which the essential oil such as *Pseudomonas aeruginosa* (ATCC 27853), *Escherichia coli* (ATCC25922), and yeast *Candida albicans* were also evaluated for antimicrobial activity. (Tahani *et al.* 2024). Despites of

these facts, the literature cited is vary scares, In recent era of Artificial intelligence and the advancement of scientific instruments. It must be redefining the value of bioactive compounds. Uses are numerous in food flavour, though it is a very popular ingredients for Arab and Asian countries for pan masala from centuries ago (Teresa-Martinez *et al.* 2025). Some had a belief of aphrosaidic in nature and causing internal heat. Therefore, it is used as “first night” milk or juice or pan masala ingredients in many Indians family's tradition too.

Real *et al.* (2015) determine the presence of hormone-like activities dependent on the activation of human estrogen receptor alpha (hER) and/or androgen receptor (hAR) in methanol extracts prepared and the analysis of the nutritional and therapeutic properties of fatty acids derived from *Elettaria cardamomum* reveals significant potential for both health benefits and culinary applications. Research indicates that extracts from cardamom seeds exhibit estrogenic and androgenic activities, suggesting their capability to influence hormonal function, which could be particularly relevant in addressing hormone-related health concerns. It has many roles in Hinduism pujasthal and

“shreelaxmi- poojan” (Worshipping goddess of money) too. To knowing these facts and rumour researcher has keen interest in chemotypes or chemical profiling of Elachi or cardamom seeds inside the capsules. Though the black or brown seeds inside have variability in size and structure. The experiment was laid out with the phytochemical evaluation through GC MS extracts in both volatile and fixed oils through study of fatty acids profiling in *Elettaria cardamomum* (L.) Maton, It has more uses especially relevance due to their implications in both culinary and medicinal contexts. Cardamom, a spice cherished for its aromatic properties, possesses a distinct biochemical composition that contributes not only to its flavor but also to its health-promoting attributes (Masoumi-Ardakaniet *al.*, 2016; Alam *et al.*, 2019, Bhutia *et al.*, 2022; Vijayan *et al.*, 2017; Ashokkumar *et al.*, 2021; Noumi *et al.*, 2018 and Tan *et al.*, 2023). Understanding the fatty acid profile of this plant can elucidate mechanisms responsible for various health benefits, such as anti-inflammatory and antioxidant effects. Furthermore, the identification and quantification of different fatty acids can aid in the assessment of cardamoms nutritional value and potential applications in food science and pharmacology. By examining the lipid composition of *Elettaria cardamomum*, this research aims to bridge the gap between traditional usage and contemporary scientific insights, thereby enriching the existing body of knowledge surrounding this valuable crop and fostering greater appreciation for its multifaceted roles.

MATERIAL AND METHODS

Extraction: Methanolic extracts of powdered form of *Elettaria cardamomum* seeds were used. The Soxhlet oil extracted 2 % oils in dry weight basis. It was used for the FAME making and same was injected in autosampler. Protocol developed at FTL (Food testing laboratory JAU) Junagadh. The fatty acids were analysed by Rathod *et al.* (2025).

Instruments programme and conditions: The GC–MS system consisted of a Shimadzu QP2010S mass spectrometer with an autosampler (Shimadzu, Kyoto, Japan). The column temperature was programmed as follows: 60 °C, hold for 0 min, ramp at 150 °C/2min to 240 °C, hold for 5 min. Column Oven Temp. :60.0 °C, Injection Temp.: 250.00 °C, Injection Mode: Split, Flow Control Mode: Pressure, Pressure: 57.4 kPa, Total Flow: 54.0 mL/min, Column Flow: 1.00 mL/min, Linear Velocity: 36.5 cm/sec. Purge Flow: 3.0 mL/min, Split Ratio: 50.0; High Pressure Injection, Carrier Gas Saver, Splitter Hold: OFF for GCMS-QP2010 Plus.; Ion Source Temp: 230.00 °C, Interface Temp.: 240.00 °C, Solvent Cut Time: 2.00 min,

Detector Gain Mode: Relative, Detector Gain: +0.00 kV, Threshold: 1000 for MS table; Start Time: 2.30 min End Time: 31.50 min, ACQ Mode: Scan, Event Time: 0.50 sec, Scan Speed: 2000, Start m/z: 50.00, End m/z: 1000.00.

RESULTS AND DISCUSSION

Fatty acids profiling: The fatty acid profile of *Elettaria cardamomum* known as cardamom or Elachi oil was esterified and make FAME Ester used in autosampler for GCMS analysis (Table.1). The chromatogram is presented in fig.1 The diverse range of class fatty acids presence was found to be saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA). (Table.1). The Results of analysis shown 18 fatty acids in cardamom, with six number of Saturated Fatty Acids (SFA) and 10 were found as Monounsaturated Fatty Acids (MUFA) with total area of 69.71% while Two fatty acids of Polyunsaturated Fatty Acids (PUFA) with total area of 23.12%. The data shown Maximum amounts of Mono unsaturated fatty acids in *Elettaria cardamomum*, which constitutes higher amounts that was 69.71% of the total fatty acid content as compared to PUFA and SFA. In case of key Bioactive compounds in Elachi showed Hexa decanoic acid (Palmitic acid): as 23.08% fatty acid. The 8-Octadecenoic acid (oleic acids) was detected as highest area (42.48%) and the second most percent area (16.85%) was detected as 9,12-Octadecadienoic acid (Linoleic acid). The findings in line with Ramadan *et al.* (2022) studied on fixed oil, and cold pressed cardamom oil (CPCO) and they found Oleic (C18:1, 43.7%), palmitic (C16:0, 21.6%) and linoleic (C18:2, 17.6%) were the major fatty acids in CPCO. The levels of monounsaturated fatty acids (MUFA), saturated fatty acids (SFA), and polyunsaturated fatty acids (PUFA) were 47%, 32%, and 21%, respectively. Similarly, the calculation through ratio of MUFA/PUFA was suggested as 3.02 This indicated the higher presence of monounsaturated fats compared to polyunsaturated fats. There are many references said that MUFA protect the hearts of human being against cardiovascular diseases. They analysed of FAs via GC-MS revealed the presence of 8 fatty acids., The predominant fatty acids identified include oleic acid (42.75%) and palmitic acid (21.20%), polyunsaturated fatty acids (PUFAs) α -Linoleic acid (10.67%) and α -Linolenic acid (2.9%). They also determined the temperature sensitivity on fatty acids composition of Cardamom (*Elettaria cardamomum*). In case of Unsaturated Fatty Acids/SFA Ratio was found to be 12.95 which was indicated that higher unsaturated then the saturated fatty acids, this indicator also suggest the dietary healthier oils of cardamum.

Table.1 Fatty acids profiling of *Elettaria cardamomum* (L.) Maton

Peak#	R.Time	Area%	Name	Chemical Formula	Carbon No	Class
1	6.902	0.06	Nonanoic acid	C ₉ H ₁₈ O ₂	9	SFA
2	8.056	0.1	METHYL DECANOATE	C ₁₁ H ₂₂ O ₂	14	SFA
3	8.419	0.06	4-Decenoic acid	C ₁₀ H ₁₈ O ₂	10	MUFA
4	10.904	0.4	Dodecanoic acid	C ₁₂ H ₂₄ O ₂	12	SFA
5	11.177	0.08	6-Nonenoic acid	C ₉ H ₁₆ O ₂	9	MUFA
6	14.312	0.65	Methyl tetradecanoate	C ₁₅ H ₃₀ O ₂	15	SFA
7	15.812	0.25	Decanal dimethyl acetal	C ₁₂ H ₂₄ O ₂	12	SFA
8	16.123	0.4	Pentadecanoic acid	C ₁₅ H ₃₀ O ₂	15	SFA
9	16.461	0.15	Nonanedioic acid	C ₉ H ₁₆ O ₄	9	SFA
10	17.985	23.08	Hexadecanoic acid	C ₁₆ H ₃₂ O ₂	18	SFA
11	18.429	2.08	9-Hexadecenoic acid	C ₁₆ H ₃₀ O ₂	18	MUFA
12	19.784	0.48	Hexadecanoic acid	C ₁₆ H ₃₂ O ₂	18	SFA
13	21.591	3.71	Octadecanoic acid	C ₁₈ H ₃₆ O ₂	18	SFA
14	21.961	42.48	8-Octadecenoic acid	C ₁₈ H ₃₄ O ₂	18	MUFA
15	22.729	16.85	9,12-Octadecadienoic acid	C ₁₈ H ₃₂ O ₂	18	PUFA
16	23.822	6.27	9,12,15-Octadecatrienoic acid	C ₁₈ H ₃₀ O ₂	18	PUFA
17	25.012	1.27	Eicosanoic acid	C ₂₀ H ₄₀ O ₂	20	SFA
18	28.482	1.63	Docosanoic acid	C ₂₂ H ₄₄ O ₂	22	SFA
Total		99.78				
Name of class				% Area	No. of Fatty acids	
SFA (Saturated Fatty acids)				7.17	6	
MUFA (Mono Unsaturated Fatty acids)				69.71	10	
PUFA(Poly Unsaturated Fatty acids)				23.12	2	
MUFA/PUFA				3.015		
UnsFA/SFA (Unsaturated Fatty acids/SFA)				12.95		

In the previous studies also reported the terpenes are the major aroma compounds responsible for the odour of black pepper samples and their essential oil products.

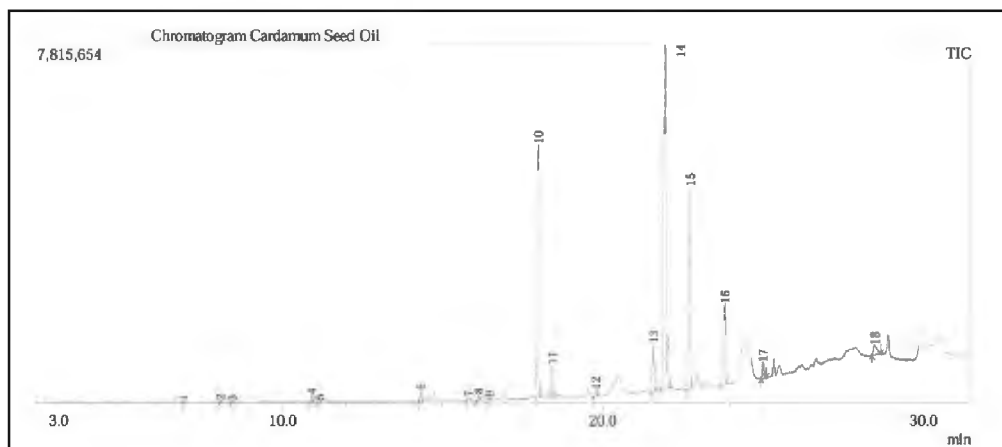


Figure 1 : Chromatogram of fixed oils of *Elettaria cardamomum* (L.) Maton

Phytochemicals: Analysis through phytochemical protocols in volatile Oil of *Elettaria cardamomum* through GC MS are presented in table.2 and figure 2. The volatile oil extracted from *Elettaria cardamomum* (cardamom) contains a range of classes of compounds, each contributing to its unique aroma and flavor characteristics features. The analysis through mass spectrometry revealed 50 compounds, with varying area percentages and 54 peaks. This Findings of experimental results suggested that Compounds which were more than Area > 5% was found as Eucalyptol: 25.79% and Eucalyptol, also known as 1,8-cineole, is a monoterpene oxide that contributes a fresh, minty aroma. Other compounds shown many times peak at different RT was 3-Cyclohexene-1-methanol with sum of area % was 37.05 Many scientists had proven their potential anti-inflammatory and antimicrobial properties. Same in the range or less than five % area covered include that Limonene and It was found to be 3.15% Mostly limonene is responsible for the scent in fresh herbs Therefore it is used in perfumery. This can also be recognized for aroma therapy and potential health benefits.

In case of compounds with Minimal Presence (Area % < 1%): Camphene was found as 0.02% and it is under the class of bicyclic monoterpene and shown a camphor-like aroma, therefore it is used in fragrances and as a flavouring agent. 3-Carene was found with 0.27% area also A bicyclic

monoterpene that has a sweet, pungent aroma, often found in pine and cedar. Phenol, 2-methoxy-3-(2-propenyl) with 0.27% and This compound has a clove-like aroma and is used in flavouring and fragrance applications. n-Hexadecanoic acid: 0.02% also known as saturated fatty acid that contributes a waxy, fatty note to the aroma profile. Farnesol: 0.01% recognized as A sesquiterpene alcohol with a floral scent, commonly used in perfumes and cosmetics. The flavour compounds identified in the volatile oil of *Elettaria cardamomum* classified based on their chemical structure and aroma characteristics. The data shown Monoterpenes with an example of Limonene, Eucalyptol, Camphene with characteristics flavour of fresh, citrusy, or herbal aroma. In Sesquiterpenes class with examples of Farnesol, Germacrene D and it was contributed to deeper, earthy, or woody notes many alcohol derivatives especially 3-Cyclohexene-1-methanol, Terpeneol Similarly in Aldehydes provides sweet, floral, or fruity aromas 2,6-Octadienal many ester compounds like Methyl cinnamate which was characterized as fruity and sweet in aroma. Overall compounds were detected through cardamom volatile oils suggested 54 compounds and similar results also compared with bioactivity founds in literatures cited here with references in table.5 it suggested antifungal, antimicrobial, insecticidal, flavouring compounds in food as well as the

Table.4 Volatile /Essential oils from different seeds and plant parts.

Peak No.	RT (min)	Area (%)	Compound Identified
1	7.37	1.15	(1R)-2,6,6-Trimethylbicyclo[3.1.1]hept-2-ene
2	8.254	0.02	Camphene
3	9.349	3.41	Bicyclo[3.1.0]hexane, 4-methylene-1-(1-methylethyl)-
4	9.82	1.63	β.-Myrcene
5	10.356	0.27	3-Carene
6	10.786	0.41	Bicyclo[4.1.0]hept-2-ene, 3,7,7-trimethyl-
7	11.294	3.15	Limonene
8	12.199	25.79	Eucalyptol
9	12.468	0.81	1,4-Cyclohexadiene, 1-methyl-4-(1-methylethyl)-
10	13.078	0.73	Terpineol, cis-β.-
11	13.279	0.83	Cyclohexene, 1-methyl-4-(1-methylethylidene)-
12	13.645	0.62	Cyclohexane, 2-ethenyl-1,1-dimethyl-3-methylene-
13	13.946	1.23	1,6-Octadien-3-ol, 3,7-dimethyl-
14	14.251	1.3	cis-β.-Terpineol
15	14.852	0.81	2-Cyclohexen-1-ol, 1-methyl-4-(1-methylethyl)-, trans-
16	15.624	0.92	2-Cyclohexen-1-ol, 1-methyl-4-(1-methylethyl)-, cis-
17	16.386	0.59	2-Octenoic acid, methyl ester, (E)-
18	16.752	3.07	3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-
19	17.402	2.45	(+)-.α.-Terpineol (p-menth-1-en-8-ol)

Peak No.	RT (min)	Area (%)	Compound Identified
20	17.905	1.63	1,6-Octadien-3-ol, 3,7-dimethyl-, 2-aminobenzoate
21	18.999	2.49	1,6-Octadien-3-ol
22	19.332	0.75	Bicyclo[2.2.1]heptan-2-ol, 1,7,7-trimethyl-, acetate, (1S-endo)-
23	19.801	1.11	2,6-Octadienal
24	21.439	37.05	3-Cyclohexene-1-methanol
25	21.674	0.25	cis-Dodec-5-enal
26	21.821	1.12	2,6-Octadien-1-ol, 3,7-dimethyl-, acetate
27	21.996	0.48	.gamma.-Elemene
28	22.459	0.51	LONGIPINENE <B-> DB5-1393
29	22.727	0.5	3-Cyclohexene-1-methanol, α .,4-trimethyl-, propanoate
30	22.866	0.27	Phenol, 2-methoxy-3-(2-propenyl)-
31	23.383	0.54	Germacrene D
32	23.554	1.27	Eudesma-4(14),11-diene
33	23.938	0.46	METHYL CINNIMATE <(E)-> DB5-1342
34	24.232	0.37	Naphthalene, 1,2,3,4,4a,5,6,8a-octahydro-7-methyl-4-methylene-1-(1-methylethyl)-, (1. α .,4a. β .,8a. α .)-
35	24.815	0.27	3,7,11-Tridecatrienitrile, 4,8,12-trimethyl-
36	25.126	0.84	1,6,10-Dodecatrien-3-ol, 3,7,11-trimethyl-, (E)-
37	25.485	0.3	GERMACRENE B
38	26.023	0.14	cis,cis,cis-7,10,13-Hexadecatrienal
39	26.345	0.14	1H-Cycloprop[e]azulene, decahydro-1,1,7-trimethyl-4-methylene-, [1aR-(1a. α .,4a. α .,7. α .,7a. β .,7b. α .)]-
40	27.286	0.1	GERMACRENE D-4-OL
41	27.749	0.02	Acetic acid, 1-methyl-1-(4-methyl-5-oxo-cyclohex-3-enyl)ethyl ester
42	28.467	0	SELIN-11-EN-4 A-OL
43	29.17	0.04	2,6,10-Dodecatrien-1-ol, 3,7,11-trimethyl-, (Z,E)-
44	29.76	0.02	2,6,10-Dodecatrienal, 3,7,11-trimethyl-, (E,E)-
45	30.975	0.02	2,6,10-Dodecatrien-1-ol, 3,7,11-trimethyl-, acetate, (E,E)-
46	31.877	0.01	Acetic acid, 1-[2-(2,2,6-trimethyl-bicyclo[4.1.0]hept-1-yl)-ethyl]-vinyl ester
47	32.389	0.02	n-Hexadecanoic acid
48	34.179	0.01	1,2-Benzenedicarboxylic acid, bis(2-methylpropyl) ester
49	35.13	0.03	1,2-Benzenedicarboxylic acid, butyl 2-methylpropyl ester
50	35.457	0.01	Tetradecane
51	37.04	0.02	Retinal, 9-cis-
52	38.37	0.01	Tetratetracontane
53	39.985	0.01	2,6,10-Dodecatrien-1-ol, 3,7,11-trimethyl-, (Z,E)-
54	41.441	0.01	FARNESOL

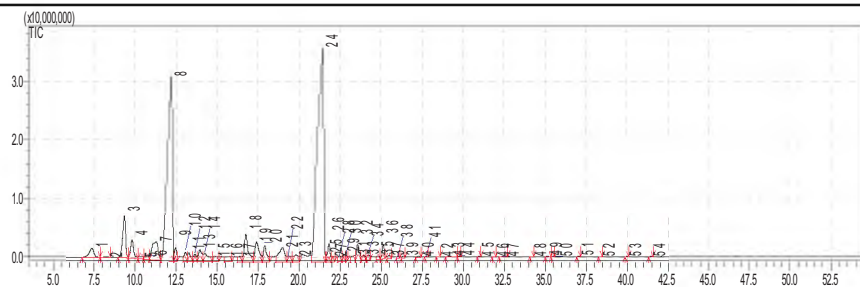


Figure 2 : Chromatogram of Volatile oils of Elettaria cardamomum (L.) Maton

Table.3 : Application and bioactivity reported compounds Volatile and fixed oil of cardamom

No.	Compound	Reported activity or properties	Reference
1	(1R)-2,6,6-Trimethylbicyclo[3.1.1]hept-2-ene	Antimicrobial	Alam <i>et al.</i> , 2019 Bhutia <i>et al.</i> , 2022; Noumi <i>et al.</i> , 2018 Alam <i>et al.</i> , 2019; Singh <i>et al.</i> , 2008
2	Camphene	Antifungal	Bhutia <i>et al.</i> , 2022; Noumi <i>et al.</i> , 2018
3	Bicyclo[3.1.0]hexane, 4-methylene-1-(1-methylethyl)	Insect-repellent/insecticidal potential	Hosseinpour <i>et al.</i> , 2011 Bhutia <i>et al.</i> , 2022; Vijayan <i>et al.</i> , 2017 Masoumi-Ardakani <i>et al.</i> , 2016 Bhutia <i>et al.</i> , 2022; Ashokkumar <i>et al.</i> , 2021; Tan <i>et al.</i> , 2023
4	β -Myrcene	Analgesic	Masoumi-Ardakani <i>et al.</i> , 2016
5	3-Carene	Anti-inflammatory	Bhutia <i>et al.</i> , 2022; Noumi <i>et al.</i> , 2018 Singh <i>et al.</i> , 2008
6	Bicyclo[4.1.0]hept-2-ene,	Antioxidant	Bhutia <i>et al.</i> , 2022; Noumi <i>et al.</i> , 2018 Ahamad, 2024; Alam <i>et al.</i> , 2019 Bhutia <i>et al.</i> , 2022; Ashokkumar <i>et al.</i> , 2021; Tan <i>et al.</i> , 2023
7	Limonene	Anticancer	Masoumi-Ardakani <i>et al.</i> , 2016; Alam <i>et al.</i> , 2019; Bhutia <i>et al.</i> , 2022; Vijayan <i>et al.</i> , 2017; Ashokkumar <i>et al.</i> , 2021; Noumi <i>et al.</i> , 2018; Tan <i>et al.</i> , 2023
8	Eucalyptol (1,8-Cineole)	Respiratory stimulant / respiratory	Tan <i>et al.</i> , 2023
9	1,4-Cyclohexadiene	Cytotoxic activity	Noumi <i>et al.</i> , 2018 Masoumi-Ardakani <i>et al.</i> , 2016
10	cis- β -Terpineol	Sedative effects	Ashokkumar <i>et al.</i> , 2021; Tan <i>et al.</i> , 2023
11	Cyclohexene	Solvent properties	Tan <i>et al.</i> , 2023
12	Cyclohexane	Industrial solvent	Tan <i>et al.</i> , 2023 Singh <i>et al.</i> , 2008; Alam <i>et al.</i> , 2019 Bhutia <i>et al.</i> , 2022; Ashok kumar <i>et al.</i> , 2021; Noumi <i>et al.</i> , 2018; Tan <i>et al.</i> , 2023
13	1,6-Octadien-3-ol (Linalool)	Antimicrobial	Singh <i>et al.</i> , 2008; Masoumi-Ardakani <i>et al.</i> , 2016; Ashokkumar <i>et al.</i> , 2021; Noumi <i>et al.</i> , 2018; Tan <i>et al.</i> , 2023
14	cis- β -Terpineol	Antioxidant	Tan <i>et al.</i> , 2023
15	2-Cyclohexen-1-ol	Flavoring	Tan <i>et al.</i> , 2023
16	cis-2-Cyclohexen-1-ol	Fragrance	Tan <i>et al.</i> , 2023
17	2-Octenoic acid	Antimicrobial	Noumi <i>et al.</i> , 2018; Tan <i>et al.</i> , 2023
18	3-Cyclohexen-1-ol	Flavor enhancer	Tan <i>et al.</i> , 2023 Masoumi-Ardakani <i>et al.</i> , 2016; Singh <i>et al.</i> , 2008; Bhutia <i>et al.</i> , 2022; Vijayan <i>et al.</i> , 2017; Ashokkumar <i>et al.</i> , 2021; Tan <i>et al.</i> , 2023
19	(+)- α -Terpineol	Relaxant effects	Tan <i>et al.</i> , 2023; Noumi <i>et al.</i> , 2018
20	1,6-Octadien-3-ol	Potential neuroprotective	Singh <i>et al.</i> , 2008; Ashokkumar <i>et al.</i> , 2021; Noumi <i>et al.</i> , 2018; Tan <i>et al.</i> , 2023
21	1,6-Octadien-3-ol (Linalool)	Antioxidant	Bhutia <i>et al.</i> , 2022; Vijayan <i>et al.</i> , 2017
22	Bicyclo[2.2.1]heptan-2-ol	Insect pheromone mimic	Tan <i>et al.</i> , 2023
23	2,6-Octadienal	Flavoring agent	

No.	Compound	Reported activity or properties	Reference
24	3-Cyclohexene-1-methanol	Fragrance	Tan <i>et al.</i> , 2023
25	cis-Dodec-5-enal	Antimicrobial	Noumi <i>et al.</i> , 2018 Alam <i>et al.</i> , 2019; Singh <i>et al.</i> , 2008
26	2,6-Octadien-1-ol	Antimicrobial	Noumi <i>et al.</i> , 2018; Tan <i>et al.</i> , 2023
27	γ -Elemene	Antitumor	Noumi <i>et al.</i> , 2018 Hosseinpour <i>et al.</i> , 2011; Bhutia <i>et al.</i> , 2022;
28	Longipinene	Insecticidal	Noumi <i>et al.</i> , 2018
29	3-Cyclohexene-1-methanol, $\alpha,\alpha,4$ -trimethyl-, propanoate	Antioxidant	Singh <i>et al.</i> , 2008; Noumlet <i>et al.</i> , 2018; Tan <i>et al.</i> , 2023
30	Phenol, 2-methoxy-3-(2-propenyl)-	Antifungal	Singh <i>et al.</i> , 2008
31	Germacrene D	Antimicrobial	Noumi <i>et al.</i> , 2018 Alam <i>et al.</i> , 2019; Noumi <i>et al.</i> , 2018
32	Eudesma-4(14),11-diene	Anti-inflammatory	Masoumi-Ardakani <i>et al.</i> , 2016
33	Methyl cinnamate	Analgesic	Noumi <i>et al.</i> , 2018
34	Naphthalene derivative (1H-Cycloprop[e]azulene)	Antimicrobial	Tan <i>et al.</i> , 2023 Alam <i>et al.</i> , 2019; Singh <i>et al.</i> , 2008
35	3,7,11-Tridecatrienitrile, 4,8,12-trimethyl-	Insect repellent	Noumlet <i>et al.</i> , 2018
36	1,6,10-Dodecatrien-3-ol	Antioxidant	Hosseinpour <i>et al.</i> , 2011; Bhutia <i>et al.</i> , 2022; Noumi <i>et al.</i> , 2018
37	Germacrene	Antimicrobial	Singh <i>et al.</i> , 2008; Noumi <i>et al.</i> , 2018
38	cis,cis,cis-7,10,13-Hexadecatrienal	Insect pheromone	Alam <i>et al.</i> , 2019; Noumi <i>et al.</i> , 2018
39	1H-Cycloprop[e]azulene	Cytotoxic effects	Noumlet <i>et al.</i> , 2018;
40	Germacrene D-4-ol	Antimicrobial	Majeed <i>et al.</i> , 2023; Noumi <i>et al.</i> , 2018
41	Acetic acid	Antimicrobial properties	Alam <i>et al.</i> , 2019; Noumi <i>et al.</i> , 2018 Singh <i>et al.</i> , 2008; Noumi <i>et al.</i> , 2018; Tan <i>et al.</i> , 2023
42	Selin-11-en-4 α -ol	Anti-inflammatory	Masoumi-Ardakani <i>et al.</i> , 2016; Noumi <i>et al.</i> , 2018
43	2,6,10-Dodecatrien-1-ol	Antioxidant	Singh <i>et al.</i> , 2008; Noumi <i>et al.</i> , 2018
44	2,6,10-Dodecatrienal	Antimicrobial	Singh <i>et al.</i> , 2008; Noumi <i>et al.</i> , 2018
45	2,6,10-Dodecatrien-1-ol	Antimicrobial	Singh <i>et al.</i> , 2008; Noumi <i>et al.</i> , 2018
46	Acetic acid	—	Singh <i>et al.</i> , 2008; Tan <i>et al.</i> , 2023 Singh <i>et al.</i> , 2008, Tan <i>et al.</i> , 2023; Noumlet <i>et al.</i> , 2018
47	n-Hexadecanoic acid (Palmitic acid)	Antimicrobial properties	
48	1,2-Benzenedicarboxylic acid (Phthalic acid)	Plasticizer	Tan <i>et al.</i> , 2023;
49	1,2-Benzenedicarboxylic acid	Plasticizer	Tan <i>et al.</i> , 2023
50	Tetradecane	Biocompatibility	Tan <i>et al.</i> , 2023
51	Retinal	Vision-related function	Tan <i>et al.</i> , 2023
52	Tetratetracontane	Hydrophobic property	Tan <i>et al.</i> , 2023
53	2,6,10-Dodecatrien-1-ol	—	Singh <i>et al.</i> , 2008; Noumi <i>et al.</i> , 2018 Singh <i>et al.</i> , 2008; Noumi <i>et al.</i> , 2018; Tan <i>et al.</i> , 2023
54	Farnesol	Antifungal properties	

CONCLUSION

Studies on key bioactive compounds in Volatile of cardamom through analytical instruments of GCMS showed α -Terpinyl acetate (37.05%), Eucalyptol (25.79%) and Sabinene (3.41%). The volatile oil of *Elettaria cardamomum* composed of more than 50 compounds with Eucalyptol and 3-Cyclohexene-1-methanol were found to be maximum including the presence of various monoterpenes, sesquiterpenes, and alcohols these were pertaining to flavor and aroma contribution in cardamom, thus it is being used as ingredient in culinary and aromatic in food application. The compounds detection through literatures indicated many bioactivities were reported and has potential health benefits with uses in traditional and modern era.

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Integration of various approaches to manage sucking pests of green gram

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ABSTRACT

An investigation was carried out to evaluate various integrated pest management modules against sucking pests of green gram [*Vigna radiata* (L.) Wilczek] at Agronomy Instructional Farm, C. P. College of Agriculture, S. D. Agricultural University, Sardarkrushinagar- 385 506 during summer, 2019. The experiment was laid out in Completely Randomized Design (large plot sampling). Among various five modules, module M₁ comprised of border crop with maize + seed treatment with imidacloprid 600 FS + yellow sticky trap + two sprays of azadirachtin 10,000 ppm 0.3% was the most effective module as it recorded lowest number of sucking pests viz., aphid (0.72/3 leaves), jassid (0.40/3 leaves), whitefly (1.28/3 leaves) and thrips (0.58/3 flowers) without interfering population of natural enemies viz., ladybird beetle, green lacewing and spiders which resulted into highest seed yield (1006 kg/ha), increase in yield over control (80.61%) and economics (1:8.61) in summer green gram.

Keywords: Integrated Pest Management, green gram, sucking pests

INTRODUCTION

Green gram [*Vigna radiata* (L.) Wilczek], Family: Leguminosae is third most important pulse crop of India after chickpea and pigeon pea (Veds *et al.*, 2008), commonly known as mung, moong, mungo, mung bean, golden gram, Chickasaw pea, oreganpea etc. Contribution of green gram to the overall pulse production in India accounted for 10% of the total pulse production (Anon., 2021). Area occupied by pulses in India is 29.03 million hectares with 23.40 million tonnes production and productivity of 806 kg/ha. Major green gram growing states are Odisha, Andhra Pradesh, Maharashtra, Karnataka, Gujarat and Bihar. In Gujarat, total area under cultivation of green gram is 153000 ha with 86000 tonnes production and 561 kg/ha productivity (Anon., 2018). Sucking pests viz., aphid, *Aphis craccivora* Koch; jassid, *Empoasca kerri* Pruthi; whitefly, *Bemisia tabaci* Gennadius; flower thrips, *Megalurothrips usitatus* Bagnall are known to cause significant damage to green gram foliage and flowers besides causing damage to other related legumes. The annual yield loss due to insect-pests has been estimated to the tune of 30 per cent in green gram (Soundarajan and

Chitra, 2011). Whitefly alone can cause losses ranging from 30 to 70 per cent in green gram (Swaminathan *et al.*, 2012) and 80 to 100 per cent in green gram and black gram (Naimuddin, 2001), whereas thrips cause at least 40 per cent yield loss in green gram (Sreekanth, 2002). Meena *et al.* (2025) also confirmed that flower thrips and whiteflies contribute significantly to production decline in green gram. The cowpea aphid, *A. craccivora* may cause 20 to 40 per cent yield loss in case of vegetable cowpea and other pulses (Reddy *et al.*, 2014). Chemical insecticides are used as the frontline defense sources against insect pests in India. However, indiscriminate and repeated use of chemical pesticides creates a few consequences such as development of resistance, pest resurgence and environmental hazards including residue in soil, water and food chain. Integration of various control measures not only bring down the pest population below a certain limit, also it minimizes the load of hazardous chemical pesticides from the crop as well as environment. Research on IPM modules against sucking pests of green gram in past was found scanty. Therefore, the present investigation was carried out on integration of various approaches to manage sucking pests of green gram.

MATERIALS AND METHODS

To evaluate the different five modules (Table 1) against sucking pests infesting green gram, a field experiment was conducted at Agronomy Instructional Farm, C. P. College of Agriculture, S. D. Agricultural University, Sardarkrushinagar during summer, 2019. The experiment was laid out in Completely Randomized Design (large plot

sampling). Green gram cultivar, GM 4 was grown following recommended agronomical practices in plot size of 4.8 m × 4.0 m (for each module) at spacing of 30 cm between two rows and 10 cm within the row. Four quadrates (1.5 m × 1.5 m) from each module were selected randomly and five plants from each quadrate were selected randomly for recording observations. Each quadrate was considered as a repetition.

Table 1 : Details of treatments in various modules

Module No.	Treatments
M ₁	Two rows of maize as border crop during sowing of main crop + Seed treatment with imidacloprid 600 FS @ 5 ml/kg seed + Installation of yellow sticky trap @ one/module + Two sprays of azadirachtin 10000 ppm 0.3% (30 ml/10 liter of water)
M ₂	Alternate spray of cow urine 10% + neem leaf extract 10% and cow urine 10% + custard apple leaf extract 10%
M ₃	Alternate spray of cow urine 10% + <i>Ipomea</i> leaf extract 10% and cow urine 10% + <i>Lantana camera</i> leaf extract 10%
M ₄	Alternate spray of <i>Lecanicillium lecanii</i> (1×10^9 cfu/g) 1.15 WP 0.5% (50g/10 liter of water) and <i>Beauveria bassiana</i> (1×10^9 cfu/g) 1.15 WP 0.5% (50g/10 liter of water)
M ₅	Untreated control

In module M₁, green gram seeds were treated thoroughly with imidacloprid 600 FS. For the purpose, insecticidal solution was prepared by mixing imidacloprid 600 FS 0.06% @ 5 ml/kg seed in water (50 ml/kg seed) and the seeds were smeared with insecticidal solution in the polythene bag and dried in shade before sowing. Two weeks after sowing yellow sticky trap @ one/module was installed at the centre of the module. At the initiation of any pests, foliar spray of azadirachtin 10000 ppm 0.3% @ 30 ml/ 10 litre water was applied using manually operated knapsack sprayer and second spray was applied after 10 days of 1st spray. In module M₂, M₃ and M₄ first spray was applied at the

appearance of any sucking pests and subsequent two sprays were applied at the 10 days interval.

Method of recording observations

For the purpose, the number of sucking pests were recorded weekly from three leaves (top, middle and bottom) on five randomly selected plants in each quadrate starting from second week after sowing till maturity of the crop. Number of natural enemies (lady bird beetle, green lacewing and spider) were also counted from same selected plants in each quadrate. At harvest, the seed yield was recorded separately from each quadrate. Avoidable losses and increase in yield over control was calculated applying formula suggested by Khosla (1977).

$$\text{Avoidable loss (\%)} = \frac{\text{Highest yield in treated plot} - \text{Yield in treatment}}{\text{Highest yield in treated plot}} \times 100$$

$$\text{Increase in yield over control (\%)} = \frac{\text{Yield in treatment} - \text{Yield in control}}{\text{Yield in control}} \times 100$$

Statistical analysis

The data on the population of sucking pests were statistically analysed. On the basis of yield, the economics were calculated as per the methodology adopted by Patel (2019).

RESULTS AND DISCUSSION

Evaluation of various modules against sucking pests of green gram

Aphid, *A. craccivora*

The data (Table 2) pertaining to aphid population on green

gram during 3rd week after sowing (WAS) showed that all modules had similar population except module M₁ as it recorded significantly the lowest aphid population (0.05/3 leaves). During 4th week after sowing, all the modules were significantly superior over untreated control (1.15/ 3 leaves). Significantly the lowest (0.10/3 leaves) number of aphid was registered in module M₁ comprising of border crop with maize + seed treatment with imidacloprid 600 FS + yellow sticky trap + two sprays of azadirachtin 10,000 ppm 0.3%. The superiority of module M₁ was noticed at

subsequent week after sowing from 5th WAS till maturity of the crop. It was obvious that module M₁ exhibited minimum aphid (0.72/3 leaves) population in summer green gram and proved to be the most effective module. Module M₄ stood as second most efficient module with 1.56 aphid/3 leaves. Module M₂ and M₃ registered 2.04 and 2.22 aphids per three leaves and found as less effective. Saranya *et al.* (2010) and Saranya and Ushakumari (2011) reported that higher effectiveness of *B. bassiana* and *V. lecanii* against *A. craccivora* in black gram. Shobharani *et al.* (2017) revealed that the higher dose of imidacloprid 600 FS @ 15 ml/kg seed as seed treatment proved superior in protecting the black gram against the early season attack of aphid, *A. craccivora*. Thus, present results are in conformity with earlier findings.

Jassid, *E. kerri*

The data presented in Table 3 revealed that all modules had more or less similar jassid population except module M₁ 4th WAS. No jassid population was observed in the plot framed with module M₁ at 4th WAS which clearly showed its effectiveness against *E. kerri* in green gram. At 5th WAS, module M₁ exhibited significantly the lowest (0.05) jassid population per three leaves and found to be most effective. However, highest population (0.60 jassid/3 leaves) was observed in the module M₃ which was at par with module M₂ and M₄ with 0.39 jassid per 3 leaves. Similarly, module M₁ stood as most effective against jassid throughout the observation period (6th to 11th WAS). It was evident from the overall mean that module M₁ proved as most effective module in protecting the crop from jassid (0.40/3 leaves) infestation followed by module M₄ (0.82), M₂ (0.93) and module M₃ (1.24) as against the jassid population in untreated control (1.77). Singh and Singh (2015) reported that green gram seed treatment with Imidacloprid 600 FS (5ml kg⁻¹) followed by one spray of NSKE (5%) at 30 days after sowing and triazophos 40 EC 0.04% were effective in reducing the incidence of *E. kerri*. Shobharani *et al.* (2017) revealed that seed treatment with imidacloprid 600 FS @ 15 ml/kg seed as proved superior in protecting the black gram against the early season attack of *E. kerri* (1.63/3 leaves). Thus, present results are in conformity with earlier findings.

Whitefly, *B. tabaci*

Data (Table 4) of whitefly population recorded in summer green gram during 4th WAS showed that there was no significant difference in whitefly population among various modules except module M₁. There was no incidence of whitefly in module M₁ at 4th WAS which clearly showed its effectiveness against *B. tabaci* in green gram. Module M₁ continued to remain as most effective against whitefly throughout the observation period till maturity (11th WAS). It was obvious that module M₁ exhibited minimum mean population of whitefly (1.28/3 leaves) in green gram and proved as most effective module followed by module M₄ (2.23). Module M₂ (2.72) and M₃ (3.03) harboured higher number of whiteflies and they were less effective. Jat and Jeyakumar (2006) reported that *B. bassiana* in cotton found

highly effective whereas neem products viz., neem oil and NSKE proved to be mediocre in their effectiveness against *B. tabaci*. Singh and Singh (2015) reported that green gram seed treatment with Imidacloprid 600 FS (5ml kg⁻¹) followed by one spray of NSKE (5%) and triazophos 40 EC 0.04 per cent were effective in reducing the incidence of white fly, *B. tabaci*. Thus, present results are in accordance with earlier findings.

Thrips, *M. usitatus*

The results (Table 5) showed that all modules were significantly different from untreated control (0.74 thrips/3 flowers) as far as number of thrips is concerned at 6th WAS. The lowest (0.05/3 flowers) thrips population was recorded in the module M₁ and it was at par with module M₄ (0.10) and M₂ (0.19). However, module M₃ recorded 0.30 thrips per three flowers and proved to be least effective in green gram. Similarly, the lowest number of thrips was recorded from plots framed with module M₁ at subsequent weekly observations till maturity of crop and it was at par with module M₄. It was evident from overall mean that the module M₁ proved the most effective module in reducing the thrips (0.58/3 flowers) population followed by module M₄ (0.87). Module M₂ (1.09) and M₃ (1.34) registered comparatively higher number of thrips in summer green gram and found less effective. Singh and Singh (2015) reported that green gram seed treatment with Imidacloprid 600 FS (5ml kg⁻¹) followed by one spray of NSKE (5%) and triazophos 40 EC 0.04 per cent were effective in reducing the incidence of thrips, *Caliothrips indicus*. Shobharani *et al.* (2017) revealed that the higher dose of imidacloprid 600 FS @15 ml/kg seed as seed treatment proved superior in protecting the blackgram against the early season attack of thrips (1.96/3 leaves). Thus, present results are more or less in accordance with earlier findings.

Impact of various modules on natural enemies in summer green gram

The data on number of coccinellids (grubs + adults), *Chrysoperla* spp. (grubs) and spiders (adults + spiderlings) recorded in different modules are presented in Table 6, 7 and 8, respectively. The population of various natural enemies were homogenous in all modules as the difference was non-significant at each observation starting from 4th WAS till crop maturity i.e., 11th WAS which clearly indicated that all the modules did not interfere the predatory fauna in summer green gram.

Yield, increase in yield over control and avoidable loss

Seed yield

The results indicated that all the modules were significantly different from untreated control (557 kg/ha) in terms of seed yield (Table 9). Significantly the highest green gram seed yield (1006 kg/ha) was harvested from module M₁. Plots treated with module M₄ produced 880 kg seed per hectare and stood as second best module as far as yield is concerned. Module M₂ and M₃ yielded comparatively lower (727 and 697 kg/ha, respectively).

Table 2: Evaluation of various modules against aphid, *A. craccivora* on green gram during summer 2019

Module No.	Treatments	Number of aphid/ 3 leaves at Week After Sowing (WAS)									Mean
		3 rd	4 th	5 th	6 th	7 th	8 th	9 th	10 th	11 th	
M ₁	Border crop with maize + seed treatment with imidacloprid 600 FS + yellow sticky trap + two sprays of Azadirachtin 10,000 ppm 0.3%	0.74 ^a (0.05)	0.77 ^a (0.10)	0.83 ^a (0.19)	1.16 ^a (0.87)	1.44 ^a (1.57)	1.57 ^a (1.97)	1.38 ^a (1.41)	0.91 ^a (0.30)	0.74 ^a (0.05)	0.72
M ₂	Alternate spray of cow urine 10% + neem leaf extract 10% and cow urine 10% + custard apple leaf extract 10%	1.09 ^b (0.70)	1.00 ^b (0.49)	1.24 ^c (1.03)	1.71 ^c (2.44)	2.12 ^c (3.99)	2.91 ^c (5.23)	1.89 ^b (3.09)	1.24 ^b (1.05)	0.92 ^{bc} (0.34)	2.04
M ₃	Alternate spray of cow urine 10% + <i>Ipomea</i> leaf extract 10% and cow urine 10% + <i>Lantana camara</i> leaf extract 10%	1.12 ^b (0.75)	1.07 ^b (0.64)	1.26 ^c (1.08)	1.77 ^c (2.64)	2.19 ^c (4.28)	2.45 ^c (5.48)	1.97 ^b (3.39)	1.32 ^b (1.25)	1.02 ^c (0.54)	2.22
M ₄	Alternate spray of <i>Lecanicillium lecanii</i> (1×10^9 cfu/g) 1.15 WP 0.5% and <i>Beauveria bassiana</i> (1×10^9 cfu/g) 1.15 WP 0.5%	1.09 ^b (0.69)	0.99 ^b (0.49)	1.04 ^b (0.59)	1.58 ^b (1.99)	1.92 ^b (3.18)	2.03 ^b (3.61)	1.74 ^b (2.53)	1.13 ^b (0.77)	0.83 ^{ab} (0.19)	1.56
M ₅	Untreated control	1.12 ^b (0.75)	1.28 ^c (1.15)	1.46 ^d (1.64)	2.06 ^d (3.73)	2.51 ^d (5.82)	2.79 ^d (7.26)	2.26 ^c (4.59)	1.55 ^c (1.90)	1.18 ^d (0.89)	3.08
S.Em. ±		0.04	0.05	0.05	0.07	0.09	0.10	0.08	0.05	0.04	-
C.V. %		8.16	9.55	8.79	7.98	8.38	8.98	8.49	8.67	8.15	-

Note: Figures in parentheses are retransformed value of $\sqrt{x + 0.5}$ transformed values; Treatment means with the letter(s) in common are not significant by DNMRT at 5 per cent level of significance

Table 3 : Evaluation of various modules against jassid, *E. kerri* on green gram during summer 2019

Module No.	Treatments	Number of jassid/3 leaves at Week After Sowing (WAS)									Mean
		4 th	5 th	6 th	7 th	8 th	9 th	10 th	11 th		
M ₁	Border crop with maize + seed treatment with imidacloprid 600 FS + yellow sticky trap + two sprays of Azadirachtin 10,000 ppm 0.3%	0.71 ^a (0.00)	0.74 ^a (0.05)	0.89 ^a (0.28)	1.19 ^a (0.91)	1.22 ^a (0.99)	1.01 ^a (0.53)	0.97 ^a (0.43)	0.74 ^a (0.05)	0.40	
M ₂	Alternate spray of cow urine 10% + neem leaf extract 10% and cow urine 10% + custard apple leaf extract 10%	0.96 ^b (0.42)	0.95 ^b (0.39)	1.20 ^b (0.95)	1.50 ^b (1.74)	1.68 ^c (2.33)	1.34 ^{bc} (1.29)	1.26 ^{bc} (1.09)	0.89 ^{ab} (0.30)	0.93	
M ₃	Alternate spray of cow urine 10% + <i>Ipomea</i> leaf extract 10% and cow urine 10% + <i>Lantana camera</i> leaf extract 10%	0.97 ^b (0.44)	1.05 ^b (0.60)	1.24 ^b (1.05)	1.59 ^{bc} (2.04)	1.77 ^c (2.63)	1.41 ^c (1.49)	1.34 ^c (1.29)	0.92 ^{bc} (0.34)	1.24	
M ₄	Alternate spray of <i>Lecanicillium lecanii</i> (1 × 10 ⁹ cfu/g) 1.15 WP 0.5% and <i>Beauveria bassiana</i> (1 × 10 ⁹ cfu/g) 1.15 WP 0.5%	0.95 ^b (0.39)	0.95 ^b (0.39)	1.07 ^{ab} (0.64)	1.37 ^{ab} (1.38)	1.53 ^b (1.84)	1.22 ^b (0.98)	1.15 ^{ab} (0.83)	0.80 ^{ab} (0.14)	0.82	
M ₅	Untreated control	0.99 ^b (0.49)	1.18 ^c (0.89)	1.46 ^c (1.63)	1.81 ^c (2.78)	2.03 ^d (3.62)	1.64 ^d (2.19)	1.55 ^d (1.89)	1.07 ^d (0.64)	1.77	
S.Em. ±		0.04	0.04	0.05	0.07	0.06	0.06	0.05	0.04	-	
C.V. %		8.37	8.90	8.23	8.91	8.31	8.92	8.75	8.95	-	

Note: Figures in parentheses are retransformed value of $\sqrt{x+0.5}$ transformed values; Treatment means with the letter(s) in common are not significant by DNMRT at 5 per cent level of significance

Table 4 : Evaluation of various modules against whitefly, *B. tabaci* on green gram during summer 2019

Module No.	Treatments	Number of whitefly/3 leaves at Week After Sowing (WAS)									Mean
		4 th	5 th	6 th	7 th	8 th	9 th	10 th	11 th		
M ₁	Border crop with maize + seed treatment with imidacloprid 600 FS + yellow sticky trap + two sprays of Azadirachtin 10,000 ppm 0.3%	0.71 ^a (0.00)	0.89 ^a (0.30)	0.99 ^a (0.48)	1.26 ^a (1.08)	1.64 ^a (1.57)	1.70 ^a (2.37)	1.76 ^a (2.59)	1.53 ^a (1.84)	1.28	
M ₂	Alternate spray of cow urine 10% + neem leaf extract 10% and cow urine 10% + custard apple leaf extract 10%	0.99 ^b (0.48)	1.16 ^b (0.84)	1.32 ^{bc} (1.24)	1.83 ^c (2.84)	2.05 ^b (3.69)	2.15 ^b (4.13)	2.23 ^b (4.47)	2.13 ^{bc} (4.03)	2.72	
M ₃	Alternate spray of cow urine 10% + <i>Ipomea</i> leaf extract 10% and cow urine 10% + <i>Lantana camara</i> leaf extract 10%	1.02 ^b (0.54)	1.22 ^{bc} (0.98)	1.41 ^c (1.50)	1.88 ^c (3.03)	2.15 ^b (4.13)	2.34 ^b (4.96)	2.31 ^b (4.84)	2.19 ^c (4.28)	3.03	
M ₄	Alternate spray of <i>Lecanicillium lecanii</i> (1 × 10 ⁹ cfu/g) 1.15 WP 0.5% and <i>Beauveria bassiana</i> (1 × 10 ⁹ cfu/g) 1.15 WP 0.5%	0.99 ^b (0.48)	1.07 ^{ab} (0.64)	1.22 ^b (0.99)	1.56 ^b (1.94)	1.92 ^b (3.20)	2.10 ^b (3.90)	2.05 ^{ab} (3.70)	1.87 ^b (3.01)	2.23	
M ₅	Untreated control	1.05 ^b (0.60)	1.40 ^c (1.45)	1.61 ^d (2.10)	2.20 ^d (4.33)	2.44 ^c (5.44)	2.65 ^c (6.53)	2.66 ^c (6.59)	2.49 ^d (5.69)	4.09	
S.Em. ±		0.04	0.05	0.06	0.07	0.09	0.10	0.10	0.10	-	
C.V. %		7.97	8.08	8.75	8.52	8.77	8.84	8.98	9.81	-	

Note: Figures in parentheses are retransformed value of $\sqrt{X+0.5}$ transformed values; Treatment means with the letter(s) in common are not significant by DNMRT at 5 per cent level of significance

Table 5: Evaluation of various modules against thrips, *M. usitatus* on green gram during summer 2019

Module No.	Treatments	Number of thrips/3 flowers at Week After Sowing (WAS)					Mean
		6 th	7 th	8 th	9 th	10 th	11 th
M ₁	Border crop with maize + seed treatment with imidacloprid 600 FS + yellow sticky trap + two sprays of Azadirachtin 10,000 ppm 0.3%	0.74 ^a (0.05)	0.83 ^a (0.19)	1.06 ^a (0.63)	1.36 ^a (1.34)	1.09 ^a (0.68)	1.04 ^a (0.58)
M ₂	Alternate spray of cow urine 10% + neem leaf extract 10% and cow urine 10% + custard apple leaf extract 10%	0.83 ^{ab} (0.19)	1.01 ^b (0.53)	1.28 ^{bc} (1.15)	1.64 ^{ab} (2.19)	1.36 ^b (1.34)	1.30 ^{ab} (1.19)
M ₃	Alternate spray of cow urine 10% + <i>Ipomea</i> leaf extract 10% and cow urine 10% + <i>Lantana camara</i> leaf extract 10%	0.89 ^b (0.30)	1.15 ^{bc} (0.83)	1.39 ^c (1.44)	1.74 ^b (2.52)	1.37 ^b (1.38)	1.44 ^{bc} (1.59)
M ₄	Alternate spray of <i>Lecanicillium lecanii</i> (1×10^9 cfu/g) 1.15 WP 0.5% and <i>Beauveria bassiana</i> (1×10^9 cfu/g) 1.15 WP 0.5%	0.77 ^{ab} (0.10)	0.94 ^{ab} (0.38)	1.16 ^{ab} (0.84)	1.55 ^{ab} (1.89)	1.26 ^{ab} (1.08)	1.20 ^{ab} (0.95)
M ₅	Untreated control	1.12 ^c (0.74)	1.32 ^c (1.25)	1.59 ^d (2.03)	2.15 ^c (4.14)	1.72 ^c (2.44)	1.70 ^c (2.39)
S.Em. $\pm$		0.04	0.05	0.06	0.07	0.06	0.06
C.V. %		9.03	8.64	9.84	8.53	8.64	8.63

Note: Figures in parentheses are retransformed value of $\sqrt{X + 0.5}$ transformed values; Treatment means with the letter(s) in common are not significant by DNNMRT at 5 per cent level of significance.

Table 6: Impact of various modules on ladybird beetle in green gram during summer, 2019

Module No.	Treatments	Number of ladybird beetle/plant at Week After Sowing (WAS)									Mean
		4 th	5 th	6 th	7 th	8 th	9 th	10 th	11 th		
M ₁	Border crop with maize + seed treatment with imidacloprid 600 FS + yellow sticky trap + two sprays of Azadirachtin 10,000 ppm 0.3%	1.07 ^a (0.65)	1.04 ^a (0.59)	1.49 ^a (1.72)	1.64 ^a (2.19)	1.54 ^a (1.88)	1.83 ^a (2.84)	1.26 ^a (1.10)	1.00 ^a (0.50)	1.43	
M ₂	Alternate spray of cow urine 10% + neem leaf extract 10% and cow urine 10% + custard apple leaf extract 10%	0.97 ^a (0.45)	1.09 ^a (0.69)	1.48 ^a (1.69)	1.67 ^a (2.28)	1.56 ^a (1.94)	1.84 ^a (2.89)	1.20 ^a (0.95)	0.97 ^a (0.45)	1.41	
M ₃	Alternate spray of cow urine 10% + <i>Ipomea</i> leaf extract 10% and cow urine 10% + <i>Lantana camera</i> leaf extract 10%	1.07 ^a (0.65)	1.02 ^a (0.55)	1.46 ^a (1.64)	1.64 ^a (2.18)	1.65 ^a (2.23)	1.89 ^a (3.07)	1.21 ^a (0.97)	0.89 ^a (0.28)	1.45	
M ₄	Alternate spray of <i>Lecanicillium lecanii</i> (1 × 10 ⁹ cfu/g) 1.15 WP 0.5% and <i>Beauveria bassiana</i> (1 × 10 ⁹ cfu/g) 1.15 WP 0.5%	0.96 ^a (0.42)	1.02 ^a (0.55)	1.37 ^a (1.38)	1.61 ^a (2.08)	1.55 ^a (1.89)	1.78 ^a (2.67)	1.18 ^a (0.90)	0.86 ^a (0.25)	1.26	
M ₅	Untreated control	1.00 ^a (0.50)	1.15 ^a (0.80)	1.43 ^a (1.54)	1.62 ^a (2.13)	1.62 ^a (2.13)	1.83 ^a (2.87)	1.22 ^a (1.00)	0.92 ^a (0.35)	1.41	
S.Em. ±		0.05	0.04	0.06	0.08	0.08	0.06	0.06	0.05	-	
C.V. %		9.33	8.90	9.07	10.61	9.56	9.39	9.68	8.80	-	

Note: Figures in parentheses are retransformed value of $\sqrt{X + 0.5}$ transformed values; Treatment means with the letter(s) in common are not significant by DNMRT at 5 per cent level of significance.

Table 7: Impact of various modules on green lacewing in green gram during summer, 2019

Module No.	Treatments	Number of green lacewing/ plant at Week After Sowing (WAS)						Mean
		6 th	7 th	8 th	9 th	10 th	11 th	
M ₁	Border crop with maize + seed treatment with imidacloprid 600 FS + yellow sticky trap + two sprays of Azadirachtin 10,000 ppm 0.3%	0.77 ^a (0.10)	0.86 ^a (0.25)	1.16 ^a (0.85)	1.05 ^a (0.60)	1.02 ^a (0.55)	0.80 ^a (0.15)	0.41
M ₂	Alternate spray of cow urine 10% + neem leaf extract 10% and cow urine 10% + custard apple leaf extract 10%	0.77 ^a (0.10)	0.89 ^a (0.30)	1.18 ^a (0.90)	1.04 ^a (0.59)	0.95 ^a (0.39)	0.83 ^a (0.19)	0.42
M ₃	Alternate spray of cow urine 10% + <i>Ipomea</i> leaf extract 10% and cow urine 10% + <i>Lantana camara</i> leaf extract 10%	0.80 ^a (0.15)	0.86 ^a (0.25)	1.16 ^a (0.85)	1.07 ^a (0.64)	1.00 ^a (0.50)	0.80 ^a (0.15)	0.42
M ₄	Alternate spray of <i>Lecanicillium lecanii</i> (1×10^9 cfu/g) 1.15 WP 0.5% and <i>Beauveria bassiana</i> (1×10^9 cfu/g) 1.15 WP 0.5%	0.71 ^a (0.00)	0.80 ^a (0.14)	1.06 ^a (0.63)	1.00 ^a (0.50)	0.89 ^a (0.28)	0.77 ^a (0.10)	0.27
M ₅	Untreated control	0.80 ^a (0.15)	0.92 ^a (0.35)	1.16 ^a (0.84)	1.02 ^a (0.54)	1.00 ^a (0.50)	0.80 ^a (0.15)	0.43
S.Em. $\pm$		0.05	0.05	0.05	0.08	0.07	0.09	-
C.V. %		9.33	9.14	9.81	9.47	9.09	9.41	-

Note: Figures in parentheses are retransformed value of $\sqrt{x+0.5}$ transformed values; Treatment means with the letter(s) in common are not significant by DNMRT at 5 per cent level of significance

Table 8: Impact of various modules on spiders in green gram during summer, 2019

Module No.	Treatments	Number of spider/ plant at Week After Sowing (WAS)									Mean
		4 th	5 th	6 th	7 th	8 th	9 th	10 th	11 th		
M ₁	Border crop with maize + seed treatment with imidacloprid 600 FS + yellow sticky trap + two sprays of Azadirachtin 10,000 ppm 0.3%	0.86 ^a (0.25)	1.07 ^a (0.65)	1.38 ^a (1.40)	1.64 ^a (2.20)	1.74 ^a (2.54)	1.50 ^a (1.74)	1.16 ^a (0.84)	0.86 ^a (0.25)	1.23	
M ₂	Alternate spray of cow urine 10% + neem leaf extract 10% and cow urine 10% + custard apple leaf extract 10%	0.84 ^a (0.20)	1.09 ^a (0.70)	1.40 ^a (1.45)	1.70 ^a (2.39)	1.71 ^a (2.43)	1.48 ^a (1.69)	1.16 ^a (0.84)	0.80 ^a (0.15)	1.22	
M ₃	Alternate spray of cow urine 10% + <i>Ipomea</i> leaf extract 10% and cow urine 10% + <i>Lantana camera</i> leaf extract 10%	0.89 ^a (0.30)	1.16 ^a (0.84)	1.28 ^a (1.15)	1.70 ^a (2.39)	1.71 ^a (2.43)	1.50 ^a (1.74)	1.12 ^a (0.74)	0.80 ^a (0.15)	1.21	
M ₄	Alternate spray of <i>Lecanicillium lecanii</i> (1 × 10 ⁹ cfu/g) 1.15 WP 0.5% and <i>Beauveria bassiana</i> (1 × 10 ⁹ cfu/g) 1.15 WP 0.5%	0.80 ^a (0.15)	1.02 ^a (0.54)	1.24 ^a (1.05)	1.63 ^a (2.14)	1.64 ^a (2.20)	1.39 ^a (1.44)	1.07 ^a (0.64)	0.74 ^a (0.05)	1.02	
M ₅	Untreated control	0.89 ^a (0.28)	1.15 ^a (0.83)	1.40 ^a (1.47)	1.66 ^a (2.25)	1.74 ^a (2.53)	1.50 ^a (1.76)	1.09 ^a (0.69)	0.84 ^a (0.20)	1.25	
S.Em. ±		0.06	0.04	0.06	0.08	0.08	0.06	0.06	0.05	-	
C.V. %		9.18	8.90	10.07	9.61	9.56	9.39	9.68	8.80	-	

Note: Figures in parentheses are retransformed value of $\sqrt{X + 0.5}$ transformed values; Treatment means with the letter(s) in common are not significant by DNMRT at 5 per cent level of significance.

Table 9 : Impact of various modules on yield, increase in yield over control, avoidable loss and economics in green gram

Module No.	Treatments	Seed yield (kg/ha)	Increase in yield over control (%)	Avoidable loss (%)	PCBR
M ₁	Border crop with maize + seed treatment with imidacloprid 600 FS + yellow sticky trap + two sprays of Azadirachtin 10,000 ppm 0.3%	1006 ^a	80.61	-	1:8.61
M ₂	Alternate spray of cow urine 10% + neem leaf extract 10% and cow urine 10% + custard apple leaf extract 10%	727 ^c	30.52	27.73	1:1.71
M ₃	Alternate spray of cow urine 10% + <i>Ipomea</i> leaf extract 10% and cow urine 10% + <i>Lantana camara</i> leaf extract 10%	697 ^c	25.13	30.71	1:1.23
M ₄	Alternate spray of <i>Lecanicillium lecanii</i> (1×10^9 cfu/g) 1.15 WP 0.5% and <i>Beauveria bassiana</i> (1×10^9 cfu/g) 1.15 WP 0.5%	880 ^b	57.99	12.52	1:1.86
M ₅	Untreated control	557 ^d	-	44.63	-
S.E.m.±		33.83	-	-	-
C.V. %		8.75	-	-	-

Note: Treatment means with the letter(s) in common are not significant by DNMRT at 5 per cent level of significance.

Increase in yield over control

Maximum increase in yield was obtained in the plots framed with M₁ (80.61%) followed by module M₄ which recorded 57.99 per cent over control (Table 9). Module M₂ and M₃ registered 30.52 and 25.13 per cent increase in yield over control, respectively.

Avoidable loss

It can be seen from the data that the maximum seed yield was obtained in the module M₁ which proved as the best module (Table 9). The avoidable losses in green gram yield was minimum in module M₄ (12.52%) followed by module M₂ (27.73%) and module M₃ (30.71%). The maximum avoidable loss in green gram yield due to sucking pests was incurred in untreated control (44.63%).

Economics

The economics of various modules presented in Table 9 revealed that the highest Protection Cost Benefit Ratio (PCBR) was calculated from the module M₁ (1:8.61) which clearly indicated that module M₁ was most economical among various modules. Module M₄, M₂ and M₃ showed PCBR of 1:1.86, 1:1.71 and 1:1.23, respectively and found less economical.

CONCLUSION

It can be concluded that among various modules, M₁ comprised of border crop with maize + seed treatment with imidacloprid 600 FS + yellow sticky trap + two sprays of Azadirachtin 10,000 ppm 0.3% was the most effective module as it recorded lowest number of sucking pests viz., aphid (0.72/3 leaves), jassid (0.40/3 leaves), whitefly (1.28/3 leaves) and thrips (0.58/3 flowers) without interfering natural enemies viz., ladybird beetle, green lacewing and spider resulting in to highest seed yield (1006 kg/ha), increase in yield over control (80.61%) and found most economical (1:8.61) in summer green gram.

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Genetic architecture and combining ability analysis for forage yield and attributing traits in pearl millet (*Pennisetum glaucum* L.) utilizing a Line $\times$ Tester design

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ABSTRACT

Getting insight into the genetic architecture and combining ability analysis in pearl millet (*Pennisetum glaucum* L.) is the essential step for developing superior and nutritionally rich forage cultivars. This study evaluated 40 F_1 hybrids obtained from a Line $\times$ Tester mating design with their 8 lines and 5 testers during *kharif* 2024 in a Randomized Block Design with three replications. Fourteen distinct morphological, yield, and nutritional traits were analyzed to estimate General Combining Ability (GCA), Specific Combining Ability (SCA) and the nature of gene action. Biometrical analysis revealed that the ratio of general to specific combining ability variance ($\sigma^2_{gca}/\sigma^2_{sca}$) was less than unity for all fourteen evaluated characters, suggesting that non-additive gene action predominantly controls the inheritance of fodder yield and quality. Among the parents, lines AFB-23 and AFB-67, and testers RBB-1 and, were identified as superior general combiners for green fodder yield per plant. For specific combining ability, the hybrid AFB-66 $\times$ RBB-1 showed the highest positive SCA effect for green fodder yield per plant, followed by AFB-25 $\times$ Baif and AFB-23 $\times$ Giant Bajra. The findings emphasize that breeding programs should capitalize on specific non-additive cross combinations to develop commercial heterotic hybrids and select desirable transgressive segregants for enhancing forage biomass and nutritional quality in pearl millet.

Keywords : Combining ability (GCA and SCA), Forage nutritional quality, Gene action, Green fodder yield, Line $\times$ Tester design, Pearl millet

INTRODUCTION

India possesses one of the world's largest livestock populations and animal husbandry sector plays an essential role in national development and the prosperity of rural economies (Bhardwaj *et al.*, 2018). In this sector, achieving higher income relies heavily on increasing milk production. This can be achieved by animal feed management and the provision of green fodder. To meet these demands farmers must adopt scientific cultivation methods for fodder crops.

In the regions that have irregular rainfall and poor soil fertility, forage pearl millet (*Pennisetum glaucum* L.) serves as a vital biological crop. As a fast-growing and short-duration cereal crop, it shows robust resistance to water Scarcity and heat, allowing it to thrive across diverse soil types. Pearl millet is known for its rapid growth cycle and high nutritional profile, which yields a substantial amount of dry matter alongside superior crude protein content and

excellent ruminant digestibility (Anonymous 2023). Furthermore, the recent development of specialized multi-cut varieties for green fodder has significantly enhanced its agricultural utility. With its noticeable genome size (~1.79 GB) (Varshney *et al.*, 2017) and an inherent allogamous mating system characterized by protogyny, pearl millet exhibits profound genetic variability.

Despite this vast genetic potential, it is necessary to get a precise understanding of the underlying genetic architecture governing yield and quality traits in addition to phenotypic selection. The success of any hybridization program is intrinsically linked to the careful selection of parental lines capable of transmitting desirable performance to their progeny. Combining ability analysis, as proposed by Sprague and Tatum (1942), provides a biometric framework to evaluate these inbred lines, partitioning genetic variance into General Combining Ability (GCA) and Specific Combining Ability (SCA).

To evaluate a wide array of germplasm efficiently, the Line $\times$ Tester (L $\times$ T) mating design [Kempthorne (1957)] offers a robust biometrical approach to precisely estimate these additive and non-additive gene actions. While the agronomic performance of pearl millet hybrids is well-documented, the specific genetic mechanisms controlling multicut forage biomass and nutritional attributes require further delineation. Consequently, this study utilizes a L $\times$ T mating design with the specific objectives of (1) evaluating the general and specific combining ability effects of selected parental lines, (2) investigating the nature and relative magnitude of gene action governing forage traits, and (3) identifying superior combiners for deployment in future forage pearl millet improvement initiatives.

MATERIAL AND METHODS

Experimental Material

To assess the combining ability and genetic architecture of forage traits, a crossing block was established at the Centre for Forage Research, S. D. Agricultural University, Sardarkrushinagar during the summer 2024. Eight diverse pearl millet lines were crossed with five testers (Table 1) using a Line $\times$ Tester mating framework, generating 40 unique F₁ hybrid combinations. Strict pollination protocols were followed by utilizing butter paper bags to prevent foreign pollen contamination given the protogynous and highly allogamous nature of the crop.

Lines	Testers	Check
L ₁ : 'HC-20'	T ₁ : 'Baif'	'GAFB- 4'
L ₂ : 'AFB-44'	T ₂ : 'Giant Bajra'	
L ₃ : 'AFB-21'	T ₃ : 'ICMO-1604'	
L ₄ : 'AFB-24'	T ₄ : 'RBB-1'	
L ₅ : 'AFB-67'	T ₅ : 'AFB-45'	
L ₆ : 'AFB-23'		
L ₇ : 'AFB-25'		
L ₈ : 'AFB-66'		

Field Evaluation

The 40 experimental hybrids, along with their 13 respective parental lines and check, were evaluated during the *kharif* 2024 in a Randomized Block Design comprising three replications. Genotypes were accommodated in single-row plots of 4.0-meter length, with inter-row and intra-row spacing maintained at 30 cm and 10 cm, respectively. Fourteen distinct yield and nutritional parameters were evaluated (*i.e.* days to flowering, plant height, number of tillers per plant, stem diameter, leaves per plant, leaf length, internode length, leaf width, leaf stem ratio, green fodder

yield per plant, dry matter yield per plant, dry matter content, crude protein content and iron content). Morphological traits (such as plant height, tillering, stem diameter, leaf dimensions, and fodder yield) were recorded from five randomly selected plants per plot, while phenological and biochemical metrics (flowering time, dry matter content, crude protein, and iron content) were analyzed on a per-plot basis.

Biometrical and Genetic Analysis

The partitioning of total genetic variance into general combining ability (GCA) and specific combining ability (SCA) components was executed strictly according to the Line $\times$ Tester biometrical procedure outlined by Kempthorne (1957).

The total variance among hybrids was divided to calculate the variance attributable to females (lines), males (testers), and their interaction. The additive and non-additive gene actions were assessed by calculating the GCA variance (σ^2_{GCA}) and SCA variance (σ^2_{SCA}), respectively. The potence ratio was subsequently determined to ascertain the predominant nature of gene action:

$$\text{Potence ratio} = \frac{\sigma^2_{gca}}{\sigma^2_{sca}}$$

A potence ratio exceeding unity indicates predominantly additive gene action, whereas a ratio below unity signifies non-additive (dominance/epistatic) gene action. The individual GCA effects for the i^{th} line (g_i) and j^{th} tester (g_j), as well as the SCA effect for the ij^{th} specific cross combination (s_{ij}), were estimated using the standard additive model:

$$X_{ij} = m + g_i + g_j + s_{ij} + e_{ijk}$$

Where m is the population mean and e_{ijk} represents the associated environmental error. The significance of these combining ability effects was tested using standard error estimates and standard 't' tests at the 5% and 1% levels of probability.

RESULTS AND DISCUSSION

The analysis of variance (Table 2) for combining ability revealed highly significant differences for the Line $\times$ Tester interaction across all evaluated traits, confirming that specific combinations of parents behaved distinctly differently than predicted by their independent additive effects. Furthermore, the mean sum of squares for the lines was significant for all characters, while the male testers showed significance for all traits except plant height. A critical biometrical reality observed in this study is that the ratio of general to specific combining ability variance

($\sigma^2_{gca}/\sigma^2_{sca}$) was less than unity for every trait evaluated.

The higher magnitude of σ^2_{sca} compared σ^2_{gca} dictates that non-additive gene actions specifically dominance and epistatic interactions predominantly control the inheritance of fodder yield and nutritional quality in this pearl millet germplasm. This non-additive genetic variance plays a primary role in the inheritance of traits including days to flowering, plant height, number of tillers per plant, stem diameter, leaves per plant, leaf length and width, internode length, leaf:stem ratio, green fodder and dry matter yield per plant, dry matter content, as well as crude protein and iron content. Similar results were also reported by Shinde and Mehetre (2014) and Ashwini *et al.* (2021) for all the traits.

While non-additive variance dominates, identifying strong general combiners remains the foundational step in assembling a successful crossing block. The general combining ability variance estimates for the lines (σ^2_{lines}) were predominantly non-significant for all the characters except crude protein content, whereas the tester variances (σ^2_{tester}) showed significance for specific traits such as iron content. Because the GCA effects were negative for days to flowering, number of tillers per plant, leaves per plant, and dry matter content, these were not counted in the positive directional analysis. For the primary economic trait *i.e.*, green fodder yield per plant, the lines AFB-67 and AFB-23 emerged as the most valuable general combiners, exhibiting highly significant positive GCA effects. Among the testers, RBB-1 and Baif provided the most favorable additive genes for this trait, with RBB-1 additionally

serving as a strong general combiner for dry matter yield per plant.

The estimates of general combining ability (GCA) and specific combining ability (SCA) effects of genotypes for fourteen traits are presented in Table 3. Good, average and poor combinations meant significant positive, non-significant and significant negative gene actions, respectively. Yield is governed by complex inheritance pattern which is noticeable because no single cross exhibited favorable SCA effects for every trait simultaneously. Nevertheless, a significant number of hybrids showed desirable SCA effects for many traits. For example, ten hybrids showed favourable SCA effects for internode length, leaf:stem ratio, and crude protein content; nine for plant height, number of tillers per plant, stem diameter, leaves per plant, and green fodder yield per plant; eight for leaf length; and seven for days to flowering, dry matter yield per plant, dry matter content, and iron content.

While discussing in detail, line AFB-23 emerged as a top good general combiner. Since it showed desirable significant values for GCA for majority of traits namely, plant height (3.75), number of tillers per plant (0.20), number of leaves per plant (2.58), leaf length (2.46), leaf width (0.18), leaf stem ratio (0.03), green fodder yield per plant (14.70), dry matter yield per plant (4.17) and iron content (3.30). This line is followed by line AFB-67 for days to flowering (-2.00), number of tillers per plant (0.49), leaves per plant (2.12), leaf length (2.43), leaf width (0.15), green fodder yield per plant (14.76), dry matter yield per plant (3.59) and dry matter content (1.44).

Table 2: Analysis of variance for combining ability and its component characters in forage pearl millet

Source of variation	df	Days to flowering	Plant height	Number of tillers per plant	Stem diameter	Leaves per plant	Leaf length	Internode length
Replications	2	30.55	17.49	0.06	0.01	1.95	18.06	0.23
Hybrids	39	56.30**	539.25**	1.03**	0.21**	28.36**	61.46**	9.95**
Lines	7	43.05**	897.20**	1.03**	0.28**	41.93**	42.43**	10.50**
Testers	4	60.55**	279.27	0.70**	0.21**	11.61**	101.12**	21.15**
Lines × Testers	27							
Testers		59.01**	486.90**	1.08**	0.19**	27.35**	60.55**	8.21**
Error	78	13.45	119.78	0.10	0.04	2.84	12.47	1.95
ESTIMATES								
σ^2_L		-1.06	27.35	-0.003	0.01	0.97	-1.20	0.15
σ^2_T		0.06	-8.65	-0.015	0.01	-0.66	1.69	0.53
σ^2_{GCA}		-0.36#	5.19	-0.011#	0.01	-0.03#	0.57	0.39
σ^2_{SCA}		15.18**	122.37**	0.326**	0.05**	8.17**	16.02**	2.08**
$\sigma^2_{GCA}/\sigma^2_{SCA}$		-0.02	0.04	-0.033	0.05	-0.01	0.03	0.18

*, ** indicates significant at 5% and 1% levels of probability, respectively.

Table 2Contd.....

Source of variation	df	Leaf width	Leaf: stem ratio	Green fodder yield per plant	Dry matter yield per plant	Dry matter content	Crude Protein content	Iron content
Replications	2	0.02	0.01	479.43	13.80	5.68	0.03	29.22
Hybrids	39	0.22**	0.01**	1945.88**	139.53**	16.46**	3.26**	288.99**
Lines	7	0.22**	0.02**	1741.92**	128.36**	14.03**	7.84**	87.15*
Testers	4	0.40**	0.01**	2572.78**	186.70**	13.53**	4.35**	1037.69**
Lines × Testers	27	0.19**	0.01**	1907.31**	135.58**	17.49**	1.96**	232.49**
Error	78	0.04	0.01	194.01	12.64	3.17	0.13	35.18
ESTIMATES								
$\sigma^2 L$		0.01	0.00	-11.02	-0.48	-0.23	0.39**	-9.68
$\sigma^2 T$		0.01	0.00	27.72	2.12	-0.16	0.09	33.54**
σ^2_{GCA}		0.01	0.01	12.82	1.12	-0.19#	0.21	16.91
σ^2_{SCA}		0.05**	0.01**	571.10**	40.98**	4.77**	0.60**	65.77**
$\sigma^2_{GCA}/\sigma^2_{SCA}$		0.11	0.06	0.02	0.02	-0.03	0.34	0.25

was not counted in analysis due to negative value.

Table 3 : Summary of promising general and specific combiners along with their significant GCA and SCA effects for forage traits in pearl millet

Traits	Promising Lines (GCA Effect)	Promising Testers (GCA Effect)	Top Hybrids (SCA Effect)
Days to flowering	AFB-67 (-2.00*), AFB-25 (-2.00*)	AFB-45 (-1.72*)	AFB-67 × Baif (-8.61**), AFB-25 × Giant Bajra (-7.15**)
Plant height	AFB-25 (6.63*), AFB-23 (3.75**)	Giant Bajra (5.34*)	AFB-67 × AFB-45 (16.21*), AFB-24 × Giant Bajra (15.99*), AFB-23 × ICMO-1604 (15.27*)
Number of tillers per plant	AFB-67 (0.49**), AFB-23 (0.20*)	AFB-45 (0.22**), Baif (0.13*)	AFB-67 × ICMO-1604 (1.31**), AFB-66 × RBB-1 (1.07**)
Stem diameter	AFB-44 (-0.12*), AFB-24 (-0.11*), AFB-66 (-0.10*), HC (-0.10*)	Giant Bajra (-0.10*)	AFB-25 × Giant Bajra (-0.49**), AFB-23 × AFB-45 (-0.39**)
Leaves per plant	AFB-23 (2.58**), AFB-67 (2.12**)	Baif (0.70*)	AFB-66 × RBB-1 (4.62**), AFB-24 × Baif (4.19**)
Leaf length	AFB-23 (2.46**), AFB-67 (2.43**)	AFB-45 (2.22**), Baif (1.98**)	HC-20 × RBB-1 (7.63**), AFB-24 × AFB-45 (6.41**)
Internode length	AFB-21 (-0.94*)	RBB-1 (-1.35**)	AFB-21 × Giant Bajra (-2.94**), AFB-24 × Baif (-2.06*)
Leaf width	AFB-23 (0.18**), AFB-67 (0.15**)	ICMO-1604 (0.09*), Baif (0.08*)	AFB-25 × Baif (0.49**), AFB-44 × RBB-1 (0.44**)
Leaf: stem ratio	AFB-23 (0.03*), AFB-24 (0.03*), AFB-25 (0.03*)	Baif (0.02*), AFB-45 (0.02*)	AFB-23 × Giant Bajra (0.10**), AFB-21 × ICMO-1604 (0.09**)
Green fodder yield per plant	AFB-67 (14.76**), AFB-23 (14.70**)	RBB-1 (10.35**), Baif (6.43*)	AFB-66 × RBB-1 (53.58**), AFB-25 × Baif (32.36**), AFB-23 × Giant Bajra (30.96**)
Dry matter yield per plant	AFB-23 (4.17**), AFB-67 (3.59**)	RBB-1 (2.91**), Baif (1.45*)	AFB-66 × RBB-1 (15.33**), AFB-23 × Giant Bajra (10.22**)
Dry matter content	AFB-67 (1.44**), AFB-21 (1.05*)	Baif (0.77*), AFB-45 (0.73*)	AFB-23 × AFB-45 (5.74**), AFB-66 × Baif (4.01**)
Crude Protein content	HC-20 (1.20**), AFB-44 (0.49**), AFB-21 (0.41**), AFB-24 (0.29*)	ICMO-1604 (0.47**), AFB-45 (0.34**)	AFB-21 × ICMO-1604 (2.11**), AFB-24 × AFB-45 (1.45**)
Iron content	AFB-66 (3.46*), AFB-23 (3.30*)	ICMO-1604 (5.67**), AFB-45 (5.58**)	AFB-67 × Baif (15.81**), AFB-24 × Giant Bajra (12.70**), AFB-44 × Baif (12.12**), AFB-67 × Giant Bajra (8.56**)

* Significant at 5% level of probability; ** Significant at 1% level of probability. Negative values are desirable for days to flowering, stem diameter, and internode length. Positive values are desirable for all other traits.

While discussing about SCA, the earliness is the desirable character in pearl millet crop since it allows farmers to harvest multiple cut in a season. Desirable value is negative significant for this trait as well as for internode length and stem diameter. Since, less inter node length promote more number of leaves. Specific combining ability effects were found desirable for AFB-67 $\times$ Baif (-8.61**) and AFB-25 $\times$ Giant Bajra (-7.15**) for earliness. Khandagale *et al.* (2014) and Shinde and Meheretre (2014) reported similar results earlier.

Considering the stem properties, plant height is directly related with green forage yield. The cross-combination AFB-67 $\times$ AFB-45 (16.21) recorded highest significant specific combining ability effect in a desirable direction for plant height followed by AFB-24 $\times$ Giant Bajra (15.99) and AFB-23 $\times$ ICMO-1604 (15.27). The earlier findings of Patel *et al.* (2008), Shinde and Mehetre (2014) and Sharma *et al.* (2019) were similar to the present findings. More number of tillers per plant increase the fodder yield. Total nine crosses recorded significant positive SCA effects in desirable direction among which one cross AFB-67 $\times$ ICMO-1604 (1.31) surpassed the other crosses. A study of estimation of general combining ability effects for stem diameter revealed that parent AFB-44 (-0.12), AFB-24 (-0.11), AFB-66 (-0.10) and HC-20 (-0.10) among lines and Giant Bajra (-0.10) among testers showed significant negative general combining ability effects. Therefore, these parents were good combiners for stem diameter. Ashwini *et al.* (2021) also reported similar significant SCA effects earlier for stem diameter. Also, smaller internode is preferred and cross combination AFB-21 $\times$ Giant Bajra (-2.94) recorded highest significant SCA effects for this trait [supported by Govintharaj *et al.* (2021)].

Leaves characteristics are important for fodder since; animal preference is more towards the leaves than stem. Highest SCA effect was 4.62 (AFB-66 $\times$ RBB-1) for number of leaves per plant; 7.63 (HC-20 $\times$ RBB-1) for leaf length; 0.49 (AFB-25 $\times$ Baif) for leaf width; 0.10 (AFB-23 $\times$ Giant Bajra) for leaf: stem ratio. Similar results were also reported by Maitry (2011) and Ashwini *et al.* (2021). The hybrids which showed positive direction for SCA can be directly considered as a best combination. Biomass of plant (specially for fodder plant) is the ultimate character for income generation for farmer. For green fodder yield per plant, the most successful specific crosses consistently involved combinations of Average $\times$ Good, Good $\times$

Average, or Good $\times$ Good GCA parents. The highest positive SCA effect for green fodder yield was recorded by the cross AFB-66 $\times$ RBB-1 ($L_8 \times T_4 = 53.58$), which resulted from an Average $\times$ Good combiner interaction. This was followed by AFB-25 $\times$ Baif ($L_7 \times T_1 = 32.36$) and AFB-23 $\times$ Giant Bajra ($L_6 \times T_2 = 30.96$). This pattern demonstrates that crossing parents with the highest individual GCA does not automatically guarantee the most vigorous hybrid. Instead, selecting crosses that pair at least one strong general combiner, such as AFB-23 or RBB-1, with a genetically divergent partner triggers the highest specific combining ability. Ultimately, breeders must focus on exploiting these specific cross combinations rather than relying solely on the mass selection of parents. Capitalizing on this exclusive non-additive gene action will be highly useful for producing superior, heterotic hybrids at a commercial scale, while also facilitating the production of transgressive segregants to aid in the selection of better recombinants for overall forage yield and associated nutritional traits. Khandagale *et al.* (2014), Shinde and Mehetre (2014) and Bhardwaj *et al.* (2023) also reported similar results earlier.

Mere green fodder yield is not enough; it should be supplemented with dry matter content also. For dry matter yield per plant, the highest SCA effects was 15.33 (AFB-66 $\times$ RBB-1). The highest SCA effects for dry matter content was 5.74 (AFB-23 $\times$ AFB-45). Similar results were previously reported by Ashwini *et al.* (2021) and Bhardwaj *et al.* (2023).

Plant variety or hybrid with only high biomass is not enough nowadays. Fodder with high nutritional quality is necessary for better livestock health. For this, the parents HC-20 (1.20), AFB-44 (0.49), AFB-21 (0.41), AFB-24 (0.29) among lines and ICMO-1604 (0.47) and AFB-45 (0.34) among testers had emerged out as good general combiners for crude protein content. Considering the iron content, the highest SCA effects was 15.81 (AFB-67 $\times$ Baif) followed by 12.70 (AFB-24 $\times$ Giant Bajra), 12.12 (AFB-44 $\times$ Baif) and 8.56 (AFB-67 $\times$ Giant Bajra). The present findings were similar to results reported by Nandaniya *et al.* (2016), Gavali *et al.* (2018).

CONCLUSION

In conclusion, this study demonstrates that the inheritance of all fourteen evaluated forage yield, morphological, and nutritional traits in pearl millet - including crude protein and iron content - is predominantly governed by non-additive gene action, as evidenced by a general-to-specific combining ability variance ratio ($\sigma^2_{gca}/\sigma^2_{sca}$) of less than unity. Among the evaluated parents, lines AFB-23 and AFB-

67, along with testers RBB-1 and Baif, emerged as superior general combiners for green fodder yield per plant, whereas lines HC-20, AFB-44, AFB-21, AFB-24, and tester ICMO-1604 proved to be favorable general combiners for enhancing crude protein content. However, the results indicate that pairing parents with the highest individual GCA effects does not automatically guarantee the most vigorous hybrid. Notably, the top-performing specific combinations for green fodder yield per plant such as AFB-66 × RBB-1, AFB-25 × Baif, and AFB-23 × Giant Bajra—resulted from pairing at least one strong general combiner with a genetically divergent partner. Consequently, future forage pearl millet breeding programs should prioritize capitalizing on specific non-additive cross combinations rather than relying solely on the mass selection of parents. Exploiting this non-additive gene action will be instrumental for developing commercial heterotic hybrids and selecting superior transgressive segregants with enhanced forage biomass and nutritional quality in pearl millet.

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Impact of nano urea on growth, yield attributes, yield, quality and economics of *Bt. cotton* (*Gossypium hirsutum* L.) under irrigated condition

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ABSTRACT

A two-year field experiment was conducted during *kharif* 2023–24 and 2024–25 at the Cotton Research Station, Junagadh Agricultural University, Junagadh, to evaluate the effect of foliar-applied nano urea with different levels of the recommended dose of nitrogen (RDN) on the growth, yield and economics of irrigated *Bt. cotton* hybrid G. Cot. Hy. 24 BG II. The experiment was laid out in a Randomized Block Design with 14 treatments and three replications. Treatments included different combinations of 100, 75 and 50% RDN with foliar sprays of urea (1 or 2%) or nano urea (2 or 4 ml/lit) applied at 40, 70 and 90 DAS. Pooled analysis revealed non-significant year and year $\times$ treatment interaction effects for most parameters. Application of 100% RDN + nano urea 4 ml/lit (T_{10}) produced significantly higher plant growth, dry matter, SPAD value, sympodial branches, bolls per plant, seed cotton yield (2433 kg/ha), lint yield (861 kg/ha) and stalk yield (5458 kg/ha) which is representing increases of 90.8% over the absolute control. Treatments T_9 (100 % RDN with foliar spray of nano urea 2 ml/ lit water at 40, 70 and 90 DAS), T_4 (100 % RDN + foliar spray of 2 % urea at 40, 70 and 90 DAS), T_3 (100 % RDN + foliar spray of 1 % urea at 40, 70 and 90 DAS), T_{12} (75 % RDN with foliar spray of nano urea 4 ml/ lit water at 40, 70 and 90 DAS) and T_{11} (75 % RDN with foliar spray of nano urea 2 ml/ lit water at 40, 70 and 90 DAS) were statistically at par with T_{10} . Treatment T_{11} (75% RDN + nano urea 2 ml/lit) achieved comparable yield and benefit ratio of 1.80 despite 25% lower soil nitrogen. Fibre quality and oil content remained unaffected, indicating that nano urea can partially replace soil-applied nitrogen while sustaining productivity and improving profitability.

Keywords: *Bt. cotton*; nano urea; foliar application; seed cotton yield; economics

INTRODUCTION

India's position in global cotton production is a study in disparities. India, the United States, and Brazil combined contribute 64% of the world's cotton area and 71% of the world's production. India has the biggest area under cotton of any nation, but this only translates to around 21% of world production because its average productivity of 448 kg/ha is far below that of top growers like Australia, China, Turkey, Brazil, Mexico, and the United States. Biotic and abiotic stresses together with growing competition from other crops have reshaped the sector considerably in recent years. According to the Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, India produced 299.26 lakh bales (170 kg each) of cotton in 2024-25 from 113.6 lakh hectares at a productivity of 448 kg lint/ha, with the area under cotton down 10.46 per cent and

output down 7.98 per cent on the previous year. Maharashtra, Gujarat, Karnataka, Madhya Pradesh, Punjab, Rajasthan, Haryana, Tamil Nadu, and Uttar Pradesh are the country's principal cotton-growing states, with Gujarat leading national output followed by Punjab and Maharashtra. Gujarat alone supplies close to 30 per cent of India's cotton; the Committee on Cotton Production and Consumption (COCPC) put the state's 2024-25 output at 84.01 lakh bales from 23.92 lakh hectares, an average yield of 597 kg/ha (PIB, 2024). Saurashtra, Kutch, and parts of North Gujarat form the state's main rainfed growing tracts; the area under *Bt* cotton continues to expand each year; and Surendranagar district records the highest output among Gujarat's districts (CICR, 2024-25). The yield potential of any crop is the outcome of a complex interplay of internal and external factors, and sound nutrient management plays a decisive role in realizing this potential across diverse agro-

climatic situations. Among agronomic interventions, nitrogen management assumes particular significance in cotton (*Gossypium hirsutum* L.) a long-duration, nutrient-exhaustive crop grown widely under irrigated conditions in India. Among plant nutrients, nitrogen (N) occupies a particularly central role in cotton. It sustains photosynthesis in the leaves, forms an integral part of protein synthesis and through its contribution to chlorophyll formation, the plant converts light into carbohydrates. Urea supplies more than 82% of the nitrogenous fertilizer used on Indian crops, with national consumption running to about 33 million tonnes a year. Too little nitrogen causes nutrient deficiency, which slows both vegetative and reproductive growth, leads to early aging of the plant and reduces yield. On the other hand, too much nitrogen promotes excessive vegetative growth, delays maturity and can also reduce crop productivity.

Conventional fertilizers such as urea, although used extensively, suffer from poor nutrient-use efficiency owing to losses through leaching, volatilization and fixation, which not only raise the cost of cultivation but also aggravate environmental problems such as eutrophication and greenhouse gas emissions. Nano-scale nitrogen fertilizers, such as nano urea, address these constraints by exploiting the principles of nanotechnology. Owing to their small particle size (<100 nm), large surface area and high reactivity, nano urea particles are absorbed more readily through the stomata and epidermal layers when sprayed on foliage, and release nutrients in a controlled, targeted manner that synchronizes nutrient supply with crop demand at critical growth stages while curtailing losses. Compared with conventional chemical fertilizers, nano fertilizers are preferred mainly for their efficiency and environmental compatibility. Conventional urea delivers nitrogen to the plant with only 30-50 per cent efficiency whereas nano urea exceeds 80 per cent. Since urea already accounts for 82 per cent of India's nitrogenous fertilizer consumption, some 33.6 million tonnes in 2019-20, nano urea and similar nano-nitrogen fertilizers hold real potential to improve nutrient-use efficiency and reduce input costs for farmers, particularly given how heavily today's agricultural productivity depends on fertilizer use (Pratima *et al.*, 2021). Incorporating foliar nano urea into the nutrient management schedule of *Bt.* cotton, in combination with reduced levels of soil-applied nitrogen, therefore offers a promising means of raising yield and improving the economics and sustainability of cotton production. Since information dealing directly with the response of *Bt.* cotton to nano urea remains limited, the present investigation was undertaken with the specific objective of evaluating the effect of foliar nano urea, applied together with varying levels of the recommended dose of nitrogen, on the growth, yield attributes, yield, quality and economics of *Bt.* cotton under irrigated conditions of the South Saurashtra Agro-climatic Zone of Gujarat.

MATERIALS AND METHODS

A field experiment entitled "Effect of nano urea on *Bt.* cotton under irrigated condition" was conducted during *kharif* 2023-24 and 2024-25 at the B-3 plot of the Cotton Research Station, Junagadh Agricultural University, Junagadh (21°30' N, 70°18' E) which falls under the South Saurashtra Agro-climatic Zone of Gujarat and experiences a semi-arid climate with hot, dry summers, moderate monsoon rainfall and cool, dry winters. The first shower of monsoon was received during third week of June in 2023 and fourth week of June in 2024. The crop growth periods of 2023-2024 and 2024-2025 saw total rainfall of 1700.7 and 2296.3 mm, respectively. The experimental soil was clayey in texture, slightly alkaline in reaction (pH 7.74-7.78), medium in available nitrogen (245-268 kg/ha) and phosphorus (23-27 kg/ha), and high in organic carbon and available potassium (386-401 kg/ha).

The *Bt.* cotton hybrid G. Cot. Hy. 24 BG II (SorathSwet Kanak), released by the Cotton Research Station, JAU, Junagadh in 2020 was used as the test crop. The experiment was laid out in a Randomized Block Design (RBD) with fourteen treatments replicated three times (42 plots), each gross plot measuring 6.30 m x 6.00 m with a net plot of 5.40 m x 2.40 m, at a spacing of 120 cm x 45 cm. The recommended dose of fertilizer (RDF) was 240-50-150 kg N-P₂O₅-K₂O/ha, with N applied in five splits (20% basal and 20% each at 30, 60, 90 and 120 DAS) and P₂O₅ and K₂O applied basally with a split top-dressing of K₂O at 30 DAS.

The fourteen treatments comprised: T₁: absolute control; T₂: 100% RDN + water spray at 30, 60 and 90 DAS; T₃ and T₄: 100% RDN + foliar urea at 1% and 2%, respectively; T₅ and T₆: 75% RDN + foliar urea at 1% and 2%; T₇ and T₈: 50% RDN + foliar urea at 1% and 2%; T₉ and T₁₀: 100% RDN + foliar nano urea at 2 and 4 ml/lit; T₁₁ and T₁₂: 75% RDN + foliar nano urea at 2 and 4 ml/lit; and T₁₃ and T₁₄: 50% RDN + foliar nano urea at 2 and 4 ml/lit, all foliar sprays being applied at 40, 70 and 90 DAS.

Observations were recorded on plant population, plant height (75, 125 DAS and harvest), dry matter accumulation (45, 75, 100 DAS), number of monopodial and sympodial branches, SPAD (chlorophyll) value (75 and 125 DAS), average boll weight, number of bolls per plant, ginning percentage, seed cotton yield, stalk yield, lint yield, and quality parameters (fibre length, fibre strength, micronaire value, oil content). Fibre quality parameters measured by digital Stapler at the cotton quality evaluation laboratory, cotton research station, J.A.U., Junagadh and oil content by nuclear magnetic resonance (NMR) spectroscopy method. Economics of each treatment was worked out in terms of cost of cultivation, gross realization, net realization and benefit:cost ratio, based on prevailing market prices (seed cotton Rs. 75/kg; cotton stalk Rs. 1/kg). Data were

statistically analyzed with RBD design by the procedure of Panse and Sukhatme (1985) and pooled analysis of variance was carried out over the two years of experimentation.

RESULTS

Growth parameters

Initial plant population and plant population at harvest were not significantly influenced by any treatment. Plant height, dry matter accumulation, number of sympodial branches and SPAD value were significantly influenced by the treatments. Treatment T₁₀ (100% RDN + nano urea 4 ml/lit) consistently recorded the significantly higher plant height at 75 DAS, 125 DAS and at harvest (130.50 cm pooled), remaining statistically at par with T₉ (100 % RDN with foliar spray of nano urea 2 ml/ lit water at 40, 70 and 90 DAS), T₄ (100 % RDN + foliar spray of 2 % urea at 40, 70 and 90 DAS), T₃ (100 % RDN + foliar spray of 1 % urea at 40, 70 and 90 DAS), T₁₂ (75 % RDN with foliar spray of nano urea 4 ml/ lit water at 40, 70 and 90 DAS) and T₁₁ (75 % RDN with foliar spray of nano urea 2 ml/ lit water at 40, 70 and 90 DAS), while the absolute control (T₁) recorded the significantly lowest height (75.83 cm) throughout. Dry matter accumulation at 45 DAS did not differ significantly among treatments, but at 75 and 100 DAS, T₁₀ recorded the significantly higher accumulation (1662 and 1988 kg/ha respectively) on par with T₉, T₄, T₃, T₁₂ and T₁₁. The number of monopodial branches remained statistically unaffected (2.00-2.33), whereas sympodial branches were significantly higher under T₁₀ (14.67), on par with the same group of treatments. SPAD value was significantly higher at both 75 DAS (70.67) and 125 DAS (64.83) under T₁₀, which was at par with treatment T₃, T₄, T₉, T₁₁ and T₁₂ (Table 1 & 2). Average boll weight and ginning percentage remained statistically unaffected by the treatments (pooled range 3.76-4.10 g and 32.16-35.31%, respectively). The number of bolls per plant was significantly higher under T₁₀ (33.22), on par with T₃, T₄, T₉, T₁₁ and T₁₂, against the lowest number (18.67) under T₁. The consistent superiority of treatment T₁₀ (100% RDN + foliar nano urea 4 ml/lit) across growth, yield and yield-attributing characters may be attributed to the nano-scale particle size and higher surface area of nano urea, which permits ready penetration through stomata and efficient translocation through plasmodesmata, thereby making nitrogen instantaneously available to actively growing meristematic tissues. Nitrogen being an essential constituent of protoplasm, protein and chlorophyll, its enhanced and timely availability through nano urea sprays likely favoured greater cell division and elongation, higher chlorophyll formation (reflected in higher SPAD values) and consequently better vegetative growth, more sympodial branches, greater boll retention and higher dry matter accumulation, ultimately translating into higher seed

cotton, lint and stalk yields. These findings are in close agreement with those reported by Hayyawati *et al.* (2018), Alzreejawi and Al-Juthery (2020), Reddy *et al.* (2022), Gousia *et al.* (2023), Sajjan *et al.* (2025) and Bhimashankar *et al.* (2024).

Seed cotton yield the principal economic parameter was significantly influenced by the treatments. The significantly higher seed cotton yield (2433 kg/ha), lint yield (861 kg/ha) and stalk yield (5458 kg/ha) were recorded under T₁₀ which was statistically at par with treatment T₃, T₄, T₉, T₁₁ and T₁₂, representing increases of 90.8% over the absolute control and 22.3% over 100% RDN with plain water spray (T₂). Among the 75% RDN treatments, foliar nano urea (T₁₁, T₁₂) produced seed cotton yield comparable to 100% RDN with conventional urea (T₃, T₄) indicating that a quarter of the soil-applied nitrogen could be substituted through foliar nano urea without yield penalty (Figure 1). Its markedly higher nutrient-use efficiency (>80%) relative to conventional urea (30-50%), its smaller particle size (20-50 nm) and its slow, targeted release pattern matching the critical nitrogen demand of squaring, flowering and boll-development stages can substitute a meaningful share of soil-applied nitrogen without penalising yield. This finding is corroborated by Modhvadiya *et al.* (2012), Basavanneppa *et al.* (2015), Malik *et al.* (2021) and Manibharathi *et al.* (2025) who similarly reported that a part of the recommended nitrogen dose could be compensated through foliar nutrition in *Bt. cotton*.

Quality parameters

Fibre length (27.10-28.47 mm), fibre strength (30.99-32.62 g/tex), micronaire value (4.49-4.99 µg/inch) and seed oil content (17.77-18.32%) were not significantly influenced by any treatment, indicating that the yield improvement obtained through nano urea and urea foliar sprays was achieved without deterioration of fibre or seed quality. The non-significant response of fibre quality traits and seed oil content confirms that these characters are predominantly governed by the genetic constitution of the hybrid rather than by the level or form of nitrogen nutrition, once the basic nutrient requirement of the crop is met, consistent with the reports of Singh *et al.* (2015), Zakzok *et al.* (2018), Kanjana (2020) and Omar *et al.* (2022).

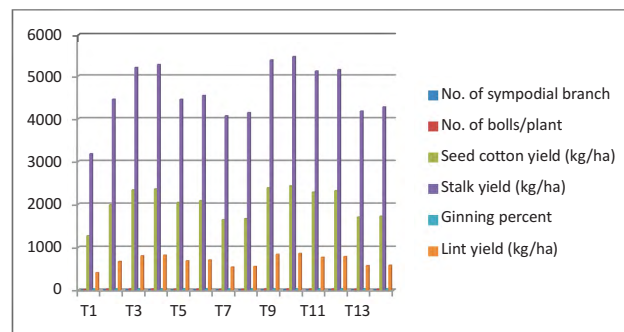


Fig 1: Graphical presentation on effect of nano urea on growth and yield parameters of *Bt. cotton* (Pooled results)

Table 1. Effect of nano urea on selected growth parameters of *Bt.* cotton (pooled mean of two years)

Treat. No.	Detail	Plant height (cm)			Dry matter accumulation (kg/ha)			SPAD value	
		At 75 DAS	125 DAS	At harvest	At 45 DAS	At 75 DAS	At 100 DAS	At 75 DAS	At 125 DAS
T ₁	Absolute control	63.61	73.50	75.83	442	1113	1441	38.50	35.67
T ₂	100 % RDN + water spray at 30, 60 and 90 DAS	82.83	97.67	101.50	475	1374	1702	59.17	51.83
T ₃	100 % RDN + foliar spray of 1 % urea	97.67	114.00	119.83	522	1569	1896	67.83	61.83
T ₄	100 % RDN + foliar spray of 2 % urea	100.83	117.50	124.50	525	1607	1936	69.83	63.33
T ₅	75 % RDN + foliar spray of 1 % urea	82.56	96.67	102.83	489	1403	1748	63.67	57.50
T ₆	75 % RDN + foliar spray of 2 % urea	85.89	99.33	104.67	496	1413	1741	64.17	58.50
T ₇	50 % RDN + foliar spray of 1 % urea	78.50	92.67	94.83	451	1265	1593	53.00	48.00
T ₈	50 % RDN + foliar spray of 2 % urea	79.95	96.33	96.17	458	1308	1636	54.50	49.00
T ₉	100 % RDN + foliar spray of nano urea 2 ml/ lit water	102.78	119.33	126.83	535	1631	1958	69.17	63.50
T ₁₀	100 % RDN + foliar spray of nano urea 4 ml/ lit water	108.50	123.83	130.50	543	1662	1988	70.67	64.83
T ₁₁	75 % RDN + foliar spray of nano urea 2 ml/ lit water	97.06	112.33	117.17	511	1528	1856	65.33	59.33
T ₁₂	75 % RDN + foliar spray of nano urea 4 ml/ lit water	99.22	114.83	119.33	514	1547	1875	66.17	61.00
T ₁₃	50 % RDN + foliar spray of nano urea 2 ml/ lit water	80.67	95.33	97.50	462	1334	1662	55.33	50.50
T ₁₄	50 % RDN + foliar spray of nano urea 4 ml/ lit water	82.06	96.33	100.83	466	1363	1691	56.83	51.17
S.E.m.±		4.52	4.27	4.03	25.22	50.89	66.10	2.48	2.65
C.D. at 5 %		12.82	12.13	11.44	NS	144	188	7.04	7.51
C.V. %		12.48	10.11	11.15	12.55	8.67	9.17	9.95	11.69
Y									
S.E.m.±		1.71		1.62	1.95	9.53	19.23	24.98	0.94
C.D. at 5 %		NS		NS	NS	NS	NS	NS	NS
Y x T									
S.E.m.±		5.81		6.05	7.29	35.66	71.96	93.48	3.51
C.D. at 5 %		NS		NS	NS	NS	NS	NS	NS

Table 2 : Effect of nano urea on selected growth and yield parameters of *Bt. cotton* (pooled mean of two years)

Treat. No.	No. of monopodial branch	No. of sympodial branch	No. of bolls/plant	Seed cotton yield (kg/ha)	Stalk yield (kg/ha)	Ginning percent	Lint yield (kg/ha)	Av. boll wt. (g)
T ₁	2.17	6.78	18.67	1275	3183	32.16	411	3.757
T ₂	2.00	11.00	27.05	1990	4460	33.84	674	4.002
T ₃	2.17	13.39	31.06	2337	5202	34.56	805	4.050
T ₄	2.33	14.00	31.78	2359	5273	34.77	821	4.074
T ₅	2.17	9.78	26.61	2046	4458	33.52	686	3.945
T ₆	2.17	10.78	27.06	2084	4548	33.93	707	3.982
T ₇	2.33	9.56	23.28	1650	4071	32.82	542	3.856
T ₈	2.00	9.84	24.17	1675	4147	33.17	556	3.881
T ₉	2.17	14.28	32.78	2387	5378	35.19	840	4.089
T ₁₀	2.00	14.67	33.22	2433	5458	35.31	861	4.104
T ₁₁	2.17	13.06	29.67	2285	5119	33.76	772	3.987
T ₁₂	2.33	13.22	30.61	2319	5152	34.05	788	4.022
T ₁₃	2.00	9.95	24.67	1712	4183	33.59	576	3.934
T ₁₄	2.17	10.22	25.45	1732	4280	33.69	585	3.953
S.E.m.±	0.16	0.59	1.40	84	193	0.66	31.52	0.071
C.D. at 5 %	NS	1.68	3.97	239	548	NS	89	NS
C.V. %	18.68	12.65	12.43	10.22	10.21	4.80	11.23	4.37
Y								
S.E.m.±	0.06	0.22	0.53	32	73	0.25	12	0.027
C.D. at 5 %	NS	NS	NS	NS	NS	NS	NS	NS
Y x T								
S.E.m.±	0.23	0.84	1.979	119	273	0.94	44	0.100
C.D. at 5 %	NS	NS	NS	NS	NS	NS	NS	NS

Table 3. *Bt.* cotton quality parameters as influenced by nano urea (pooled mean of two years)

Treat. No.	Fibre length (mm)	Fibre strength (g/tex)	Micronaire value	Oil content (%)
T ₁	27.10	30.99	4.985	18.10
T ₂	28.36	31.90	4.717	18.42
T ₃	28.37	32.17	4.674	18.45
T ₄	28.33	32.33	4.567	18.48
T ₅	27.73	31.70	4.683	18.47
T ₆	27.77	31.79	4.745	18.64
T ₇	27.77	31.36	4.878	18.59
T ₈	27.93	31.15	4.875	18.60
T ₉	28.39	32.40	4.519	18.53
T ₁₀	28.47	32.61	4.492	18.59
T ₁₁	28.01	32.22	4.568	18.61
T ₁₂	28.12	31.73	4.631	18.53
T ₁₃	27.98	31.69	4.810	18.52
T ₁₄	28.00	31.89	4.755	18.45
S.Em.±	0.28	0.361	0.110	0.183
C.D. at 5 %	NS	NS	NS	NS
C.V. %	2.41	2.78	5.75	2.42
Y				
S.Em.±	0.104	0.137	0.042	0.069
C.D. at 5 %	NS	NS	NS	NS
Y x T				
S.Em.±	0.389	0.511	0.156	0.259
C.D. at 5 %	NS	NS	NS	NS

Economics

The data presented in Table 4 revealed that the cost of cultivation progressively increased with an increase in the level of RDN as well as with the use of nano urea over conventional urea, ranging from ₹76,098/ha under the absolute control (T₁) to ₹1,02,839/ha under treatment T₁₀, on account of the added cost of fertilizers and the nano urea or urea sprays. Notwithstanding the higher input cost, the highest gross return (₹1,02,839/ha) and the highest net return (₹85,094/ha) were recorded under treatment T₁₀, closely followed by T₉ (₹83,500/ha) (100 % RDN with foliar

spray of nano urea 2 ml/ lit water at 40, 70 and 90 DAS), T₄ (₹82,810/ha) (100 % RDN + foliar spray of 2 % urea at 40, 70 and 90 DAS), T₃ (100 % RDN + foliar spray of 1 % urea at 40, 70 and 90 DAS), T₃ (₹81,451/ha), T₁₂ (₹79,449/ha) T₁₂ (75 % RDN with foliar spray of nano urea 4 ml/ lit water at 40, 70 and 90 DAS) and T₁₁ (₹78,661/ha) (75 % RDN with foliar spray of nano urea 2 ml/ lit water at 40, 70 and 90 DAS), the same group of treatments that recorded the significantly higher seed cotton yield. The lowest net return (₹22,710/ha) was recorded under the absolute control (T₁) despite its lowest cost of cultivation, on account of its

markedly lower yield. With regard to benefit:cost ratio, the highest value (1.83) was recorded under treatment T₁₀ and T₄ followed closely by T₃ (1.82) and 1.80 (T₁₁ and T₁₂), all recording a benefit : cost ratio of 2.40, indicating that treatment T₁₁ (75% RDN + foliar spray of nano urea 2 ml/lit at 40, 70 and 90 DAS), despite receiving 25 per cent less soil-applied nitrogen than T₃, T₄, T₉ and T₁₀, produced an economic efficiency almost at par with the treatments

receiving the full recommended dose of nitrogen. From the economic standpoint, the superior benefit:cost ratio of T₁₁ despite 25% lower soil-applied nitrogen underlines the practical value of foliar nano urea as a partial substitute for conventional fertilizer, a conclusion consistent with the economic gains reported for nano urea in other crops by Kumar *et al.* (2021), Dodiya *et al.* (2024), Patel *et al.* (2024) and Zalavadiya *et al.* (2024).

Table 4. Economics of *Bt. cotton* cultivation as influenced by nano urea

Treat. No.	Gross return (Rs/ha)	Cost of cultivation (Rs/ha)	Net return (Rs/ha)	B:C ratio
T ₁	98808	76098	22710	1.30
T ₂	153710	94875	58835	1.62
T ₃	180477	99026	81451	1.82
T ₄	182123	99388	82810	1.83
T ₅	157908	93752	64156	1.68
T ₆	160848	94300	66548	1.71
T ₇	127821	87253	40568	1.46
T ₈	129772	87649	42123	1.48
T ₉	184403	100903	83500	1.83
T ₁₀	187933	102839	85094	1.83
T ₁₁	176494	97833	78661	1.80
T ₁₂	179077	99628	79449	1.80
T ₁₃	132583	89270	43313	1.49
T ₁₄	134180	90903	43277	1.48
Particulars	Market rate	Particulars	Market rate	
Seed cotton sale	Rs 75.00 /kg	MOP	Rs 37.00 /kg	
Cotton stalk sale	Rs 1.00 /kg	Nano urea	Rs 400 /lit.	
Urea	Rs 5.93 /kg	DAP	Rs 27.00 /kg	

CONCLUSION

From the two-year field investigation, it may be concluded that application of 75% of the recommended dose of nitrogen (RDN) together with three foliar sprays of nano urea at 2 ml/litre of water at 40, 70 and 90 DAS constitutes the most efficient nitrogen management practice for *Bt. cotton* under irrigated conditions, since it produced seed cotton yield, yield attributes and benefit:cost ratio statistically and economically comparable to the full recommended dose of nitrogen, while saving 25% of the

soil-applied nitrogen and reducing the associated fertilizer cost and chemical load on the soil. Where the highest absolute yield is the objective, 100% RDN combined with foliar nano urea at 4 ml/lit (T₁₀) remains the superior option. Overall, nano urea can effectively substitute a part of the soil-applied nitrogen in *Bt. cotton* without compromising growth, yield, fibre quality or profitability, supporting its adoption as a sustainable component of nitrogen management in irrigated cotton production systems of the South Saurashtra Agro-climatic Zone of Gujarat.

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Practice-wise adoption of clean milk production practices and its correlation among tribal dairy farm women in Chhotaudepur district of Gujarat state

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ABSTRACT

The present study was conducted to assess the practice-wise adoption of clean milk production (CMP) practices and to determine the relationship between the adoption level and selected socio-economic characteristics of tribal dairy farm women in Chhotaudepur district of Gujarat. The study was conducted in Pavi-Jetpur and Bodeli talukas of Chhotaudepur district. From each taluka, three villages were selected and 20 tribal dairy farm women were selected from each village, resulting in a total sample of 120 respondents. Data were collected through a pre-tested structured interview schedule. The adoption of clean milk production practices was measured using a three-point continuum of “always”, “sometimes,” and “not at all”, assigned scores of 2, 1 and 0, respectively. The collected data were analyzed using frequency, percentage, mean score, rank and Pearson's correlation coefficient. The findings revealed that, among the different clean milk production practices, care to be taken by the milker during milking and care of milking utensils ranked first, with a mean score of 1.10 each, followed by care after milking (0.90), care of animal shed (0.70) and care of milch animals (0.50). The majority of respondents (70.83%) belonged to the medium adoption category, followed by 15.83 per cent with low adoption and 13.34 per cent with high adoption. Correlation analysis revealed that annual income ($r = -0.1969^{**}$) and milk production ($r = -0.2048^{**}$) had a negative and highly significant relationship with the adoption level of clean milk production practices. In contrast, education ($r = 0.3759^{**}$), experience in animal husbandry ($r = 0.1902^{**}$), occupation ($r = 0.2130^{**}$), social participation ($r = 0.2083^{**}$) and mass media exposure ($r = 0.2379^{**}$) showed a positive and highly significant relationship with the adoption level of clean milk production practices. The findings indicate the need for strengthening education, extension support, social participation and access to mass media to improve the adoption of clean milk production practices among tribal dairy farm women and thereby contribute to improved milk quality and sustainable dairy development.

Keywords: Clean milk production, tribal dairy farm women, adoption, adoption level, correlation, Chhotaudepur, Gujarat.

INTRODUCTION

The dairy sector is one of the most important components of the Indian agricultural economy and plays a vital role in strengthening rural livelihoods, employment and nutritional security. India continues to be the world's largest milk-producing country, with milk production showing a sustained upward trend owing to improvements in animal husbandry practices, dairy development programmes, technological interventions and increasing participation of rural households. The livestock sector makes an important contribution to agricultural Gross Value Added (GVA), while dairying provides a regular source of income and employment and serves as an important livelihood diversification strategy, particularly for landless, marginal and small farm households. Unlike crop production, which is often seasonal and vulnerable to climatic fluctuations,

dairy farming can provide a relatively continuous flow of income and food to rural families (Government of India, 2024).

Women play a central role in the Indian dairy production system and are actively involved in almost all livestock-related activities, including feeding and watering animals, cleaning animal sheds, fodder collection, calf care, milking, processing and, in many cases, marketing of milk and milk products. The contribution of women becomes particularly important in tribal communities, where livestock rearing is closely integrated with household farming systems and rural livelihoods. Previous studies have indicated that women's participation in extension activities, access to mass media, social participation, education and experience in animal husbandry influence their knowledge and adoption of improved dairy management practices (Patel and Chauhan, 2018; Meena *et al.*, 2019). Thus, improving

women's knowledge and adoption of scientific dairy practices can contribute not only to enhanced milk production but also to better household income, nutritional security and overall livelihood improvement.

Milk is a highly nutritious food and, at the same time, a highly perishable commodity. Its rich nutrient composition provides favourable conditions for the multiplication of microorganisms when hygienic conditions are not maintained. Contamination may occur at different stages of milk production and handling through unclean animals, contaminated udders, unhygienic hands of milkers, dirty utensils, contaminated water, unclean animal sheds, improper milking procedures and inadequate storage conditions. Such contamination can deteriorate milk quality, reduce its keeping quality and potentially increase public-health risks. Consequently, maintaining hygienic conditions from the animal and milking environment through collection, handling and storage is essential for ensuring safe and quality milk (Codex Alimentarius Commission, 2022). Clean Milk Production (CMP) encompasses a set of scientific and hygienic practices adopted before, during and after milking to minimize physical, chemical and microbial contamination and to maintain the natural quality and nutritional properties of milk. These practices include maintaining animal health and cleanliness, ensuring udder and milker hygiene, using clean milking utensils, maintaining cleanliness of the animal shed, filtering and properly handling milk, and adopting appropriate storage and transportation practices. Adoption of CMP practices can improve milk quality and shelf life, reduce spoilage and rejection, minimize the risk of milk-borne infections, enhance consumer confidence and improve the economic value of milk. Therefore, CMP is not merely a milk-quality issue but is also an important component of sustainable dairy development, farm profitability and public health (Singh *et al.*, 2015; Codex Alimentarius Commission, 2022).

Although the importance of hygienic milk production is well established, the adoption of CMP practices at the farm level is not necessarily uniform across all practices or categories of dairy farmers. Existing studies have largely focused on general knowledge, awareness or overall adoption of improved dairy practices, while comparatively less attention has been given to practice-wise adoption of specific clean milk production practices among tribal dairy farm women. Moreover, recent evidence specifically examining the association between socio-economic characteristics of tribal dairy farm women and their adoption of individual CMP practices remains limited, particularly in Gujarat. This represents an important research gap because adoption is often practice-specific and a farmer may regularly follow certain hygienic practices while neglecting others. Identifying such practice-wise differences can help extension personnel develop more

focused and need-based interventions rather than relying only on generalized dairy-management recommendations. Chhotaudepur district of Gujarat provides an appropriate setting for the present investigation because of its substantial tribal population and the important role of livestock rearing in the livelihood systems of rural households. Dairy activities are closely associated with household-level resource use and women's labour in the district. However, the specific extent to which tribal dairy farm women adopt individual clean milk production practices and the socio-economic characteristics associated with such adoption, require systematic assessment. A district-specific study is therefore justified to generate location-specific evidence that can complement broader studies on dairy development and help identify practices requiring greater extension attention.

In view of the above research gap and the livelihood and public-health significance of hygienic milk production, the present study was undertaken in Chhotaudepur district of Gujarat to assess the practice-wise adoption of clean milk production practices among tribal dairy farm women and to examine the relationship between selected socio-economic characteristics and their adoption of clean milk production practices. The findings are expected to provide useful empirical information for extension agencies, dairy development organizations and policymakers in formulating need-based training, awareness and intervention strategies for improving milk quality, strengthening dairy-based livelihoods and promoting safer milk production among tribal farming communities.

MATERIALS AND METHODS

The present investigation was conducted in Chhotaudepur district of Gujarat State. A multistage sampling procedure was followed for the selection of the study area and respondents. Pavi-Jetpur and Bodeli talukas of Chhotaudepur district were purposively selected considering the presence of a sizeable tribal population and a considerable number of tribal dairy farm women actively engaged in animal husbandry. From each selected taluka, three villages were purposively selected based on the prevalence of tribal dairy farming and the availability of eligible respondents, resulting in a total of six villages. From each selected village, 20 tribal dairy farm women actively engaged in dairy farming and animal husbandry were purposively selected, constituting a total sample size of 120 respondents. A well-structured and pre-tested interview schedule was developed in consultation with experts in Dairy Science, Veterinary Science, and Agricultural Extension Education to collect the required information. The interview schedule was prepared in accordance with the objectives of the study. Before the final

survey, the interview schedule was pre-tested with a small group of respondents outside the selected study area and necessary modifications were made to improve its clarity, relevance and validity.

The practice-wise adoption of clean milk production practices was measured using a three-point continuum, namely 'Always', 'Sometimes' and 'Not at all', with scores of 2, 1, and 0, respectively. The total adoption score for each respondent was computed by summing the scores obtained for all the selected practices. Further, the mean score for each practice was calculated and the practices were ranked based on their mean scores to determine the relative extent of adoption. The overall adoption was measured with mean and standard deviation. The required data were collected through the personal interview method. The collected data

were systematically classified, tabulated, and analyzed using appropriate statistical tools such as frequency, percentage, mean score, rank and Pearson's correlation coefficient to achieve the objectives of the study and draw meaningful conclusions.

RESULTS AND DISCUSSION

Practice-wise adoption of clean milk production by tribal dairy farmwomen

An attempt was made to ascertain practice-wise adoption of clean milk production by dairy farmwomen. The data regarding practice wise adoption of clean milk production are presented in Table 1.

Table 1 : Practice-wise adoption of clean milk production by tribal dairy farmwomen

n=120

Sr. no.	Clean milk production practices	Always	Sometimes	Not at all	Total score	Mean score	Rank
1	Care of milch animal	12 (10.00)	35 (29.17)	73 (60.83)	059	0.50	IV
2	Care be taken by the milker while milking	51 (42.50)	27 (22.50)	42 (35.00)	129	1.10	I
3	Care of milking utensils	52 (43.34)	25 (20.84)	43 (35.82)	129	1.10	I
4	Care of animal shed	28 (23.30)	31 (25.80)	61 (50.90)	087	0.70	III
5	Care after milking	39	26	55	104	0.90	II

Figures in brackets indicate percentages

The practice-wise adoption of clean milk production (CMP) practices among tribal dairy farm women is presented in Table 1. The findings indicated that care to be taken by the milker during milking and care of milking utensils were the most frequently adopted practices, each securing the first rank with a mean score of 1.10. These were followed by care after milking (mean score = 0.90), care of the animal shed (mean score = 0.70) and care of milch animals (mean score = 0.50), which ranked second, third and fourth, respectively. The comparatively higher adoption of care of milking utensils (43.34%) and care to be taken by the milker while milking (42.50%) may be attributed to the direct and visible relationship of these practices with milk cleanliness and quality. Further, practices such as using clean and dry utensils, cleaning milking utensils after milking, maintaining personal hygiene, keeping fingernails short, covering the head during milking and avoiding smoking or chewing tobacco during milking can be performed at the household level with comparatively less expenditure. The relatively better adoption of these practices may therefore be associated with their simplicity, familiarity and direct

relevance to milk quality and marketability.

However, the adoption of practices related to care of milch animals was comparatively low, with a mean score of 0.50 and 60.83 per cent of the respondents reported that they did not follow these practices regularly. Similarly, adoption of animal shed care was relatively low, with a mean score of 0.70 and 50.90 per cent of respondents reported that they did not follow the recommended practices. The lower adoption of these practices may be attributed to inadequate technical knowledge regarding animal hygiene and health management, additional labour requirements, limited availability of resources, financial constraints and inadequate access to veterinary and extension services. These findings indicate that although farmwomen were comparatively more attentive to immediate milking and utensil hygiene, greater emphasis is required on preventive animal health and hygienic housing management for achieving comprehensive clean milk production. These findings are in agreement with Gade *et al.* (2014), Usadadiya and Prajapati (2023), Usadadiya *et al.* (2023) and Singh *et al.* (2024).

Table 2 : Overall adoption level of clean milk production by tribal dairy farmwomen

Sr. no.	Adoption level	Frequency	Percentage
1	Low (below 24.34 score)	19.00	15.83
2	Medium (between 24.34 to 34.04 score)	85.00	70.83
3	High (above 34.04 score)	16.00	13.34
Total		120	100.00

The distribution of tribal dairy farmwomen according to their overall adoption of clean milk production practices is presented in Table 2. The findings revealed that the majority of the respondents (70.83%) belonged to the medium adoption category, followed by 15.83 per cent who had a low level of adoption and 13.34 per cent who had a high level of adoption. Thus, the overall adoption of clean milk production practices among the tribal dairy farmwomen was predominantly medium.

The predominance of medium adoption may be attributed to the adoption of simple and familiar practices that can be routinely performed at the household level, particularly those related to milking hygiene, cleaning of utensils and routine animal-shed management. However, adoption of practices requiring specialized technical knowledge, additional inputs or greater financial investment, such as udder and teat disinfection, post-milking teat dipping, proper drainage, pucca flooring and fly-control measures, was comparatively low. Consequently, although the respondents had adopted several basic clean milk production practices, the adoption was not sufficiently comprehensive to place the majority of respondents in the

high adoption category. The relatively small proportion of respondents in the high adoption category (13.34%) indicates considerable scope for improving the adoption of recommended clean milk production practices. Similarly, the 15.83 per cent of respondents belonging to the low adoption category require greater attention through targeted extension interventions. Differences in technical knowledge, access to veterinary and extension services, availability of resources, financial capacity and exposure to dairy-related information may have contributed to the variation in adoption levels. These findings are in agreement with Gade *et al.* (2014), Usadadiya and Prajapati (2023), Usadadiya *et al.* (2023) and Singh *et al.* (2024).

Relationship between profile of tribal dairy farm women and their adoption of clean milk production practices:

An attempt was also made in this investigation to ascertain the relationship between socio-economic characteristics of the tribal dairy farm women and their adoption of clean milk production practices. The data in this regard are presented in Table 3.

Table 3 : Relationship between the profile of tribal dairy farm women and extent of adoption

Sr. No.	Independent variable	Co-efficient of correlation value 'r'
1	Age	-0.1234 NS
2	Education	0.3759**
3	Experience in animal husbandry practices	0.1902**
4	Occupation	0.2130**
5	Land holding	0.0340 NS
6	Annual income	-0.1969 **
7	Herd size	-0.0450 NS
8	Milk production	-0.2048 **
9	Family type	0.1115 NS
10	Social participation	0.2083**
11	Mass media exposure	0.2379**

* 5 per cent level of significance

** 1 per cent level of significance

The correlation analysis presented in Table 3 indicated that annual income ($r = -0.1969^{**}$) and milk production ($r = -0.2048^{**}$) had a negative and highly significant relationship with the adoption of clean milk production practices. Conversely, education ($r = 0.3759^{**}$), experience in animal husbandry ($r = 0.1902^{**}$), occupation ($r = 0.2130^{**}$), social participation ($r = 0.2083^{**}$), and mass media exposure ($r = 0.2379^{**}$) showed a positive and highly significant association with adoption. The variables age, landholding, herd size, and family type did not exhibit any significant relationship with the adoption level.

The positive association of education, farming experience, social participation, and mass media exposure indicates that respondents with better access to knowledge, extension services and social networks were more likely to adopt recommended clean milk production practices. The negative association of annual income and milk production with adoption suggests that higher values of these variables were associated with comparatively lower adoption scores in the present study. However, the observed correlation does not establish a causal relationship, and the underlying reasons for this pattern require further investigation. The present findings corroborate those of Rathod *et al.* (2012), Kumar *et al.* (2017) and Verma *et al.* (2021)

CONCLUSION

The study revealed that among the various clean milk production practices, care to be taken by the milker during milking and care of milking utensils were the most widely adopted practices, followed by care after milking, care of the animal shed and care of milch animals. The findings indicate that tribal dairy farm women had relatively higher adoption of hygienic practices directly associated with the milking process than practices related to animal health and housing management. The correlation analysis demonstrated that education, occupation, experience in animal husbandry, social participation, and mass media exposure were significantly and positively associated with adoption of clean milk production practices. In contrast, annual income and milk production exhibited a significant negative association with adoption. The study highlights the need to strengthen extension education programmes, practical training, mass media communication and capacity-building initiatives targeted at tribal dairy farm women to improve the adoption of recommended clean milk production practices. Such interventions will enhance milk quality, improve public health, increase farmers' incomes and ensure sustainable dairy development in tribal regions.

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Gujarat Amaranth 6 (SKNA 401): Development, multi-environment evaluation and characterization of a grain amaranth (*Amaranthus hypochondriacus* L.) variety

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ABSTRACT

Grain amaranth (*Amaranthus* spp.) is a nutritionally important pseudo cereal with considerable potential for enhancing food and nutritional security. The present study reports the development, multi-environment evaluation and biochemical characterization of SKNA 401, subsequently identified as Gujarat Amaranth 6 (GA 6). The genotype was developed through pure-line selection and evaluated over a ten year period (2008-09 to 2017-18) under state varietal trials and the All India Coordinated Research Project (AICRP) on Potential Crops. Across state level evaluations, SKNA 401 recorded an overall mean grain yield of 1884 kg/ha, representing yield advantages of 10.37% and 10.82% over the local check GA 3 and the national check GA 2, respectively. Under Gujarat agroecological conditions in AICRP trials, the genotype outperformed the national checks GA 2, Suvarna, BGA-2 and RMA-7. SKNA 401 exhibited desirable agronomic characteristics, including early maturity, reduced plant height and an erect mono stem growth habit. The genotype also recorded higher protein (11.52%) and lysine (8.58 g/100 g protein) contents than the check varieties, along with satisfactory field tolerance to the major diseases and insect pests encountered during the evaluation period. The results demonstrate that SKNA 401 is a high-yielding and nutritionally superior grain amaranth variety suitable for cultivation under the agro-climatic conditions of Gujarat.

Keywords: Grain yield, multi-environment evaluation, pure-line selection, grain quality, lysine, varietal development.

INTRODUCTION

Grain amaranth (*Amaranthus* spp.) is an underutilized C₄ pseudocereal recognized for its high nutritional value and remarkable adaptability to diverse agro-climatic conditions. The grain is an excellent source of high-quality protein with a favourable lysine-rich amino acid profile and contains appreciable amounts of dietary fibre, minerals, vitamins and bioactive compounds (Caselato-Sousa and Amaya-Farfan, 2012; Rivero-Meza *et al.*, 2023). Its C₄ photosynthetic pathway enables efficient carbon fixation under high temperature, intense solar radiation and limited moisture conditions, making it suitable for cultivation in marginal and stress-prone environments (Stetter *et al.*, 2018). In addition, its gluten-free nature and functional properties have increased its importance as a nutritious food crop and

attracted growing scientific and commercial interest worldwide (Caselato-Sousa and Amaya-Farfan, 2012; Stetter *et al.*, 2018).

In India, grain amaranth is cultivated in several states, including Gujarat, Rajasthan, Uttarakhand, Himachal Pradesh, Maharashtra and parts of the North-Eastern region, where it contributes to food and nutritional security (Joshi *et al.*, 2018; Stetter *et al.*, 2018). In Gujarat, where it is commonly known as rajgira, the crop is mainly grown during the *rabi* season and is widely consumed as flour, popped grain and confectionery products. Despite its nutritional and agronomic advantages, grain amaranth remains underexploited, highlighting the need for the development of improved cultivars with higher grain yield, early maturity, lodging resistance and superior grain quality (Joshi *et al.*, 2018; Stetter *et al.*, 2018). Comprehensive

evaluation of agronomic performance, grain yield and grain quality is essential for identifying superior grain amaranth genotypes suitable for varietal development.

Therefore, the present study was undertaken to evaluate the agronomic performance, grain yield and biochemical quality of the promising grain amaranth genotype SKNA 401. The study aimed to generate comprehensive evidence on its performance and assess its potential for varietal development and cultivation under Gujarat conditions.

MATERIALS AND METHODS

Plant material and breeding method

The grain amaranth genotype SKNA 401 was developed through pure-line selection from a locally adapted germplasm maintained at the Centre for Crop Improvement, Sardarkrushinagar Dantiwada Agricultural University (SDAU), Sardarkrushinagar, Gujarat, India. A superior individual plant was selected based on desirable agronomic attributes and advanced through successive generations of progeny selection to achieve genetic uniformity and stability before its evaluation in comparative varietal trials.

Multi-environment evaluation

The performance of SKNA 401 was assessed over a ten year period (2008-09 to 2017-18) through a series of state and national coordinated varietal trials. At the state level, the genotype was evaluated in the State Seed Varietal Trials (SSVT) during 2008-09 to 2011-12 at the Centre for Crop Improvement, SDAU, Sardarkrushinagar. Subsequently, it was evaluated in the Large Scale Varietal Trials (LSVT) during 2015-16 to 2017-18 at four locations in Gujarat, namely Sardarkrushinagar, Ladol, Kholwada and Aseda.

At the national level, SKNA 401 was evaluated under the All India Coordinated Research Project (AICRP) on Potential Crops in the Initial Varietal Trial (IVT) during 2012-13 and the Advanced Varietal Trial-I (AVT-I) during 2014-15 across seven locations representing diverse agro-climatic regions of India, viz., Sardarkrushinagar (Gujarat), Mandor (Rajasthan), Rahuri (Maharashtra), Ambikapur (Chhattisgarh), Bhubaneswar (Odisha), Delhi and Ranchi (Jharkhand).

The genotype was compared with the local check GA 3 and the national check GA 2 in the state trials, whereas under the AICRP trials it was evaluated against GA 2 together with the national checks Suvarna, BGA-2 and RMA-7. All experiments were conducted in a randomized block design with three replications following the standard experimental protocols prescribed under the AICRP on Potential Crops.

Crop management and recording of observations

The crop was grown under irrigated *rabi* conditions using a

spacing of 45 cm × 10-15 cm, a seed rate of 1.5 kg/ha and the recommended fertilizer dose of 60:40:0 kg N:P₂O₅:K₂O. All recommended agronomic and crop protection practices were adopted uniformly across experimental sites.

Observations were recorded on grain yield, plant height, days to 50% flowering, days to maturity, inflorescence length, inflorescence girth, straw yield and test weight following the standard descriptors for grain amaranth. The incidence of major diseases and insect pests was monitored under natural field conditions throughout the crop growth period.

Biochemical analysis

Grain samples of SKNA 401 and the check varieties were analysed at the Central Instrumentation Laboratory, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, for protein, oil, iron, zinc, copper, manganese and lysine contents using standard analytical procedures.

Statistical analysis

The experimental data were subjected to analysis of variance (ANOVA) appropriate for a randomized block design. Mean grain yield, standard error of the mean [S.E.m. (±)], critical difference (CD) at the 5% probability level and coefficient of variation (CV%) were computed following the standard statistical procedures adopted under the AICRP on Potential Crops. The percentage superiority of SKNA 401 over the respective check varieties was estimated based on pooled mean grain yield across environments.

Results and discussion

Grain yield performance in state trials

The grain yield performance of SKNA 401 was evaluated under the State Seed Varietal Trial (SSVT) and Large Scale Varietal Trial (LSVT) during 2008-09 to 2017-18 (Table 1). Across all state level evaluations, SKNA 401 recorded an overall mean grain yield of 1884 kg/ha, compared with 1707 kg/ha for the local check GA 3 and 1700 kg/ha for the national check GA 2, representing yield advantages of 10.37% and 10.82%, respectively. On a weighted mean basis, SKNA 401 recorded a grain yield of 1912 kg/ha, exceeding GA 3 and GA 2 by 12.01% and 11.68%, respectively.

The superiority of SKNA 401 was evident in 13 of the 15 triallocation combinations evaluated, indicating its consistent yield performance across diverse environments. The sustained superiority over both, the local and national check varieties demonstrate the high yield potential and broad adaptability of SKNA 401 under the agro-climatic conditions of Gujarat.

Table 1 : Grain yield performance of SKNA 401 compared with the check varieties GA 3 and GA 2 in State Seed Varietal Trial (SSVT) and Large Scale Varietal Trial (LSVT) conducted in Gujarat during 2008-09 to 2017-18.

Trial	Year	SKNA 401 (kg/ha)	GA 3 – LC (kg/ha)	GA 2 – NC (kg/ha)	% inc. over GA 3	% inc. over GA 2
SSVT	2008-09 to 2011-12	1781 (mean)	1698	14.52	—	—
LSVT	2015-16 to 2017-18	1989 (mean)	1781	18.21	—	—
Overall mean	2008-09 to 2017-18	1884	1707	1700	10.37	10.82
Weighted mean	2008-09 to 2017-18	1912	1707	1712	12.01	11.68
Frequency of superiority	—	13 / 15	—	—	—	—

Source: Compiled from institutional trial records, Centre for Crop Improvement, SDAU, Sardarkrushinagar. LC = local check; NC = national check

Grain yield performance in AICRP trials

The grain yield performance of SKNA 401 was evaluated under the All India Coordinated Research Project (AICRP) on Potential Crops through the Initial Varietal Trial (IVT; 2012-13) and the Advanced Varietal Trial-I (AVT-I; 2014-15) across seven locations representing diverse agro-climatic regions of India. Across all test locations, SKNA 401 recorded an overall mean grain yield of 1134 kg/ha.

When the analysis was restricted to the Gujarat location, SKNA 401 recorded a mean grain yield of 1699 kg/ha, which exceeded the national checks GA 2, Suvarna, BGA-2 and RMA-7 by 5.07%, 38.36%, 14.48% and 11.05%, respectively (Table 2). The superior performance of SKNA 401 under Gujarat conditions, together with its consistent yield advantage in the state varietal trials, indicates its suitability for cultivation in the grain amaranth-growing regions of Gujarat.

Table 2. Mean grain yield performance of SKNA 401 (GA 6) against national checks in AICRP trials within Gujarat

Sr. No	Trial	Mean yield in Gujarat (kg/ha)	% increase over check
1.	GA 2 (national check)	1617	5.07
2.	Suvarna	1228	38.36
3.	BGA-2	1484	14.48
4.	RMA-7	1530	11.05
5.	SKNA 401	1699	-

Agronomic and morphological characteristics

SKNA 401 exhibited distinct agronomic and morphological characteristics that differentiated it from the check varieties (Table 3). The genotype possessed an erect, monostem growth habit with light-green foliage, stem and inflorescence throughout the crop growth period, whereas GA 3 exhibited light pink to light red pigmentation and GA 2 was characterized by red foliage.

SKNA 401 attained 50% flowering in an average of 54 days (range: 43-65 days) and reached physiological maturity in

105 days (range: 88-117 days), indicating earlier maturity than GA 2 (110 days) and comparable maturity to GA 3 (106 days). The mean plant height of SKNA 401 was 143.3 cm (range: 112.0-172.0 cm), which was lower than that of GA 3 (152.6 -160.7 cm) and GA 2 (169.1-178.2 cm). The genotype recorded a test weight of 8.06 g/10 ml, which was marginally higher than that of GA 3 (8.03 g/10 ml) and GA 2 (8.02 g/10 ml). The grains of SKNA 401 were light creamy-white in colour, whereas the check varieties produced creamy-white grains.

Table 3 : Characteristic features of SKNA 401 with checks

Sr. No	Character	SKNA 401	GA 3 (local check)	GA 2 (national check)
1.	Plant type	Erect, monostem	Erect, monostem	Erect, 1-2 branches
2.	Foliage / stem / inflorescence colour	Light green	Light pink / light red	Red
3.	Days to 50% flowering (mean)	54	50	53
4.	Days to maturity (mean)	105	106	110
5.	Plant height, cm (mean)	143.3	152.6-160.7	169.1-178.2
6.	Test weight, g/10 ml (mean)	8.06	8.03	8.02
7.	Grain colour	Light creamy white	Creamy white	Creamy white
8.	Average grain yield, kg/ha	1821	1642	1591

Grain quality and biochemical composition

The biochemical composition of SKNA 401 and the check varieties is presented in Table 4. SKNA 401 recorded a protein content of 11.52%, which was marginally higher than that of GA 3 (11.42%) and GA 2 (11.29%). The genotype also exhibited a higher lysine content (8.58 g/100 g protein) than GA 3 (7.69 g/100 g protein) and GA 2 (6.12 g/100 g protein), indicating its superior protein quality. The higher lysine content observed in SKNA 401 is consistent with previous reports highlighting grain amaranth as an excellent source of high-quality protein with a favourable

amino acid composition (Caselato-Sousa and Amaya-Farfan, 2012; Rivero-Meza *et al.*, 2023).

The oil content of SKNA 401 was 7.80%, while micronutrient analysis revealed iron, zinc, copper and manganese contents of 16.45, 2.90, 0.21 and 1.20 mg/100 g, respectively. Although the iron content was lower than that of GA 3, SKNA 401 recorded zinc content comparable to the check varieties. The improved protein quality together with its favourable micronutrient composition indicates the nutritional potential of SKNA 401 as a grain amaranth variety for food and nutritional security.

Table 4 : Grain biochemical composition of SKNA 401 (GA 6) and check varieties

Sr. No	Parameter	SKNA 401	GA 3	GA 2
1.	Protein content (%)	11.52	11.42	11.29
2.	Lysine (g/100 g protein)	8.58	7.69	6.12
3.	Oil content (%)	7.80	—	8.50
4.	Fe (mg/100 g)	16.45	27.0	19.40
5.	Zn (mg/100 g)	2.90	2.80	2.95
6.	Cu (mg/100 g)	0.21	0.29	0.29
7.	Mn (mg/100 g)	1.20	1.40	1.35

Reaction to diseases and insect pests

No economically important incidence of major diseases or insect pests, including storage pests, was observed in SKNA 401 under natural field conditions throughout the evaluation period. The genotype exhibited satisfactory field tolerance

to the prevailing biotic stresses and performed comparably to the check varieties under the experimental conditions.

Implications for varietal development

The results of the present study demonstrated that SKNA 401 possesses several desirable attributes, including

superior grain yield, early maturity, favourable agronomic characteristics and enhanced grain quality. The consistent performance of the genotype across multi-location evaluations under Gujarat conditions indicates its suitability for cultivation in the target production environments. Collectively, these findings highlight the potential of SKNA 401 as a valuable genetic resource for grain amaranth improvement and varietal development programmes.

The variety Gujarat amaranth 6 is released by Central Variety Release Committee and Notified under the Gazette of India with notification No. S.O. 456(E) Sr. No. 131, New Delhi, dated 29, January, 2021.

The variety Gujarat amaranth 6 is deposited at NBPGR, New Delhi for long term storage and allotted IC Number (IC 631711) by ICAR-NBPGR.

CONCLUSION

SKNA 401, a grain amaranth genotype developed through pure-line selection at the Centre for Crop Improvement, Sardarkrushinagar Dantiwada Agricultural University, was evaluated over a ten-year period under state and national coordinated trials. The genotype consistently outperformed the check varieties in grain yield under Gujarat conditions and exhibited desirable agronomic characteristics, including early maturity, reduced plant height and superior grain quality, particularly with respect to protein and lysine content. Molecular characterization confirmed its genetic distinctness from the existing check varieties, while field

evaluation demonstrated satisfactory tolerance to the major diseases and insect pests encountered during the study period. The combined agronomic performance and grain quality of SKNA 401 demonstrate its suitability for cultivation under the agro-climatic conditions of Gujarat and its potential as a valuable genetic resource for future grain amaranth improvement programmes.

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Genetic variability, trait association and yield determinants in kalingada [*Citrullus lanatus* (Thunb.) Matsum & Nakai] : implications for targeted crop improvement

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ABSTRACT

Kalingada is a nutritionally valuable yet underexploited cucurbit crop with substantial potential for genetic improvement. Effective selection requires a comprehensive understanding of the extent of genetic variability and the interrelationships among yield-contributing traits. Twenty-four kalingada genotypes were evaluated for fourteen morphological, yield-related and quality traits to assess genetic variability, trait associations and the contribution of individual traits to fruit yield. Considerable variability was observed among the genotypes, with total number of fruits per plant, total number of pickings, fruit length and fruit yield per plant exhibiting high phenotypic and genotypic coefficients of variation. These traits also recorded high heritability coupled with high genetic advance, indicating the predominance of additive gene effects and the potential effectiveness of selection. Fruit yield per plant exhibited significant positive associations with total number of fruits per plant, total number of pickings, days to last picking and primary branches per vine at both phenotypic and genotypic levels, whereas days to opening of the first female flower, days to first picking and total soluble solids (TSS) showed significant negative associations with yield. Path-coefficient analysis revealed that total number of fruits per plant and average fruit weight exerted the highest positive direct effects on fruit yield, while days to first picking, days to edible maturity, fruit length, total soluble solids (TSS) and days to last picking exhibited negative direct effects; however, fruit diameter and primary branches per vine, despite negligible direct effects, contributed to yield mainly through positive indirect effects via total number of fruits per plant. The results indicated that selection based on fruit number, picking frequency, fruit diameter and primary branches per vine could be effective for enhancing fruit yield in kalingada, whereas fruit weight, despite its high direct effect, showed limited net contribution owing to its non-significant correlation with yield, and the study provides useful information for future genetic improvement programmes

Keywords : Kalingada, genetic variability, heritability, correlation, path analysis

INTRODUCTION

Kalingada [*Citrullus lanatus* (Thunb.) Matsum & Nakai] is a diploid species ($2n = 2X = 22$) belonging to the family Cucurbitaceae and is cultivated in several parts of India, although its commercial potential remains largely underexploited (Levi *et al.*, 2001). It is known by various regional names, including Kalind in Sanskrit, Kalingad in Marathi, Tarbooj in Hindi and Mateera in Marwari. The immature fruits, weighing approximately 100-150 g, are consumed as a vegetable and are valued for their flavour, nutritional properties and tolerance to dry growing conditions. Kalingada possesses considerable nutritional

value, with its fruits and seeds containing carbohydrates, proteins, minerals, fatty acids and several bioactive compounds. The fruits are characterized by the presence of carotenoids, particularly lycopene and β -carotene, as well as phenolic compounds and ascorbic acid, which contribute to their antioxidant potential (Nagal *et al.*, 2012; Zamuz *et al.*, 2021). Kalingada also contains L-citrulline and L-arginine, important amino acids associated with nitric oxide metabolism and vascular health (Tarazona-Diaz *et al.*, 2011; Zamuz *et al.*, 2021). The seeds are nutritionally valuable owing to their appreciable oil and protein contents and their predominance of unsaturated fatty acids, particularly linoleic acid (Mahla *et al.*, 2018). These nutritional and bioactive constituents enhance the dietary and functional

importance of kalingada and provide opportunities for its utilization as a nutrient-rich vegetable and seed crop. Moreover, its adaptation to dry environments and nutritional attributes make kalingada a valuable crop for dietary diversification and sustainable production in water-limited regions (Kumar *et al.*, 2025). Despite these attributes, systematic crop-improvement efforts in kalingada have remained limited.

Any breeding programme requires an understanding of the extent of genetic variability and its heritability, as these determine the effectiveness of selection and the identification of promising genotypes for further advancement. Previous investigations in *Citrullus lanatus* (Thunb.) Matsum & Nakai have revealed substantial genetic variability for yield and its component traits, with high heritability and genetic advance reported for several characters, indicating the potential for effective selection (Mahla and Choudhary, 2013; Mahla *et al.*, 2018). Studies involving Indian *Citrullus* germplasm have also demonstrated considerable variation for phenological, fruit and yield-related traits, along with significant genetic divergence among genotypes, providing valuable opportunities for crop improvement (Singh *et al.*, 2017; Singh *et al.*, 2018). More recently, phenotypic evaluation of seed-purpose *C. lanatus* genotypes under the arid conditions of the Thar region revealed substantial variability for important agronomic traits and identified genotypes with desirable trait combinations, emphasizing the breeding potential of this germplasm (Kumar *et al.*, 2025).

Kalingada exhibits characteristic cucurbit floral morphology, with solitary, axillary, yellow flowers and monoecious sex expression, in which staminate and pistillate flowers are produced separately on the same plant. Flowering and fruit development are influenced by genotype and environmental conditions, and variation in phenological traits such as days to flowering and maturity is of considerable significance for earliness, adaptation and yield improvement (Paris, 2015). Floral biology and pollination behaviour are also important considerations in Kalingada breeding, particularly for the development of controlled crosses and the utilization of diverse germplasm. Correlation and path-coefficient analyses provide additional insight into the relationships among traits by

identifying characters that contribute directly or indirectly to yield. As kalingada has received relatively limited research attention, both in India and elsewhere, the present study was undertaken to assess genetic variability, heritability, genetic advance and inter-trait associations among vegetable-type landraces, to identify promising traits and genotypes for future breeding programmes.

MATERIAL AND METHODS

The study was conducted at the Centre for Crop Improvement (CCI), Sardarkrushinagar Dantiwada Agricultural University (SDAU), Dantiwada, Gujarat during the summer season of 2022. Twenty-four Kalingada genotypes maintained at CCI were evaluated in a Randomized Block Design with three replications, maintaining a spacing of 3.0 × 1.0 m between plants. Standard package of practices was followed throughout the crop period. Observations were recorded on five randomly selected plants from each plot for fourteen traits, viz., days to opening of the first male flower, days to opening of the first female flower, days to first picking, days to edible maturity, average fruit weight (g), fruit length (cm), fruit diameter (cm), total number of fruits per plant, total number of pickings, days to last picking, number of primary branches per vine, length of main vine (m), total soluble solids (°Brix) and fruit yield per plant (g).

Analysis of variance was performed following the procedure of Panse and Sukhatme (1985). Phenotypic and genotypic coefficients of variation, broad-sense heritability and genetic advance as a percentage of the mean were estimated following Burton and Devane (1953), Allard (1960) and Johnson *et al.* (1955), respectively. GCV and PCV were categorized according to Sivasubramanian and Madhavamenon (1973), while heritability and genetic advance as a percentage of the mean were classified as per Johnson *et al.* (1955). The respective criteria presented in Table 1. Genotypic and phenotypic correlation coefficients were estimated following Falconer (1981). Path-coefficient analysis, as proposed by Wright (1921) and adapted for plant breeding by Dewey and Lu (1959), was employed to partition the direct and indirect effects of component traits on fruit yield. The magnitude of direct and indirect effects was interpreted according to the scale suggested by Lenka

Table 1 : Categorization of genetic estimates

Estimates	GCV & PCV (%)	Heritability (h^2b) (%)	GAM (%)
Low	0 to 10	0 to 30	0 to 10
Moderate	10 to 20	30 to 60	10 to 20
High	More than 20	More than 60	More than 20

RESULTS AND DISCUSSION

Analysis of variance among the twenty-four genotypes revealed significant differences for all the traits studied, indicating the presence of substantial variability among the genotypes, which provides considerable scope for effective selection and further genetic improvement of kalingada.

Phenotypic and Genotypic Coefficient of Variation (PCV and GCV)

The highest PCV and GCV were recorded for total number

of fruits per plant, followed by total number of pickings, fruit length and fruit yield per plant (Table 2). Total soluble solids (TSS) and average fruit weight exhibited moderate PCV and GCV, whereas days to opening of the first male flower, days to opening of the first female flower, days to first picking, days to edible maturity, fruit diameter, days to last picking, primary branches per vine and length of main vine recorded comparatively low values for both parameters.

Table 2 : Variability parameters indicating variation among Kalingada genotypes for fourteen traits

Sr. No.	Trait	Mean	Range	σ^2_g	σ^2_p	GCV %	PCV %	$h^2(b)\%$	GA	GAM%
1	MF	35.54	32.67 - 39.33	1.94	3.07	3.92	4.93	63.36	2.29	6.43
2	FF	44.51	41.33 - 47.67	4.14	4.63	4.57	4.83	89.37	3.96	8.90
3	FP	56.97	54.00 - 66.00	9.41	10.74	5.38	5.75	87.59	5.91	10.38
4	DM	6.76	5.00 - 8.33	0.41	0.67	9.48	12.10	61.40	1.04	15.30
5	FW	156.52	129.97 - 190.40	274.47	341.02	10.58	11.80	80.48	30.62	19.56
6	FL	7.97	6.39 - 14.88	2.96	3.19	21.56	22.40	92.60	3.41	42.74
7	FD	6.40	5.82 - 7.00	0.07	0.13	4.17	5.59	55.50	0.41	6.39
8	TF	9.57	5.03 - 13.60	4.67	5.07	22.58	23.63	92.08	4.27	44.64
9	TP	11.51	7.00 - 17.00	6.73	7.64	22.53	24.01	88.08	5.02	43.56
10	DLP	98.47	92.00 - 103.00	8.94	11.88	3.04	3.50	75.31	5.35	5.43
11	PBV	4.08	3.47 - 5.13	0.06	0.37	5.96	14.87	16.05	0.20	4.92
12	LMV	3.26	2.64 - 4.11	0.10	0.29	9.86	16.59	35.32	0.39	12.07
13	TSS	3.81	2.87 - 4.73	0.17	0.21	10.73	12.08	78.93	0.75	19.64
14	FY	1483.1	807.35 - 1948.43	10116.9	11086.6	21.45	22.45	91.25	625.92	42.20

Where, **MF**: Days to opening of first male flower; **FF**: Days to opening of first female flower; **FP**: Days to first picking; **DM**: Days taken for edible maturity; **FW**: Average fruit weight (g); **FL**: Fruit length (cm); **FD**: Fruit diameter (cm); **TF**: Total number of fruits per plant; **TP**: Total number of pickings; **DLP**: Days taken for last picking; **PBV**: Primary branches per vine; **LMV**: Length of main vine (m); **TSS**: Total soluble solids ($^{\circ}$ Brix); **FY**: Fruit yield per plant (g). σ^2_g = Genotypic variance, σ^2_p = Phenotypic variance, **GCV** = Genotypic Coefficient of Variance, **PCV** = Phenotypic Coefficient of Variance, $h^2(b)$ = broad-sense heritability, **GA** = Genetic Advance, **GAM** = Genetic advance expressed as per cent of mean.

The differences between PCV and GCV were relatively narrow for most traits, indicating a comparatively limited environmental influence on their expression. However, comparatively larger differences were observed for primary branches per vine and length of main vine, which were associated with lower heritability estimates, indicating a

greater influence of environmental factors on the expression of these traits. The high PCV and GCV observed for several yield-related traits indicated substantial genetic variability, which could be effectively utilized in selection programmes (Gurve et al., 2021). Similar patterns of variability have been reported in other cucurbit crops, including sponge

gourd (Kumar *et al.*, 2013), cucumber (Kumari *et al.*, 2020) and bottle gourd (Rashid *et al.*, 2020).

Heritability and Genetic Advance (h^2 and GA)

Broad-sense heritability estimates ranged from 16.05 per cent for primary branches per vine to 92.60 per cent for fruit length (Table 2). High heritability was recorded for total number of fruits per plant (92.08%), fruit yield per plant (91.25%), days to opening of the first female flower (89.37%), total number of pickings (88.08%), days to first picking (87.59%), average fruit weight (80.48%), total soluble solids (78.93%), days to last picking (75.31%), days to opening of the first male flower (63.36%) and days to edible maturity (61.40%). Moderate heritability was observed for fruit diameter (55.50%) and length of main vine (35.32%), whereas primary branches per vine exhibited low heritability (16.05%).

Genetic advance as a percentage of the mean (GAM), considered along with heritability, provides an estimate of the expected response to selection. The highest GAM was recorded for total number of fruits per plant (44.64%), followed by total number of pickings (43.56%), fruit length (42.74%) and fruit yield per plant (42.20%). The lowest GAM was observed for primary branches per vine (4.92%), followed by days to last picking (5.43%), fruit diameter (6.39%) and days to opening of the first male flower (6.43%). Moderate GAM was recorded for days to first picking (10.38%), length of main vine (12.07%), days to edible maturity (15.30%), average fruit weight (19.56%) and total soluble solids (19.64%).

The occurrence of high heritability coupled with high genetic advance for several traits suggested a predominant contribution of additive genetic effects, indicating good prospects for improvement through direct selection. In particular, total number of fruits per plant, total number of pickings, fruit length and fruit yield per plant exhibited high heritability and high GAM, indicating substantial scope for genetic improvement of these traits. Similar findings have been earlier reported in other similar cucurbits like bottle gourd (Muralidharan, 2017; Varalakshmi *et al.*, 2018), bitter gourd (Talukder *et al.*, 2018) and sponge gourd (Kumar *et al.*, 2019).

Phenotypic and Genotypic Correlation

Fruit yield and its component traits are generally governed by polygenic inheritance and influenced by environmental variation. Therefore, selection for fruit yield in kalingada may be more effectively guided by the performance of associated component traits. A strong positive association between a component trait and yield may arise due to linkage or pleiotropic effects (Sprague, 1966). In the present study, fruit yield per plant exhibited significant positive correlations at both genotypic and phenotypic levels with fruit diameter, total number of fruits per plant, total number of pickings, days to last picking and primary branches per vine (Table 3). In contrast, days to opening of the first female flower, days to first picking, fruit length and total soluble solids (TSS) showed negative associations with fruit yield.

The present findings were in accordance with earlier reports of positive associations of fruit diameter, number of fruits, number of pickings, days to last picking and number of primary branches with fruit yield in bottle gourd (Deepthi *et al.*, 2016), muskmelon (Reddy *et al.*, 2017), cucumber (Kumar *et al.*, 2018; Rajawat *et al.*, 2018; Karthick *et al.*, 2019) and ridge gourd (Harshita *et al.*, 2019). These results indicated that selection for traits positively associated with fruit yield could contribute to improve fruit yield per plant in Kalingada.

Path Analysis (Direct and Indirect Effects)

Path coefficient analysis (Table 4) was performed to partition the correlations between individual traits and fruit yield into direct and indirect effects. At the genotypic level, total number of fruits per plant (0.999), total number of pickings (0.979) and average fruit weight (0.574) exhibited high positive direct effects, whereas days to opening of the first female flower (0.110) and days to first picking (- 0.122) showed low positive and negative direct effects, respectively. The remaining traits exhibited negligible direct effects according to Lenka and Mishra (1973). Although fruit diameter and primary branches per vine showed significant positive correlations with fruit yield, their positive direct effects were negligible, indicating that their associations with yield were primarily mediated through indirect effects.

Table 3 : Genotypic and phenotypic correlation coefficient among fourteen characters in Kalingada

	FF	FP	DM	FW	FL	FD	TF	TP	DLP	PBV	LMV	TSS	FY
MF	r_g -0.401 -0.294 *	0.019 -0.028 0.586 ** 0.527 **	0.251 0.220 0.116 0.085 0.201 0.163	0.305 0.254 * 0.008 0.010 0.433 * 0.367 **	0.024 0.020 0.505 * 0.462 ** 0.631 ** 0.579 **	-0.310 -0.078 -0.316 -0.199 -0.589 ** -0.399 **	0.183 0.116 -0.855 ** -0.752 ** -0.796 ** -0.728 **	0.192 0.111 -0.873 ** -0.739 ** -0.727 ** -0.648 **	-0.125 -0.107 -0.620 ** -0.489 ** -0.559 ** -0.459 **	0.068 -0.162 -0.801 ** -0.332 ** -0.376 -0.141	-0.057 -0.133 -0.184 -0.094 -0.384 -0.198	-0.295 -0.218 0.764 ** 0.676 ** 0.335 0.298 *	0.351 0.244 * -0.935 ** -0.818 ** -0.706 ** -0.643 **
FF													
FP													
DM													
FW													
FL													
FD													
TF													
TP													
DLP													
PBV													
LMV													
TSS													

*, ** significant at 5% and 1% level of significance, respectively.

MF: Days to opening of first male flower, **FF**: Days to opening of first female flower **FP**: Days to first picking, **DM**: Day taken for edible maturity, **FW**: Average fruit weight (g), **FL**: Fruit length(cm), **FD**: Fruit diameter (cm), **TF**: Total number of fruits per plant, **TP**: Total number of picking, **DLP**: Days taken for last picking, **PBV**: Primary branches per vine, **LMV**: Length of main vine (m), **TSS**: Total Soluble Solids (°Brix), **FY**: Fruit yield per plant(g), r_g : Genotypic correlation coefficient, r_p : Phenotypic correlation coefficient

Table 4 : Direct and indirect effects of yield components on fruit yield in kalingada

Sr. No.	Trait	MF	FF	FP	DM	FW	FL	FD	TF	TP	DLP	PBV	LMV	TSS	Genotypic correlation with FY
1	MF	0.059	-0.044	-0.002	-0.015	0.175	0.000	-0.015	0.183	0.002	0.001	0.002	-0.003	0.010	0.351
2	FF	-0.024	0.110	-0.072	-0.007	0.005	-0.010	-0.016	-0.855	-0.009	0.006	-0.027	-0.011	-0.025	-0.935 **
3	FP	0.001	0.065	-0.122	-0.012	0.249	-0.012	-0.029	-0.795	-0.008	0.005	-0.013	-0.023	-0.011	-0.706 **
4	DM	0.015	0.013	-0.024	-0.061	0.240	-0.010	-0.006	-0.188	-0.002	0.002	-0.005	0.006	-0.005	-0.025
5	FW	0.018	0.001	-0.053	-0.026	0.574	-0.009	-0.003	-0.411	-0.004	0.003	-0.006	-0.031	-0.005	0.048
6	FL	0.001	0.056	-0.077	-0.031	0.258	-0.020	-0.038	-0.580	-0.006	0.004	-0.009	-0.007	-0.014	-0.462 *
7	FD	-0.018	-0.035	0.072	0.007	-0.039	0.015	0.050	0.436	0.004	-0.003	-0.001	0.001	0.004	0.491 *
8	TF	0.011	-0.094	0.097	0.012	-0.236	0.011	0.022	0.999	0.010	-0.007	0.024	0.023	0.023	0.894 **
9	TP	0.011	-0.096	0.089	0.013	-0.210	0.011	0.018	0.979	0.011	-0.007	0.029	0.020	0.024	0.890 **
10	DLP	-0.007	-0.068	0.068	0.015	-0.188	0.008	0.015	0.784	0.008	-0.009	0.019	0.027	0.021	0.692 **
11	PBV	0.004	-0.088	0.046	0.008	-0.095	0.005	-0.002	0.707	0.009	-0.005	0.034	-0.017	0.021	0.626 **
12	LMV	-0.003	-0.020	0.047	-0.007	-0.303	0.002	0.001	0.382	0.004	-0.004	-0.010	0.059	0.008	0.156
13	TSS	-0.017	0.084	-0.041	-0.009	0.093	-0.008	-0.006	-0.677	-0.007	0.006	-0.022	-0.015	-0.033	-0.653 **

*, ** significant at 5% and 1% level of significance, respectively.

MF: Days to opening of first male flower, **FF**: Days to opening of first female flower **FP**: Days to first picking, **DM**: Day taken for edible maturity, **FW**: Average fruit weight (g), **FL**: Fruit length(cm), **FD**: Fruit diameter (cm), **TF**: Total number of fruits per plant, **TP**: Total number of picking, **DLP**: Days taken for last picking, **PBV**: Primary branches per vine, **LMV**: Length of main vine (m), **TSS**: Total Soluble Solids (°Brix), **FY**: Fruit yield per plant(g); (Residual effect = -

CONCLUSION

The present study revealed substantial genetic variability among the kalingada genotypes for yield and associated traits. High heritability coupled with high genetic advance for fruit number, number of pickings, fruit length and fruit yield indicated considerable potential for improvement through direct selection. Correlation and path-coefficient analyses identified fruit number and number of pickings as major direct contributors to fruit yield, while fruit diameter and primary branches per vine, despite their negligible direct effects, showed significant positive associations with yield through positive indirect effects via fruit number, indicating their potential for indirect selection. Although average fruit weight exhibited a high positive direct effect, its association with fruit yield was non-significant owing to a compensatory negative indirect effect through fruit number, suggesting limited utility as a selection criterion. Therefore, simultaneous selection for fruit number, number of pickings, fruit diameter and primary branches per vine may be effective for improving fruit yield in Kalingada. The findings provide useful baseline information for future breeding programmes aimed at developing high-yielding and regionally adapted genotypes.

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Knowledge, practices and perceptions of farmers on whitefly (*Bemisia tabaci*) management in okra cultivation in South Gujarat

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ABSTRACT

The study assessed farmers' knowledge, practices and perceptions regarding whitefly, *Bemisia tabaci* management in okra cultivation in Navsari, Surat and Bharuch district during 2023. From each of the three selected districts, 20 okra-growing farmers were randomly selected and resulting in a total sample size of 60 respondents. The findings revealed about 55.00 per cent cultivated okra on less than 1 ha, with summer and monsoon being the major preferred seasons. Almost all respondents could identify major okra pests, including whitefly; however, considerable gaps existed regarding its damaging stage and economic threshold level (ETL). Chemical control was the predominant management practice adopted by 83.33 per cent of respondent. Most farmers relied on approximate pesticide doses and applied sprays 4–6 times at intervals of 4–6 days. Although farmers were aware of pesticide disposal and environmental effects, inadequate use of personal protective measures was observed. The study highlights the need for farmer-oriented training on ETL-based pest management, correct pesticide dosage, safe handling and integrated pest management practices for sustainable and safer whitefly management in okra.

Keywords : Okra, whitefly, field survey, insecticides, pesticide use pattern

INTRODUCTION

Okra (*Abelmoschus esculentus* L. Moench) is an important vegetable crop cultivated extensively in India during summer and *kharif* seasons. The crop is valued for its nutritional and economic importance and provides an important source of income to vegetable-growing farmers. However, okra is attacked by a diverse complex of insect pests, including leafhopper (*Amrasca biguttulabiguttula* Ishida), aphid (*Aphis gossypii* Glover), whitefly (*Bemisia tabaci* gennadius) and shoot and fruit borer (*Earias* spp.). Among these, whitefly, *B. tabaci*, is a highly polyphagous and genetically diverse pest complex distributed across tropical and subtropical agricultural regions. *B. tabaci* is an important sucking pest because both nymphs and adults feed on plant sap, resulting in physiological stress, yellowing and weakening of plants. In addition to direct feeding damage, the pest is an important vector of several plant viruses thereby increasing its economic significance in vegetable production systems (Gilbertson *et al.*, 2015; Aarwe *et al.*, 2020).

The effectiveness of integrated pest management depends not only on the availability of appropriate technologies but also on farmers' knowledge, perceptions and adoption behaviour. Farmers' ability to correctly identify the pest, understand its damaging stages, recognize economic threshold level, select appropriate management options and apply pesticides at recommended doses plays a critical role in achieving effective and economical pest management. The situation is especially relevant in Gujarat, where okra is an important vegetable crop and farmers frequently depend on chemical pesticides for managing insect pests. A survey conducted among okra growers in Tapi district of South Gujarat reported considerable gaps in farmers' knowledge regarding recommended pesticides, dosage, safe harvest intervals, personal protection, label claims and proper disposal of pesticide containers. The study emphasized the need for farmer education regarding safe and judicious pesticide use for producing safer and residue-free okra (Chavan *et al.*, 2022). Jeyanthi and Kombairaju (2005) studied the pesticide use in important vegetable crops, viz. chillies, cauliflower, brinjal and okra. Average pesticide

usage has been estimated at 5.13, 2.77, 4.64 and 3.71 kg a.i./ha on chillies, cauliflower, brinjal and okra crops, respectively.

Understanding farmers' existing knowledge and practices is essential for identifying gaps between recommended pest-management technologies and their field-level adoption. Such information can help in developing need-based extension programmes focusing on pest identification, ETL-based decision-making, appropriate pesticide selection and dosage, safe pesticide handling, conservation of natural enemies and adoption of integrated pest management practices. The study specifically aimed to document farmers' knowledge of whitefly identification, assess their existing management practices and pesticide-use behavior, determine their perceptions regarding pesticide safety and environmental effects, and identify major gaps requiring attention through farmer-oriented training and extension interventions.

MATERIAL AND METHODS

Study Area

The present investigation was conducted in the major okra growing villages of **Navsari, Surat and Bharuch** of South Gujarat region were randomly selected for the present study to assess farmers' knowledge, practices and perceptions regarding the management of whitefly, *B.tabaci* in okra cultivation.

Selection of respondents and sampling procedure

A multistage random sampling procedure was followed for the selection of respondents. From each of the three selected districts, major 20 okra-growing farmers were randomly selected each from Navsari, Surat and Bharuch district and resulting in a total sample size of 60 respondents. The respondents were selected from villages where okra cultivation was undertaken during the study period. A structured interview schedule was developed to collect information on farmers' socio-economic characteristics, knowledge of whitefly identification and biology, management practices, pesticide-use behaviour, perceptions regarding pesticide safety and environmental effects, and adoption of integrated pest management practices.

Development of the interview schedule

Relevant variables and indicators were identified through an extensive review of available literature and previous research related to whitefly management, insect-pest knowledge, pesticide-use practices and integrated pest management in okra.

Data collection and statistical analysis

Primary data were collected through **personal interviews** with the selected respondents. Each farmer was interviewed individually at the farm or residence, and the responses were recorded systematically in the interview schedule. Descriptive statistical techniques were used to summarize the characteristics, knowledge, perceptions and management practices of the respondents. The frequency and percentage values were used to present and interpret the survey findings regarding farmers' knowledge, pesticide-use practices, perceptions and management of whitefly in okra cultivation.

RESULTS AND DISCUSSION

The survey was conducted among 60 okra-growing farmers in South Gujarat to assess their personal profile, cropping characteristics and knowledge regarding insect pests and pesticide use. The major findings are summarized below.

Personal profile of the respondents

The data presented in Table 1 revealed that the 60.00 per cent of the respondents belonged to the middle-age group (35–50 years), indicating that okra cultivation was mainly undertaken by economically active farmers. Regarding education, 41.67 per cent had higher secondary/diploma-level education, followed by 35.00 per cent with secondary education. This relatively satisfactory educational status may facilitate the adoption of improved pest-management practices. With respect to landholding, the largest proportion of respondents (33.33%) possessed 2–4 ha of total land, while 25.00 per cent were marginal farmers. However, okra cultivation was predominantly undertaken on a smaller area, with 55.00 per cent of farmers cultivating okra on up to 1 ha. Summer was the most preferred season (38.33%), closely followed by monsoon (36.67%), while 25.00 per cent cultivated okra during both seasons. Thus, the concentration of okra cultivation on small areas and its seasonal nature may influence farmers' pest-management decisions.

Table 1 : Personal and farm characteristics of respondents (n = 60)

Characteristic	Category	Frequency	Percentage
Age	Up to 35 years	6	10.00
	35–50 years	36	60.00
	Above 50 years	18	30.00
Education	Illiterate	0	0.00
	Primary	4	6.67
	Secondary	21	35.00
	Higher secondary/Diploma	25	41.67
	Graduate and above	10	16.67
Total land holding	Up to 1 ha	15	25.00
	1–2 ha	13	21.67
	2–4 ha	20	33.33
	4–10 ha	12	20.00
	Above 10 ha	0	0.00
Land under okra cultivation	Up to 1 ha	33	55.00
	1–2 ha	25	41.67
	2–4 ha	2	3.33
Okra growing season	Winter	0	0.00
	Summer	23	38.33
	Monsoon	22	36.67
	Summer and monsoon	15	25.00

Respondents knowledge about insect pests and pesticides use in okra crop

The survey was conducted among 60 respondents to assess their knowledge of whitefly and pesticide-use practices in okra. Most respondents (76.67%) could identify four insect pests damaging okra crop, while cent per cent could identify whitefly (Table 2 and Fig. 1). However, only 63.33 per cent

could identify the damaging adult stage and 36.67 per cent had no knowledge of its damaging stage. Chemical control was the predominant management practice, with 83.33 per cent of respondents using chemical pesticides as their first method of whitefly control. None of the respondents had knowledge of the Economic Threshold Level (ETL), indicating a major gap in scientific pest-management knowledge.

Table 2: Summary of major findings on whitefly knowledge and pesticide-use practices in okra (n=60)

Sr. No.	Parameter	Major response	Respondents (%)
1	Pests identified in okra	Identified four pests	76.67
2	Identification of whitefly	Yes	100.00
3	Damaging stage of whitefly	Adult	63.33
4	Maximum whitefly infestation stage	No idea	45.00
5	First method of whitefly control	Chemical method	83.33
6	Knowledge of ETL	No	100.00
7	Major factor in pesticide selection	Cost + efficacy	63.33
8	Preferred spray timing	Morning and evening	55.00
9	Pesticide purchased on label basis	No	60.00
10	Dose measurement	Graduated bottle cap	100.00
11	Use of recommended dose	Yes	38.33
12	Mixing pesticide with stick	Yes	100.00
13	Spraying frequency	4–6 times	73.33

Sr. No.	Parameter	Major response	Respondents (%)
14	Spraying interval	4–6 days	53.33
15	Waiting period	3–4 days	80.00
16	Method of pesticide application	Spraying	100.00
17	Mixing of pesticide formulations	No	100.00
18	Pesticide storage	Farm site away from house	70.00
19	Safety practice	Covering mouth and nose with cloth	58.33
20	Commonly used pesticide for whitefly	Fonicamid 50 WG	30.00
21	Knowledge of pesticide disposal	Yes	100.00
22	Disposal of empty containers	Burning/burying in pits	55.00
23	Knowledge of environmental effects	Yes	90.00
24	Consumption of own-farm okra	Yes	100.00

Fifty five per cent respondents preferred spraying the pesticides during morning and evening. Sixty per cent did not purchase pesticides based on label information. Although all respondents used the bottle cap for dose measurement and sticks for mixing, only 38.33 per cent reported using the recommended dose. Most respondents (73.33%) sprayed pesticides 4–6 times during the crop period and 53.33 per cent maintained a 4–6-day spraying interval. About 80.00 per cent followed a waiting period of 3–4 days. Maximum (80.00%) respondents followed 3 to 4

days of waiting period for harvesting of the okra fruits. All respondents applied pesticides through spraying and did not mix insecticide and fungicide formulations. Regarding safety, majority (58.33%) of respondents have not kept the covering of mouth and nose with cloth at time of handling or spraying of pesticides. Fonicamid 50 WG (30.00%) was the most commonly used pesticide, followed by acetamiprid 20 SP (28.33%) and imidacloprid 17.8 SL (20.00%). Although all respondents had knowledge of pesticide disposal, 55.00 per cent disposed of empty containers by burning/burying them.

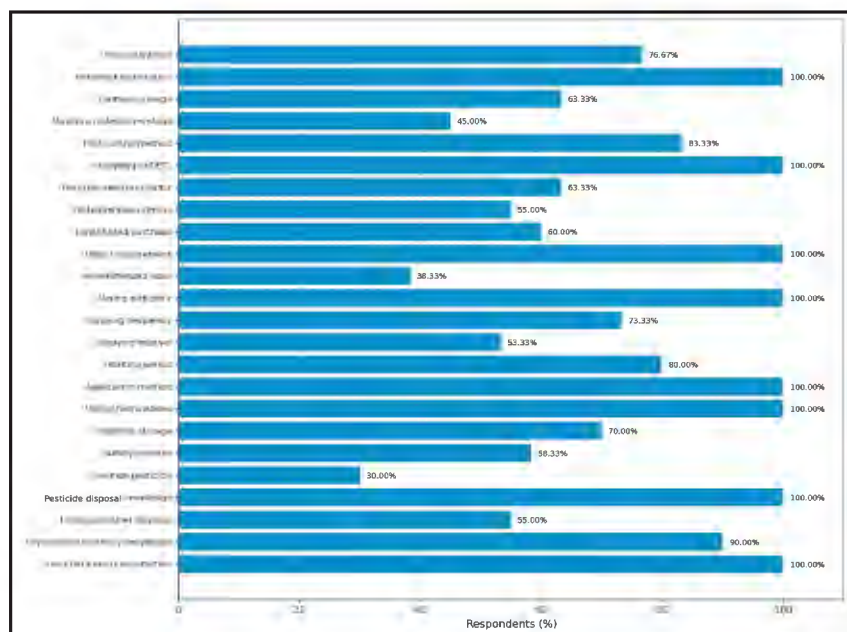


Figure 1 : Respondents' knowledge and practices regarding whitefly and pesticide use in okra crop

Overall, the respondents possessed good basic recognition of whitefly but showed inadequate knowledge of ETL, pesticide labels, recommended doses and personal protective measures. The heavy dependence on chemical control, together with frequent spraying, highlights the need for farmer training on IPM, ETL-based decisions, safe pesticide handling, proper disposal and judicious pesticide use. Despite this, the high level of awareness regarding environmental effects (90.00%) provides a useful foundation for promoting safer and more sustainable whitefly management. It was also found that 100 per cent of respondents consume okra fruits that are grown in their own fields.

The results are more closely similar with Anil Kumar *et al.*, 2017 who noted that 70.00 per cent of the farmers contacted to pesticide dealers for recommendations and only few farmers *i.e.* 16.00 per cent preferred to contact agricultural officers and about (60.00%) of the farmer followed the waiting period of week. Meenambigai *et al.* (2017) reported that the imidacloprid (36.67%) was used by farmers in okra. About 75.83 per cent of okra farmers approached pesticide retail shops for purchase pesticides and spraying interval of 10-14 days (52.33%). Though most of the farmers (93.33%) did not follow any safety measures while undertaking spraying operation, all the farmers (100.00%) have used stick for mixing of pesticide. Half of the respondents (50%) dispose by burning or buried in the soil which is line with the findings of Vani *et al.* (2005). According to Chavan *et al.* (2022), the respondents used the acetamiprid 20 SP (52.00%) maximum followed by thiamethoxam 25 WG (25.00%) in okra. Respondents preferred to apply pesticides in the following days' interval- 2-3 days (0%), 4-6 days (4%), weekly (41%) and depending upon the pest/ disease infestation/ infection (55%) before commencement of picking. Maximum (53.00%) the respondents follow 3-4 days of waiting period. Majority of the respondents (76.00%) have not followed the protective measures during spraying. Half of the respondents (50.00%) disposed the empty pesticide container/packing material by throwing away at roadside, along the borders of the field and half of the respondents (50.00%) dispose by burning or buried in the soil. All the respondents mixed the chemical by using stick and avoiding bare hands; majority of the farmers followed safe methods while storing or mixing or spraying which may be due to awareness on the effect on health and majority of the farmers measuring the pesticides by pesticide container cap was due to their habituated to its usage. Present finding confirms the findings of Anil Kumar *et al.* (2017).

CONCLUSION

The present study revealed that okra growers in South Gujarat possess basic practical knowledge of whitefly identification; however, important gaps remain in scientific, need-based and safe pest-management practices. The major knowledge gaps were related to recognition of the most damaging stage, understanding of peak infestation periods, and particularly awareness of the Economic Threshold Level (ETL) for initiating control measures. Farmers also showed inadequate understanding of pesticide label information, recommended dosages, appropriate use of personal protective equipment (PPE), and safe disposal of empty pesticide containers. The predominance of chemical control and repeated pesticide applications further indicates a need to strengthen farmers' understanding of Integrated Pest Management (IPM) and judicious pesticide use. At the same time, the high level of awareness regarding the environmental effects of pesticides provides a useful foundation for promoting safer and more sustainable practices.

Based on these findings, the following extension interventions are recommended:

Conduct regular farmer training and field demonstrations on whitefly identification, pest monitoring, ETL-based decision-making, and integration of non-chemical IPM methods to reduce unnecessary pesticide applications.

Strengthen pesticide-safety education through practical demonstrations on reading labels, using recommended doses, selecting appropriate PPE, observing pre-harvest intervals, and safely disposing of empty pesticide containers.

Promote farmer advisories and participatory IPM programmes through extension personnel, demonstrations, mobile-based advisories and input-dealer sensitization, with emphasis on need-based pesticide application and environmentally safer whitefly-management practices.

Thus, extension efforts should focus on transforming farmers' existing practical experience into scientifically informed, judicious and sustainable whitefly management practices in okra cultivation.

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SSR-based molecular profiling reveals genetic diversity and interspecific admixture between *Triticum aestivum* L. and *Triticum durum* Desf

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ABSTRACT

Wheat (*Triticum* spp.) is a global staple, with hexaploid bread wheat (*Triticum aestivum* L., $2n=6x=42$) and tetraploid durum wheat (*Triticum durum* Desf., $2n=4x=28$) accounting for the vast majority of global production. Characterizing genetic diversity and population structure across these species is essential for germplasm conservation and parental selection in breeding programs. In this study, 25 wheat genotypes (13 from *T. aestivum* and 12 from *T. durum*) were evaluated using 28 simple sequence repeat (SSR) markers to assess genetic variation and interspecific population admixture. Twelve polymorphic SSR loci yielded 33 total alleles, ranging from 2 to 4 alleles per locus (mean = 2.75). The mean polymorphic information content (PIC) and observed heterozygosity were 0.41 and 0.32, respectively, indicating moderate genetic diversity. Unweighted Pair Group Method with Arithmetic Mean (UPGMA) cluster analysis based on Nei's genetic distance effectively stratified the germplasm into two major species-specific clusters corresponding to hexaploid bread wheat and tetraploid durum wheat. Notably, two genotypes-GDW-1255 and DBPY-08-22-positioned between the primary clusters, revealing significant interspecific admixture. Furthermore, highly divergent entries such as GW-2013-503 and 18th-SBWOM-HT-85 were identified as valuable candidates for hybrid development. These findings demonstrate the utility of microsatellite markers in resolving ploidy-level population architecture, identifying admixed lines to control for structure in genome-wide association studies (GWAS), and selecting diverse parental combinations to maximize heterosis.

Keywords: Molecular diversity; Population structure; *Durum wheat* Bread wheat microsatellites; interspecific admixture

INTRODUCTION

The hexaploid wheat is staple food in major parts of the world, feeding more than one-third of the globe (Bhatta *et al.*, 2018). Wheat is the world's most widely cultivated staple food crop that possesses second important position in India. The cultivation of wheat in India was initiated more than 5,000 years back during the Indus valley civilization era, where the *Triticum sphaerococcum* found. However, nowadays *Triticum sphaerococcum* has disappeared and replaced by present species viz., *Triticum aestivum* L. (Bread wheat) (Hexaploid, $2n=6x=42$, AABBDD), *Triticum durum* Desf. (Macaroni wheat) (Tetraploid,

$2n=4x=28$, AABB), and *Triticum dicoccum* Schub L. (Emmer wheat) (Tetraploid, $2n=4x=28$, AABB) covering 87%, 12%, and 1% of the total wheat-growing area, respectively (Kulshreshtha, 1985). The bread wheat is cultivated in all the wheat-growing areas of the country, the macaroni or *durum* wheat is primarily grown in the Northern (Punjab) and Southern states. In contrast, the emmer wheat is confined to the Southern states (mainly Karnataka) and some parts of Gujarat (Das, 2008).

At the time of independence (1947), India could not produce sufficient food for the fulfillment of population demand. Now, India produces surplus production and export wheat in the global market. The production level of wheat in India

had a quantum jump from 6.46 million tons with 663 kg/ha productivity from an area of 9.75 million ha in 1950-51 to more than 103.6 million tons with 3507 kg/ha productivity from an area of about 29.14 million hectares during 2018-19 (Anonymous, 2020). The seed-storage proteins of wheat represent an essential source of food and energy, is also involved in determining bread-making quality (Cooke and Law, 1998). Wheat varieties are qualified into different classes, which exhibit various applications and differ in quantity and quality of proteins (*i.e.*, gluten). The gluten, comprising roughly 78 to 85% of total wheat endosperm protein, is a vast complex composed mainly of polymeric (multiple polypeptide chains) and monomeric (single chain polypeptides) proteins known as glutenins and gliadins, respectively (MacRitchie, 1994). Glutenins confer elasticity to dough, whereas gliadins are viscous and give extensibility to a dough (Payne *et al.*, 1984).

The genetic diversity of crops determines their potential for breeding efficiency and hence their use for the development of new varieties, which eventually may result in enhanced food production. Genetic diversity in the plant could result from geographical impact through evolution. Hence, traits could be considered as a function of variety. Estimation of genetic distance is one of the appropriate tools for parental selection of genotypes in breeding programs. Proper selection of the parents is essential to be used in crossing nurseries to enhance the genetic recombination for potential yield increase (Islam *et al.*, 2004). The traditional method for estimation of genetic diversity and relationships among groups of plants by using morphological characters, agronomic information and biochemical variations may influence by the environment and represent only visible diversity. Besides, the collection of such data is laborious. Hence, molecular markers are an attractive alternative (Storfer, 1996) widely for the evaluation of genetic diversity. Molecular markers are a relatively new breeding technology and are widely used by breeders to select variations in genotypes. Molecular markers are also helpful

to confirm gene flow, admixture present in cultivated lines received via human mediated breeding either natural or due to transformation from wild relatives. Out of various molecular markers, Simple sequence repeats (SSRs) (Tautz and Renz, 1984) has been widely exploited in wheat due to its high level of polymorphisms, co-dominant inheritance and equal distribution across the plant genome (Parker *et al.*, 2002, Röder *et al.*, 1995). SSR is more abundant, ubiquitous in presence, hypervariable in nature and has high polymorphic information content (Gupta *et al.*, 1996). SSRs markers may link with functional genes and such kind of markers may helpful for characterization of genotypes in respect to character specific diversity. The marker-based approach can determine the smallest possible allelic variation in coding regions.

With the above facts, objectives of the present investigation were i) to investigate and compare genetic diversity among 25 genotypes using 28 SSR markers, ii) to decipher the presence of population structure and cluster among population and iii) estimate the admixture proportion of individuals from the population to facilitate the hybrid breeding program

MATERIAL AND METHOD

SSR Genotyping and Cluster analysis

A set of 25 genotypes comprising of thirteen **bread wheat** (*T. aestivum* L.) and twelve **durum wheat** (*T. durum* Desf.) **genotypes** (Table. 1) was sown **under normal conditions** in a Randomized Block Design (RBD) with three replications. For genomic DNA extraction, the seedlings were collected at 15 days old and stored at -80 °C till use. Genomic DNA was extracted from the collected leaves using liquid nitrogen and the CTAB procedure with minor modifications (Doyle and Doyle, 1987). Based on quantification data from the spectrophotometer, a portion of DNA samples were diluted with an appropriate quantity of TE buffer to yield a working concentration of 50 ng/μl and stored at -20° C for further molecular analysis.

Table 1 : List of wheat genotypes used for the study

Sr. No.	Genotypes	Sr. No.	Genotypes
1	GW-451	14	GDW-1255
2	GW-496	15	DBPY-08-22
3	GW-366	16	GW-09-246
4	GW-11	17	GW-1287
5	GW-173	18	KLM-1005
6	GW-322	19	NIDW-295
7	15 th -HTWYT-9	20	VD-2013-02
8	15 th -HTWYT-12	21	GW-2010-286
9	15 th -HTWYT-21	22	QLD-23
10	15 th -HTWYT-28	23	GW-2015-691
11	15 th -SBWOM-60	24	GW-2013-503
12	18 th -SBWOM-HT-85	25	GW-1286
13	18 th -SBWOM-HT-86		

Based on the published literature (Ganal & Röder, 2007, Gupta *et al.*, 2002, Sourdille *et al.*, 2004, Guyomarc'h *et al.*, 2002, Song *et al.*, 2005) 28 SSR markers (Table 2.) were used for diversity analysis. PCR reaction was performed constituting of 15µl volume; 1.5µl of PCR buffer (10X), 200µM of dNTPs, 0.3 Unit *Taq* DNA polymerase, 5.0 pmoles/primer and 1.0 µl of template DNA (50ng). The PCR condition was: 5 min at 94°C; 35 cycles of 60s denaturation at 94°C, 60s annealing at 54°C to 58°C (depending on the melting temperature (T_m) of respective primer) and 2 min extension at 72°C in each cycle followed by 10 min at 72°C for final product extension and hold at 4°C. All the PCR amplified products were resolved on 3 per cent agarose gel.

Total number of alleles, Polymorphism Information Content (PIC) and heterozygosity (H) were analyzed by PowerMarker software version 3.25 (Liu and Muse, 2005). Genetic similarity was calculated by using Nei's similarity coefficient, and cluster analysis was performed using the UPGMA (Un-weighted Pair Group Method with Arithmetic Mean) method. Relationships between the wheat genotypes were graphically represented in a dendrogram using the PowerMarker software.

The polymorphism information content (PIC) was estimated as per the given formula (please provide reference)

$$\widehat{PIC}_1 = 1 - \sum_{u=1}^k \tilde{p}_{lu}^2 - \sum_{u=1}^{k-1} \sum_{v=u+1}^k \tilde{p}_{lu}^2 \tilde{p}_{lv}^2$$

Where,

$\tilde{p}_{lu}$ = An allele A_u having population frequency for l th locus

$\tilde{p}_{lv}$ = An allele A_v having population frequency for l th locus

At a single locus, heterozygosity (H) is estimated as

$$\hat{H}_l = 1 - \sum_{u=1}^k \tilde{p}_{lu}^2$$

Population Structure Analysis

The population structure of 25 genotypes was analysed using a model based on a clustering algorithm using the software package STRUCTURE Version 2.1 (<http://pritch.bsd.uchicago.edu/software.html>) (Pritchard and Wen, 2004). The optimum number of K was selected after five independent runs with burn-in of 50,000 iterations, followed by 50,000 iterations for each value of K (tested from $K=2$ to $K=4$). Finally, output of analysis was retrieved using the STRUCTURE harvester (version?) (Earl & VonHoldt, 2012) and the optimum number of $K=2$ was determined by calculating Evanno's (ΔK) (Evanno *et al.*, 2005). For each subpopulation identified, the mean population differentiation (F_{ST}) and H_e (Nei, 1978) were determined based upon optimal K value. The F_{ST} value (Nei, 1977) helps in providing estimating the degree of fixation of alleles within the population while, H_e (Nei, 1978) depicts the average distance between individuals within the same population. Principal coordinate Analysis (PCoA) was performed based on genetic distances among the genotypes computed with DARwin 6.0.14 software (Dissimilarity Analysis and Representation for Windows) (Perrier & Jacquemoud, 2006).

Table 2 : List of SSR primers found polymorphic in present study

Sr. no.	Primer name		Sequence (5'→3')	T_m value (°C)	%GC
1	CFA 2114	F	ATTGGAAGGCCACGATACAC	57.30	50.00
		R	CCCGTCGGGTTTATCTAGC	59.35	55.00
2	CFD 65	F	AGACGATGAGAAGGAAGCCA	57.30	50.00
		R	CCTCCCTTGTTTTGGGATT	55.25	45.00
3	CFD 71	F	CAATAAGTAGGCCGGGACAA	57.30	50.00
		R	TGTGCCAGTTGAGTTTGCTC	57.30	50.00
4	GWM 160	F	TTCAATTCAGTCTTGGCTTGG	55.92	42.86
		R	CTGCAGGAAAAAAGTACACCC	58.39	45.45
5	GWM 148	F	GTGAGGCAGCAAGAGAGAAA	57.30	50.00
		R	CAAAGCTTGACTCAGACCAAA	55.92	42.86
6	GWM 181	F	TCATTGGTAATGAGGAGAGA	53.20	40.00
		R	GAACCATTTCATGTGCATGTC	55.25	45.00
7	GWM 397	F	TGTCATGGATTATTGGTCGG	55.92	42.86
		R	CTGCACTCTCGGTATACCAGC	61.78	57.14

Sr. no.	Primer name		Sequence (5'→3')	Tm value (°C)	%GC
8	GWM 407	F	CATATTTCCAAATCCCCAACTC	56.53	40.91
		R	GGTAATTCTAGGCTGACATATGCTC	61.34	44.00
9	WMC 154	F	ATGCTCGTCAGTGTCATGTTTG	58.39	45.45
		R	AAACGGAACCTACCTCACTCTT	58.39	45.45
10	WMC 170	F	ACATCCACGTTTATGTTGTTGC	56.53	40.91
		R	TTGGTTGCTCAACGTTTACTTC	56.53	40.91
11	WMC 28	F	ATCACGCATGTCTGCTATGTAT	56.53	40.91
		R	ATTAGACCATGAAGACGTGTAT	54.66	36.36
12	WMC 44	F	GGTCTTCTGGGCTTTGATCCTG	62.12	54.55
		R	TGTTGCTAGGGACCCGTAGTGG	63.98	59.09

RESULTS AND DISCUSSION

The wheat research activities in Gujarat were initiated with the establishment of Wheat Research Station at Vijapur in 1962. Multi-disciplinary and multi-locational activities of varietal improvement, resources management, crop protection and quality improvement has been done by this research centre. Along with this, the centre has prominent share in wheat improvement in Central and Peninsular India too. To assess the molecular diversity present in this centre, 25 varieties/breeding lines were collected and molecular characterization of these lines were conducted which could provide a clear view to breeders for further crop improvement.

SSR genotyping and genetic divergence analysis

Total of twenty-eight microsatellite primers were used for molecular diversity analysis of twenty-five genotypes of wheat, out of which twelve primers were found to be polymorphic. The result obtained using twelve polymorphic primers have been presented in Table 3. SSR marker analysis of all twelve primers generated total number of 33 alleles with an average of 2.75 alleles. A total number of alleles varied from 2 (GWM 181) to 4 (WMC 170). The molecular size of bands/alleles was observed from 100 bp (GWM 181) to 296 bp (WMC 44). The PIC values in present study ranged from 0.30 (primer GWM 407) - 0.64 (primer CFD 65) with an average PIC value of

0.41. The co-dominant nature of SSR markers facilitates the analysis of the genotypic heterozygosity. The heterozygosity in the present study ranged from 0.00 (GWM 397) – 1.00 (CFD 65) with an moderate heterozygosity of 0.32. Higher heterozygosity depicted presence of higher ploidy level in genotypes. The average Major Allele Frequency was found to be 0.63 in present study.

Total number of alleles from present study were 2 to 4 with average of 2.75 which found to be in accordance with data recorded by Sharma *et al.*, 2021 as total number of alleles 2 to 6 and average of 2.58 whereas, higher total number of alleles (4-40) compared with present study has been reported previously by Roussel *et al.*, 2005 which indicated that it could be due to the separation of PCR products using a fragment analyzer. The average PIC value obtained in present study (0.41) has been in accordance with average PIC value obtained (0.35) by Sharma *et al.*, 2021. Primer pairs GWM 181, WMC 170 and CFD 65 found to be the most informative primers based upon PIC values greater than 0.5 among which WMC 170 has been previously reported to be associated with salinity tolerance in bread wheat (Gupta *et al.*, 1996) which makes it a marker of choice for trait specific studies as well as diversity analysis. Nei's genetic distances were used to generate the cluster analysis from which the highest genetic distance was noted between genotypes GW-2013-503 AND 18th-SBWOM-HT-85 supporting the fact that this both genotypes belong to different species of wheat.

Table 3 : Results of SSR analysis in twenty-five genotypes of wheat

Sr. No.	Primer	Molecular band/allele size (bp) (Approx.)	No. of polymorphic alleles	PIC	Heterozygosity	Major Allele Frequency
1	CFA 2114	209 – 229	2	0.37	0.05	0.52
2	CFD 65	155 – 216	3	0.55	1.00	0.50
3	CFD 71	146 – 209	3	0.46	0.56	0.64
4	GWM 148	145 – 169	2	0.35	0.04	0.66
5	GWM 160	181 – 204	2	0.33	0.20	0.70
6	GWM 181	100 – 162	4	0.64	0.88	0.46
7	GWM 397	188 – 232	2	0.37	0.00	0.52
8	GWM 407	131 – 174	2	0.30	0.10	0.76
9	WMC 28	158 – 198	4	0.37	0.48	0.76
10	WMC 44	207 – 296	2	0.30	0.08	0.75
11	WMC 154	114 – 162	3	0.29	0.13	0.81
12	WMC 170	198 – 230	4	0.59	0.28	0.50
Total			33	-	-	
Average			2.75	0.41	0.32	0.63

Clustering pattern obtained from SSR data analysis

Based on the SSR data, cluster analysis was performed using Nei's genetic distances, and a dendrogram was generated, showing genetic relationships among twenty-five genotypes. Nei's genetic distances for twelve primers ranged from 0.07 to 0.78. The highest genetic distance (0.78) was observed between genotypes GW-2013-503 AND 18th-SBWOM-HT-85 indicating higher genetic diversity between the genotypes on allelic level. The minimum similarity value (0.07) was observed between genotypes 15th-HTWYT-9 and GW-366 indicating the relatedness between the genotypes.

The clustering pattern of the dendrogram (Fig.1) generated using the pooled molecular data of twelve SSR loci indicated two clusters, namely 1 and 2 (Fig.2). Cluster 1 (Red circle) included all the durum wheat (*T. durum*) genotypes, while cluster 2 (Green circle) included all the bread wheat (*T. aestivum*) genotypes. The dendrogram clearly shows genotypes 14 (GDW-1255) and 15 (DBPY-08-22) admixtures from the clusters while DBPY-08-22 genotype more aligning towards cluster 1 consisting of bread wheat.

Population structure and PCoA

Population structure (Fig.2) divided 25 genotypes into two main populations. Population 1 (Pop₁-Red) and population 2 (Pop₂-Green) contain 11 and 14 genotypes, respectively. Pop₁ consisted of durum wheat genotypes while Pop₂ shows presence of bread wheat genotypes. Further, based on membership fractions, the genotypes under different

populations were categorized as pure or admixture. The genotypes with a probability of more than ≥ 0.80 were considered as pure (88%) and less than 0.80 as an admixture (12%). Pop₁ showed 10 pure (90 %) and 1 admixed (10 %) individual while, Pop₂ showed 12 pure (86 %) and 2 admixed (14 %) individuals. Genotypes GDW-1255 and DBPY-08-22 has shown higher percent of admixture among all the genotypes. Both the genotypes have been reported to be from durum wheat background but showing per cent admixtures from bread wheat.

Genotype DBPY-08-22 was received as a durum wheat, however in STRUCTURE analysis this genotype appeared in *T. aestivum* population group with higher level of admixtures of durum (40%) while genotype GDW-1255 received as a durum wheat showed admixture from *aestivum* group (20%). The molecular study is giving actual genotypic representation of particular genotype. Admixture study is indicating that due to human mediated breeding bread and durum type of admixtures gets appeared which may give opportunity for combining superior character from bread and durum for developing superior varieties. By using this admixture varieties further improvement is possible and they may work as bridging varieties for crossing between *aestivum* and durum. Similar studies on the admixture genotypes from the wheat genotypes has been reported by Khan *et al.*, 2015 using ISSR and RAPD markers to gain a better understanding of the genetic association and population structure of Indian and Turkish wheat on the basis of both geographical origin and ploidy.

Table 4 : Results of STRUCTURE analysis of for the fixation index (F_{st} ; indicating significant divergence) and average distances (expected heterozygosity)

Population	F_{st}	Exp. Heterozygosity (H_e)	No. of genotypes
Pop ₁	0.36	0.35	11
Pop ₂	0.29	0.39	14

The degree of genetic differentiation and average distance (H_e) in each subpopulation suggested that highest degree of genetic differentiation was detected in population 1 ($F_{st} = 0.36$), whereas lowest value was observed in population 2 ($F_{st} = 0.29$) (Table.4). Along with this, the lowest expected heterozygosity (H_e) was observed in population 1 ($H_e = 0.35$) and the highest H_e was observed in population 2 ($H_e = 0.39$). The results of sub-populations generated by STRUCTURE analysis based on $K=2$ value (Fig.1), UPGMA cluster analysis (Fig.2) and PCoA (Fig.3) showed a high degree of similarity with genotypes *GDW-1255* and

DBPY-08-22 showing no presence in any of the cluster specifically and thus appreciable admixtures with the bread wheat genetic constitution.

Superior F_{st} values denotes the population is fixed with the alternate alleles and this has been supported by the previous studies by Robbana *et al.*, 2019 while studying durum wheat landraces. Distinct clustering pattern in *T. durum* and *T. aestivum* genotypes of Gujarat based upon PCoA analysis has also been reported by Zala *et al.*, (2014) by employing RAPD and SSR markers showing importance of such studies in selection of genotypes for further crop improvement programme.

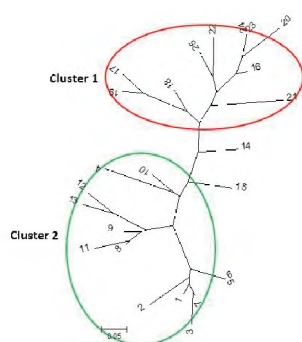


Fig.1 Dendrogram showing clustering of twenty-five wheat genotypes based on microsatellite markers

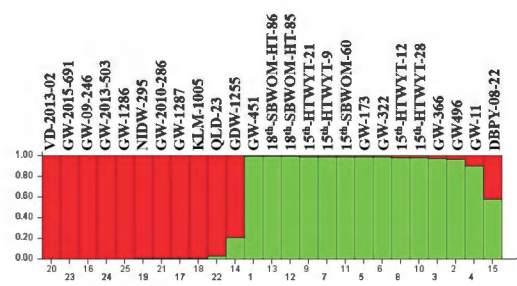


Fig.2 Assignment of Wheat germplasms into two populations based on population structure analysis

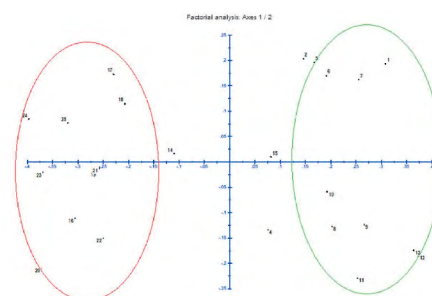


Fig.3 Principal coordinate analysis (PCoA) based on genetic distance among the bread and durum wheat genotypes based on microsatellite markers data

Conflict of interest: There is no conflict of interest

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