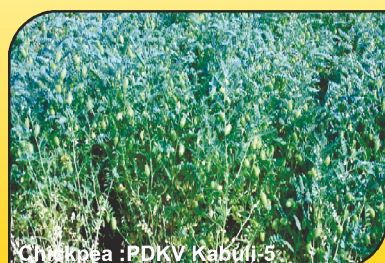


# PKV RESEARCH JOURNAL



**Dr. PANJABRAO DESHMUKH  
KRISHI VIDYAPEETH**

**(AGRICULTURAL UNIVERSITY)  
AKOLA (Maharashtra), INDIA**

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## Parameters Optimization for Sex Specific Plantlet Production Through Tissue Culture In Spine Gourd

D. R. Rathod<sup>1</sup>, Priyanka Sardar<sup>2</sup>, P. R. Shingote<sup>3</sup>, V. S. Kale<sup>4</sup>, G. D. Chandankar<sup>5</sup>, K. A. Uike<sup>6</sup>, P.M. Badge<sup>7</sup> and B. S. Mundhe<sup>8</sup>

### ABSTRACT

An investigation to optimize regeneration sex specific micropropagation protocol for male and female plantlet production through tissue culture was carried at plant tissue culture laboratory of Dr PDKV, Akola during year 2023-24 and 2024-25 with the aim for refinement and validation of sex specific regeneration protocol for male and female plantlet production through tissue culture of spine gourd var. Arka Bharat. The mother explants source was obtained from Central Horticultural Experiment Station, Chettalli, Karnataka as well as locally from research field developed at Head, Dept of Vegetable Science, Dr PDKV, Akola. The nodal explants of male and female having 3-4 months old were taken and treatment with 0.1% tween-20 for 20 mins, 1% carbendazim for 20 mins, 1% streptomycin for 20 mins and 0.1% HgCl<sub>2</sub> for 5 mins. These were inoculated in the month of Jan-Feb and shown maximum initiation rate 92.47% with lowest (20.88%) contamination percentage. In the present study, the effect of different concentrations of auxins namely IBA and NAA plant growth hormone on in vitro and ex vitro shoot and root induction were undertaken with eleven treatments in three replications using CRD. During the present investigations, it has noticed that the nodal segment shows significantly higher rate of survival, initial culture establishment, high rate of multiple shoots and shoot-let proliferation as compared to the shoot tips. Overall, across two years study, it was noticed that among all the treatment, treatment of MS + BAP (2.0 mg L<sup>-1</sup>) + LGA (2.0 mg L<sup>-1</sup>) gives better results as compare to the other treatments in spine gourd.

Kartoli, botanically called as spine gourd (*Momordica dioica* Roxb.) (2n=28) is an important but underexploited rare vegetable crop. It is a dioecious, perennial, herbaceous climber having tuberous roots belonging to *cucurbitaceae* family, under the natural order *cucurbitales*. It is believed to be originated in the tropics of old world. Spine gourd is probably native of India, plants are distributed from Himalayas to Sri Lanka, up to an altitude of 1500m. Plants of Spine gourd are found naturally growing in hilly tract of Rajmahal, Hazaribagh and Rajgir of Jharkhand and Wet hills of Maharashtra, Assam and West Bengal. West Bengal and Karnataka are two major Indian States that grow Spine gourd commercially. Spine gourd is largely cultivated in Malda and Nadia districts of West Bengal. It is grown for its immature nutritious tender fruits. The plants undergoes dormant during winter season as studied by Devi *et al.*, (2017). It is a high demandable seasonal vegetable and medicinal plant. It is free from cholesterol and has adequate amount of high energy (45.74 Kcal), water (84%), minerals and vitamins as reported by Bharadwaj

*et al.*, 2021. Fruits are rich source of protein, calcium, phosphorus, iron and highest amount of carotene (162mg/100g edible portion) among cucurbits. Fruits are also a rich source of lectins, triterpinse of ursolic acid, momordic ursenol, vitamins, iodine, flavonoids and glycosides and is described as “Good supplement for nutrient”.

India possesses greatest diversity in *Cucurbitaceae* crops including spinegourd is among one a rare vegetable. Spine gourd is underexploited mainly due to its vegetative mode of propagation and dioecious nature. Male plants dominate natural populations and sex determination is possible only when the plants start flowering. Since fruits are the main edible portion of this species, which are harvested on female plants, it is desirable to have commercial fields with a large proportion of female plants. Due to its dioecious nature, poor natural pollination of female flowers results in lower yield. To compensate this problem plantation needs 5-10 % male plants as pollinizer and it is imperative for good fruit set. It is highly cross pollinated in nature and exhibit genetic variation for morphology and growth parameters Singh

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*et al.* (2023). As the conventional methods of spine gourd propagation impose several limitations for large scale production of sex specific plants, an efficient clonal propagation is must. Improvement of plant species via biotechnological approach depends on plant tissue culture. High multiplication ratio achieved rapid multiplication of disease and pest free elite plant within short span of time and space. It can be employed as an alternative means for genetic upgradation and its application largely depends on a reliable plant regeneration system. Hence, present investigation majorly aims to optimize highly efficient regeneration sex specific protocol for var. Arka Bharat.

## MATERIAL AND METHODS

**Explant source:** The mother explants source was obtained from Central Horticultural Experiment Station, Chettalli, Karnataka in the year 2021 as well as locally from the experimental research field developed and maintained at Head, Dept of Vegetable Science, Dr PDKV, Akola.

### Media used and optimum conditions

The nodal explants of male and female having 3-4 months old were taken and treatment with 0.1% tween-20 for 20 mins, 1% carbendazim for 20 mins, 1% streptomycin for 20 mins and 0.1% HgCl<sub>2</sub> for 5 mins. These were inoculated in the month of Jan-Feb and shown maximum initiation rate 92.47% with lowest (20.88%) contamination percentage. Overall, across two years study, it was noticed that among all the treatment, treatment of MS + BAP (2.0 mg L<sup>-1</sup>) + LGA (2.0 mg L<sup>-1</sup>) gives better results as compare to the other treatments in spine gourd.

### Proliferation of shoot and root

For its efficient shoot multiplication and MS + 1mg L<sup>-1</sup> NAA for high root induction, followed by hardening for 45 days with sand/cocopeat: soil:vermicompost/FYM (1:2:1) proportion is recommended for its rapid clonal micropropagation.

### Statistical analysis

In the present study, the effect of different concentrations of auxins namely IBA and NAA plant growth hormone on in vitro and ex vitro shoot and root induction were undertaken with eleven treatments in three replications using CRD. The statistical significance of the

treatment means was analyzed by calculating the critical difference at 1%.

## RESULTS AND DISCUSSION

The experimental work consisting of in vitro propagation of explants *Momordica dioica* Roxb. by using nodal segment as a source of to generate true to type plantlets using MS media with different combinations of growth regulators. In view of the above facts, the observations were recorded on various aspects related to the objective of standardization of regeneration protocol for male and female plantlet production through tissue. In an attempt to standardize explants for tissue culture of spine gourd, two types of explants were tried for in-vitro shoot regeneration and multiplication. Effect of MS medium and manipulation of parameters during in vitro micropropagation was studied using 50 explants (per each treatment) of nodal segment excised from selected and tagged sex specific vine mother plants. observed with each treatment is presented in Table 1 and graphically as well as explant culture grown depicted in Fig 1 and 2 respectively. After 4<sup>th</sup> week of subculture 3<sup>rd</sup>, the survived explants were transferred to fresh MS medium supplemented with different growth regulators combinations like BAP (1.0 mg L<sup>-1</sup> and 2.0 mg L<sup>-1</sup>) and L-Glutamic acid (1.5, 2.0, 2.5, 3.0 mg L<sup>-1</sup>) for the multiple shoot formation. The cultures were maintained by the regular subculture on fresh medium and result shown in Fig.1 and 2.

### Multiplication index

The effect of growth regulator along with L-Glutamic acid and their combinations with different concentrations on multiplication index of shoot in the Spine gourd *var.* Arka Bharat have been studied and the results obtained are presented in Table 1 Significant differences concerning the number of shoot/explants at the level of 5% among the applied different treatments. Maximum multiplication index of shoot was found in the treatment (T<sub>9</sub>) MS + BAP (2.0 mg L<sup>-1</sup>) + LGA (2.0 mg L<sup>-1</sup>) with 8.97 followed by treatment (T<sub>10</sub>) MS + BAP (2.0 mg L<sup>-1</sup>) + LGA (2.5 mg L<sup>-1</sup>) with 7.72 while MS Medium Control (T<sub>1</sub>) showed minimum result with 2.34.

### Number leaves Explant<sup>-1</sup>

Data tabulated in Table 1 Clearly showed

## Parameters Optimization for Sex Specific Plantlet Production Through Tissue Culture In Spine Gourd

significant differences concerning the number of leaves per shoot at the level of 5% among the applied different treatments. The maximum number of leaves in the treatment ( $T_9$ ) of MS + BAP (2.0 mg L<sup>-1</sup>) + LGA (2.0 mg L<sup>-1</sup>) were recorded with 11.93 followed by treatment ( $T_{10}$ ) of MS + BAP (2.0 mg L<sup>-1</sup>) + LGA (2.5 mg L<sup>-1</sup>) in which number of leaves is 11.62. However, the minimum number of leaves per each shoot was appeared in MS control ( $T_1$ ) which is 2.53.

### Average length of shoot (cm)

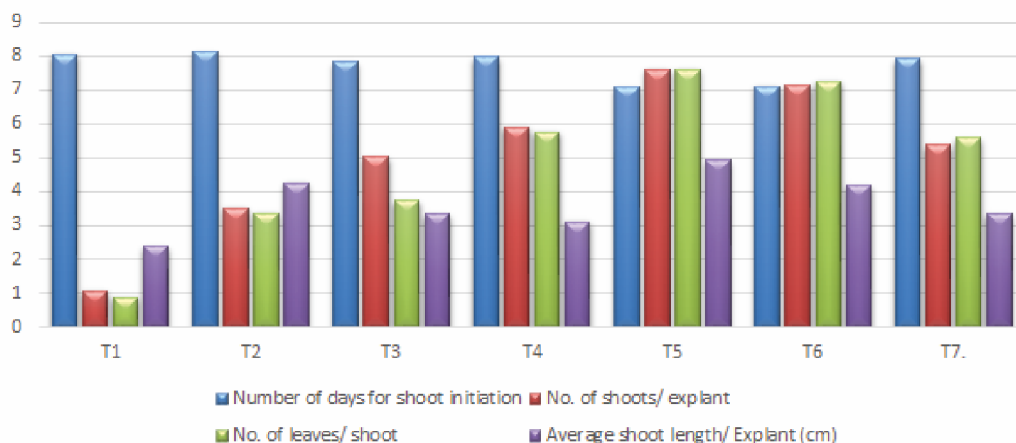
The average length of shoots per explant indicated significant differences at the level of 5% among the various media supplementations with BAP and LGA (Table 1). The minimum shoot length 3.69 cm was recorded in the treatment ( $T_6$ ) of MS media supplemented

with BAP (1.0 mg L<sup>-1</sup>) + LGA (2.5 mg L<sup>-1</sup>). The maximum length of shoot 6.89 cm was registered in treatment ( $T_2$ ) MS + BAP (1.0 mg L<sup>-1</sup>) followed by the treatment ( $T_9$ ) of MS + BAP (2.0 mg L<sup>-1</sup>) + LGA (2.0 mg L<sup>-1</sup>) with 5.27 cm.

MS medium supplemented with BAP (2.0 mg L<sup>-1</sup>) and LGA (2.0 mg L<sup>-1</sup>), the explants produced little amount of callus and shoot buds in Spine gourd. The shoot buds on successive subcultures for twice on the same medium produced multiple shoots. Shoot proliferation was further continued even after six months. Similarly, Debnath *et al.* (2013) noted maximum numbers of shoots from nodal explants of Spine gourd in MS media supplemented with 2,4-D (2.0 mg L<sup>-1</sup>) and BAP (0.5 mg L<sup>-1</sup>). Similar result was also reported by Ghive *et al.* (2006), in which MS media supplemented with BAP (0.5

**Table 1. Effect of MS medium supplemented with BAP and L-Glutamic acid on *in vitro* shoots multiplication of Spine gourd using var. Akra Bharat**

| TreatmentS     | MS media supplemented with (BAP, L-Glutamic acid), mg L <sup>-1</sup> | Multiplication index | No. of leaves shoot <sup>-1</sup> | Average shoot length (cm) |
|----------------|-----------------------------------------------------------------------|----------------------|-----------------------------------|---------------------------|
| T <sub>1</sub> | MS control                                                            | 2.34                 | 2.53                              | 4.33                      |
| T <sub>2</sub> | MS+BAP(1mg) +LGA(2mg)                                                 | 5.43                 | 6.12                              | 4.20                      |
| T <sub>3</sub> | MS+BAP(1mg) +LGA(2.5mg)                                               | 6.94                 | 7.85                              | 3.69                      |
| T <sub>4</sub> | MS+BAP(1mg) +LGA(3mg)                                                 | 7.14                 | 9.33                              | 4.38                      |
| T <sub>5</sub> | MS+BAP(2mg) +LGA(2mg)                                                 | 8.97                 | 11.93                             | 5.27                      |
| T <sub>6</sub> | MS+BAP(2mg) +LGA(2.5mg)                                               | 7.72                 | 11.62                             | 4.98                      |
| T <sub>7</sub> | MS+BAP(2mg) +LGA(3mg)                                                 | 5.79                 | 7.52                              | 4.24                      |
|                | SE (m)±                                                               | 0.70                 | 0.40                              | 0.52                      |
|                | CD at 5%                                                              | 2.06                 | 1.18                              | 1.51                      |



**Fig. 1. Effect of MS medium supplemented with BAP and L-Glutamic acid on *in vitro* shoots multiplication of Spine gourd using var. Akra Bharat**



A.) Male explants

B.) Female explant root and shoot induction

**Fig. 2. Response of sex specific explants a) male plantlets and b) female plantlets development *in vitro* showing differential growth and proliferation.**

mg L<sup>-1</sup>) in monoecious Spinegourd has exhibits a greater number of shoots after 3<sup>rd</sup> subculture. These results are at par with earlier studies reported by Alam *et al.*, 2014. Hence, during the present investigations, it has noticed that the nodal segment shows significantly higher rate of survival, initial culture establishment, high rate of multiple shoots and shoot-let proliferation as compare to the shoot tips. Overall, during two years study, it was noticed that among all the treatment, T<sub>9</sub> treatment MS supplemented with BAP (2.0 mg L<sup>-1</sup>) + LGA (2.0 mg L<sup>-1</sup>) gives better results as compare to the other treatments in spine gourd and these results are in accordance with the finding of Devnath *et al.*, 2013, Hoque *et al.*, (1982 and 2000).

### CONCLUSION

Among all the treatment under study, the treatment number (MS + BAP 2 mg L<sup>-1</sup> + L-GA 2 mg L<sup>-1</sup>) significantly increased the multiplication index, number of leaves shoot<sup>-1</sup> and average shoot length compared to control and other treatments. The proposed protocol will be effectively used for nodal segment used as explants source. Further the proposed treatment combination will be helpful for obtaining initial culture establishment, good survival and shoot multiplication rate in spine gourd.

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## Evaluation of Desi Cotton (*Gossypium arboreum* L) Genotypes for Fibre Quality

Vaibhav V. Ujjainkar<sup>1</sup> and T. H. Rathod<sup>2</sup>

### ABSTRACT

Diploid cotton (*Gossypium arboreum* L.), commonly known as desi cotton or Asiatic cotton, is one of the oldest cultivated cotton species and is indigenous to the Indian subcontinent. The present investigation was undertaken to evaluate the fibre quality performance of ten elite desi cotton genotypes under rainfed conditions. Lint samples obtained through manual ginning were analyzed using a High Volume Instrument (HVI) under standard testing conditions for five important fibre quality parameters, namely Upper Half Mean Length (UHML), Uniformity Index (UI), Micronaire, Fibre Strength, and Fibre Elongation. Considerable variability was observed among the genotypes for most fibre quality traits. UHML ranged from 26.8 to 30.9 mm, with PA 796 recording the highest fibre length, followed by PAIG 373. Uniformity Index exhibited minimal variation (82–83%), indicating consistently good fibre uniformity across genotypes. Micronaire values varied from 3.7 to 4.7, with PA 741, PA 796, and PAIG 373 producing finer fibres suitable for superior spinning quality. Fibre strength ranged from 25.2 to 30.4 g tex<sup>-1</sup>, with PAIG 77 recording the highest strength, closely followed by PAIG 373 and PA 796. Fibre elongation varied between 4.9 and 6.3%, with PA 778 exhibiting the highest elongation. Among all entries, PAIG 373 demonstrated the most desirable combination of long fibre, fine micronaire, high strength, and superior elongation, whereas PA 796 excelled for fibre length and overall quality. The study revealed substantial genetic variability for economically important fibre quality traits, indicating significant scope for genetic improvement. The superior genotypes identified can serve as valuable donor parents in breeding programs aimed at developing high-yielding desi cotton cultivars possessing enhanced fibre quality and improved spinning performance under rainfed agro-ecological conditions.

Diploid cotton (*Gossypium arboreum* L.) is an indigenous cotton species of India renowned for its resilience to drought, pests, and low-input cultivation, making it highly suitable for rainfed farming systems. Despite the dominance of tetraploid cotton, desi cotton remains an invaluable genetic resource for breeding programs aimed at improving fibre quality, climate resilience, and sustainable cotton production. It belongs to the family Malvaceae and possesses the A-genome with a chromosome number of  $2n = 2x = 26$  (Fryxell, 1979; Wendel and Grover, 2015). Archaeological evidence from the Indus Valley Civilization indicates that cotton was cultivated in India nearly 5,000 years ago, making the country one of the primary centres of origin and domestication of cultivated cotton (Brubaker *et al.*, 1999). India is unique among cotton-growing countries because it is the only nation where all four cultivated cotton species, namely *Gossypium arboreum*, *G. herbaceum*, *G. hirsutum* and *G. barbadense*, are grown commercially (Paterson, 2009). Although tetraploid upland cotton

(*G. hirsutum*) occupies the largest cultivated area, diploid cotton continues to play an important role in the rainfed and dryland production systems of India. It is predominantly cultivated in Maharashtra, Gujarat, Madhya Pradesh, Telangana, Andhra Pradesh, Karnataka, Rajasthan, Odisha and Chhattisgarh, where rainfall is uncertain and soil fertility is comparatively low (Kranthi, 2018; ICAR-CICR, 2024). Compared with tetraploid cotton, *G. arboreum* requires fewer external inputs such as irrigation, fertilizers and pesticides, making it an economically viable crop for small and marginal farmers while contributing to environmentally sustainable agriculture (Kranthi, 2018).

One of the major advantages of diploid cotton is its remarkable adaptability to adverse environmental conditions. The crop possesses a deep root system and exhibits excellent tolerance to drought, high temperature and moisture stress. It also shows natural resistance or tolerance to economically important insect pests and diseases, including jassids, bacterial blight and cotton leaf

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1. Professor (CAS) and 2. Head, Department of Agricultural Botany, Dr. PDKV, Akola.

curl disease (Wendel and Grover, 2015; ICAR-CICR, 2024). These adaptive characteristics reduce dependence on chemical pesticides and enhance crop stability under rainfed conditions.

The fibre produced by *G. arboreum* is generally shorter than that of tetraploid cotton; however, it possesses several desirable quality attributes, including good fibre maturity, satisfactory strength, excellent absorbency and durability. These characteristics make desi cotton suitable for manufacturing medium and coarse-count yarns, khadi, handloom fabrics, denim, absorbent cotton and surgical cotton (Brubaker *et al.*, 1999; Kranthi, 2018). The increasing global demand for organic and eco-friendly textiles has renewed interest in desi cotton because of its low-input cultivation and suitability for sustainable farming systems. India possesses one of the richest collections of diploid cotton germplasm in the world. Valuable genetic resources are conserved and utilized by the ICAR–Central Institute for Cotton Research (CICR), Nagpur, and the ICAR–Central Institute for Research on Cotton Technology (CIRCOT), Mumbai, the All India Coordinated Research Project (AICRP) on Cotton and various State Agricultural Universities. These institutions are actively engaged in germplasm evaluation and breeding programs for improving seed cotton yield, fibre quality, early maturity and resistance to biotic and abiotic stresses (ICAR-CICR, 2024). The rich genetic diversity of *G. arboreum* has made it an important donor species for conventional breeding as well as molecular breeding approaches aimed at developing climate-resilient cotton cultivars. In the context of climate change, declining water availability and increasing production costs, diploid cotton has gained renewed importance because of its resilience, sustainability and valuable genetic diversity. Consequently, the conservation, characterization and effective utilization of *Gossypium arboreum* germplasm are essential for developing high-yielding varieties with improved fibre quality and enhanced tolerance to environmental stresses, thereby ensuring sustainable cotton production in India.

## MATERIAL AND METHODS

The ten elite desi cotton/diploid cotton genotypes identified as a long stapled and collected throughout the

cotton growing areas of country under AICRP Project were grown at Cotton Research Unit, Dr. PDKV, Akola under rainfed condition during the year 2022. The seed cotton was harvested by traditional hand picking and lint samples were prepared using hand gins manually for quality analysis.

**Estimation of Fibre Quality Parameters:** The fibre quality parameters of the experimental material were estimated using a High Volume Instrument (HVI) under standard atmospheric conditions of  $21 \pm 1^\circ\text{C}$  and  $65 \pm 2\%$  relative humidity following the standard testing procedures recommended by the International Cotton Advisory Committee (ICAC) and ASTM International. The High Volume Instrument is the internationally accepted system for rapid, objective and reproducible measurement of cotton fibre properties and simultaneously determines fibre length, length uniformity, micronaire, strength and elongation.

Upper Half Mean Length (UHML) was determined using the fibrograph unit of the HVI. It represents the average length of the longest 50 per cent of the fibres in a sample and is expressed in millimetres (mm). The instrument measures the fibre length distribution optically and automatically computes UHML. It can be represented as:  $\text{UHML} = \sum Li / n$ , where  $Li$  is the length of individual fibres in the upper half of the fibre population and  $n$  is the total number of fibres considered. Fibre length is one of the most important determinants of spinning performance because longer fibres produce finer, stronger and more uniform yarns. (Bradow and Davidonis, 2000)

Uniformity Index (UI) was estimated by the HVI as the ratio of mean fibre length to upper half mean length and expressed as:  $\text{UI (\%)} = (\text{Mean Length} / \text{Upper Half Mean Length}) \times 100$ . A higher uniformity index indicates greater consistency in fibre length and improved spinning efficiency.

Micronaire (Mic.) was measured by the HVI micronaire module based on the principle of air permeability through a compressed cotton fibre plug. The instrument automatically converts airflow resistance into micronaire values. Micronaire reflects fibre fineness and maturity. (Bradow and Davidonis, 2000; Morton and

## Evaluation of Desi Cotton (*Gossypium Arboreum* L) Genotypes for Fibre Quality

Hearle, 2008; ASTM International.)

Fibre Strength was measured as bundle strength using the HVI strength module and expressed as grams per tex (g tex<sup>-1</sup>): Strength = Breaking Force (g) / Linear Density (tex). Fibre strength determines yarn durability and spinning performance. (ASTM D5867; ICAC; USDA NCVT; Bradow and Davidonis, 2000.)

Fibre Elongation (E%) was measured simultaneously with fibre strength and calculated as: Elongation (%) = ((Lf - L0)/L0) × 100, where L0 is the original fibre length and Lf is the fibre length at break. Fibre elongation indicates fibre elasticity and flexibility. (ASTM International; ICAC; USDANCVT.)

### RESULTS AND DISCUSSION

The evaluation of ten desi cotton genotypes for fibre quality traits revealed considerable differences in fibre length, uniformity, fineness, strength, and elongation, indicating the presence of useful genetic variability for quality improvement (Table 1). The Upper Half Mean Length (UHML) is one of the most important fibre quality traits as it determines spinning performance and yarn quality. In the present study, UHML ranged from 26.8 mm (AKA 7) to 30.9 mm (PA 796), with an overall mean

of 28.77 mm. The genotype PA 796 recorded the highest fibre length (30.9 mm), followed by PAIG 373 (30.1 mm), indicating their suitability for producing finer and stronger yarns. Genotypes PA 760 (29.1 mm), PAIG 326 (29.0 mm), PA 778 (29.0 mm) and PA 741 (28.8 mm) also possessed desirable fibre length. On the other hand, AKA 7 (26.8 mm) and AKA-8 (27.6 mm) exhibited comparatively shorter fibres, while PA 793 (27.9 mm) showed intermediate performance. The superiority of PA 796 and PAIG 373 suggests their potential use as donor parents for improving fibre length in desi cotton breeding program. The upper half mean length (UHML) ranged from 26.8 to 30.9 mm, with PA 796 and PAIG 373 exhibiting the longest fibres. Fibre length is a major determinant of spinning efficiency and yarn quality, and longer fibres generally produce finer and stronger yarns with fewer yarn imperfections. The existence of substantial variability for UHML observed in the present study agrees with the findings of Singh *et al.* (2018), who reported considerable genetic variation for fibre length among *G. arboreum* genotypes. Similar observations were also reported by Rathinavel and Gopinath (2020) and Ujjainkar (2022), who emphasized that fibre length is predominantly governed by genetic factors and can be effectively

**Table 1: Mean performance of ten desi cotton genotypes for eleven quantitative traits**

| SN | Entries  | Upper Half Mean<br>Length (UHML, mm) | Uniformity<br>Index (UI, %) | Micronaire<br>value (µg inch <sup>-1</sup> ) | Fibre Strength<br>(g tex <sup>-1</sup> ) | Elongation<br>(%) |
|----|----------|--------------------------------------|-----------------------------|----------------------------------------------|------------------------------------------|-------------------|
| 1  | PA 741   | 28.8                                 | 83                          | 3.7                                          | 25.2                                     | 4.9               |
| 2  | PAIG 326 | 29.0                                 | 83                          | 4.3                                          | 28.5                                     | 5.6               |
| 3  | PA 793   | 27.9                                 | 83                          | 4.2                                          | 28.7                                     | 5.6               |
| 4  | PAIG 77  | 28.5                                 | 83                          | 4.4                                          | 30.4                                     | 5.7               |
| 5  | PA 778   | 29.0                                 | 83                          | 4.1                                          | 29.3                                     | 6.3               |
| 6  | AKA-8    | 27.6                                 | 83                          | 4.7                                          | 28.0                                     | 5.6               |
| 7  | PAIG 373 | 30.1                                 | 83                          | 3.9                                          | 30.0                                     | 6.1               |
| 8  | PA 796   | 30.9                                 | 83                          | 3.8                                          | 29.7                                     | 5.5               |
| 9  | AKA 7    | 26.8                                 | 82                          | 4.6                                          | 28.1                                     | 5.8               |
| 10 | PA 760   | 29.1                                 | 83                          | 4.2                                          | 28.6                                     | 6.1               |
|    | Mean     | 28.77                                | 82.9                        | 4.19                                         | 28.65                                    | 5.73              |
|    | Min      | 26.8                                 | 82                          | 3.7                                          | 25.2                                     | 4.9               |
|    | Max      | 30.9                                 | 83                          | 4.7                                          | 30.4                                     | 6.3               |
|    | SD       | 1.19                                 | 0.32                        | 0.33                                         | 1.46                                     | 0.37              |
|    | CV (%)   | 4.15                                 | 0.38                        | 7.93                                         | 5.11                                     | 6.42              |

improved through selection.

Uniformity index influences yarn evenness and processing efficiency. The genotypes exhibited very little variation for this trait, ranging from 82 to 83% with an average of 82.9%. Nine genotypes recorded 83% uniformity, whereas AKA 7 had 82%. This narrow range indicates that fibre uniformity is highly stable among the evaluated material. Since all genotypes exhibited values above 82%, they can be considered acceptable for spinning purposes, suggesting that uniformity may not be a major criterion for differentiating these genotypes. The uniformity index (82–83%) exhibited very little variation among the evaluated genotypes, indicating a high degree of fibre uniformity. High uniformity is desirable because it improves spinning performance, reduces yarn irregularities, and enhances fabric quality. Similar narrow variation for uniformity index in desi cotton has been reported by Blaise *et al.* (2019), suggesting that this trait is relatively stable and less influenced by environmental conditions compared with other fibre quality characters.

Micronaire value represents fibre fineness and maturity, where intermediate values are generally preferred for textile processing. The micronaire values ranged from 3.7  $\mu\text{g inch}^{-1}$  (PA 741) to 4.7  $\mu\text{g inch}^{-1}$  (AKA-8), with a mean of 4.19  $\mu\text{g inch}^{-1}$ . Genotypes PA 741 (3.7), PA 796 (3.8) and PAIG 373 (3.9) possessed relatively finer fibres, which are desirable for manufacturing finer yarns. Genotypes PA 778 (4.1), PAIG 326 (4.3), PAIG 77 (4.4), AKA 7 (4.6) and AKA-8 (4.7) had comparatively coarser fibres, indicating higher fibre maturity. The observed micronaire values fall within the acceptable range for commercial cotton, although genotypes with lower micronaire values may be preferred for premium textile applications. Micronaire values ranged from 3.7 to 4.7  $\mu\text{g inch}^{-1}$ , indicating acceptable fibre fineness and maturity in all the genotypes. The lower micronaire values recorded in PA 741, PA 796, and PAIG 373 indicate finer fibres, whereas AKA-8 possessed comparatively coarser fibres. Moderate micronaire values are preferred in the textile industry because they represent an optimum balance between fibre fineness and maturity. These findings are consistent with those of Constable and Bange (2015) and Rathinavel (2017), who reported that

micronaire values between 3.5 and 4.9 are considered desirable for premium spinning quality germplasm.

Fibre strength is a key determinant of yarn durability and spinning performance. The genotypes exhibited fibre strength ranging from 25.2 g  $\text{tex}^{-1}$  (PA 741) to 30.4 g  $\text{tex}^{-1}$  (PAIG 77), with an average of 28.65 g  $\text{tex}^{-1}$ . PAIG 77 recorded the highest fibre strength, followed closely by PAIG 373 (30.0 g  $\text{tex}^{-1}$ ), PA 796 (29.7 g  $\text{tex}^{-1}$ ) and PA 778 (29.3 g  $\text{tex}^{-1}$ ), indicating their suitability for producing stronger yarns capable of withstanding high-speed spinning. PA 741 recorded the lowest strength, while AKA-8 (28.0 g  $\text{tex}^{-1}$ ) and AKA 7 (28.1 g  $\text{tex}^{-1}$ ) exhibited moderate strength. The superior strength observed in PAIG 77 and PAIG 373 makes these genotypes valuable genetic resources for improving fibre strength in breeding program. The fibre strength of the genotypes varied from 25.2 to 30.4 g  $\text{tex}^{-1}$ , with PAIG 77, PAIG 373 and PA 796 recording superior values. Fibre strength is one of the most important technological traits influencing yarn tenacity and processing efficiency. Strong fibres withstand mechanical stress during spinning and produce durable yarns. The present findings corroborate the reports of Blaise *et al.* (2019), and Rathinavel and Gopinath (2020), who observed significant genetic variability for fibre strength in desi cotton and emphasized that genotypes with strength exceeding 28 g  $\text{tex}^{-1}$  are highly desirable for breeding programs.

Fibre Elongation Percentage (E%) measures the elasticity and flexibility of fibres before breakage. The values ranged from 4.9% (PA 741) to 6.3% (PA 778), with an average of 5.73%. The genotype PA 778 exhibited the highest elongation (6.3%), followed by PAIG 373 (6.1%) and PA 760 (6.1%), indicating better fibre flexibility and resistance to breakage during spinning. Genotypes PAIG 77 (5.7%), PAIG 326 (5.6%), PA 793 (5.6%) and AKA-8 (5.6%) showed moderate elongation, while PA 741 (4.9%) had the lowest elongation. Higher elongation values generally contribute to improved spinning performance when accompanied by high fibre strength. The elongation percentage varied from 4.9 to 6.3%, with PA 778 exhibiting the highest elongation followed by PAIG 373 and PA 760. Fibre elongation contributes to yarn flexibility and resistance to breakage



during spinning. The moderate variation observed in the present investigation agrees with the findings of Mayee and Rao (2018) and Ujjainkar (2022), who reported that elongation is an important quality parameter that complements fibre strength in determining overall spinning performance.

Among the evaluated entries, PAIG 373 emerged as the most promising genotype because it possessed a desirable combination of long fibre length, lower micronaire, high fibre strength, and higher elongation, whereas PA 796 recorded the highest UHML with good strength and finer fibres. Similarly, PAIG 77 excelled for fibre strength and PA 778 for elongation. The simultaneous occurrence of favorable values for these economically important fibre quality traits indicates the possibility of utilizing these genotypes as parents in breeding programs aimed at improving spinning quality. Similar conclusions have been drawn by Ujjainkar (2022) and Rathinavel and Gopinath (2020), who emphasized that selection based on multiple fibre quality traits is more effective than selection based on a single character. Overall, the present results confirm that the evaluated desi cotton genotypes possess sufficient genetic variability for fibre quality improvement. The superior performance of PAIG 373, PA 796, PAIG 77 and PA 778 indicates their potential use in breeding programmes to develop varieties combining high productivity with superior fibre quality.

### CONCLUSION

On the basis of all fibre quality parameters together, PAIG 373 emerged as one of the most promising genotypes because it combined long fibre length (30.1 mm), relatively fine fibre (3.9 micronaire), high fibre strength (30.0 g tex<sup>-1</sup>), and high elongation (6.1%), representing an excellent balance of desirable fibre quality traits. PA 796 also performed exceptionally well, recording the highest fibre length (30.9 mm) along with fine fibres (3.8 micronaire) and high fibre strength (29.7 g tex<sup>-1</sup>), making it suitable for high-quality spinning applications. PAIG 77 was distinguished by its highest fibre strength (30.4 g tex<sup>-1</sup>), while PA 778 exhibited the highest elongation (6.3%) with good fibre length and strength. Conversely, PA 741 showed comparatively inferior performance due to its lower fibre strength and elongation despite possessing the finest fibre. The local checks AKA-

8 and AKA 7 exhibited moderate fibre quality and can serve as useful standards for comparison. Overall, the genotypes PAIG 373, PA 796, PAIG 77, and PA 778 demonstrated superior fibre quality attributes and therefore constitute valuable breeding materials for developing high-yielding desi cotton varieties with improved spinning and textile performance.

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## Influence of Herbicides on Weed Dynamics, Bulb Yield, Quality and Economics of Transplanted Onion

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### ABSTRACT

Field experiment was conducted at Panjabrao Deshmukh Krishi Vidyapeeth, Akola during spring month (January) of 2020-21. Herbicides treatments namely pendimethalin 677 g/ha before transplanting, pendimethalin 750 g ha<sup>-1</sup> at 0-5 DTP, oxyfluorfen 200 g ha<sup>-1</sup> (0-5 DAT), oxadiazyl 90 g ha<sup>-1</sup> (0-5 DAT), pendimethalin + oxyfluorfen 541 + 92 g ha<sup>-1</sup> (Tank-mix) (0-5 DAT), pendimethalin + oxyfluorfen 600 + 102 g ha<sup>-1</sup> (0-5 DAT), propaquizafop 100 g ha<sup>-1</sup> at 15-20 DAT, fenoxaprop-p-ethyl 78 g ha<sup>-1</sup> at 20 DAT, propaquizafop + oxyfluorfen (Ready-mix) 84 g ha<sup>-1</sup> at 20 DAT and propaquizafop 100 g ha<sup>-1</sup> at 20 DAT were applied alone or in different combinations replicated thrice in randomized block design. Pre-emergence application of pendimethalin + oxyfluorfen 541 + 92 g ha<sup>-1</sup> (Tank-mix) (0-5 DAT) recorded the highest weed control efficiency and the lowest values of weed density, dry matter accumulation of weeds and weed index, however, higher level of same herbicides was found phytotoxic. The pre-emergence application of oxyfluorfen 200 g ha<sup>-1</sup> was also found to be equally effective in controlling the weeds in onion. The yield attributing traits such as average bulb weight and total bulb yield also recorded same pattern. However, the highest net return and benefit cost ratio was reported with application of pendimethalin + oxyfluorfen (TM), 541 + 92 g ha<sup>-1</sup> (0-5 DAT) closely followed by oxyfluorfen 200 g/ha.

Onion (*Allium cepa* L.) is a commercially important vegetable crop globally, with India being the second-largest producer after China. Onions are often referred to as the “Queen of the kitchen” due to their versatile use and unique flavor profile. In India, Maharashtra leads in onion production, covering an area of 4.81 mha with a production of 37.34 mt and a productivity of 14.0 t ha<sup>-1</sup>. Weeds significantly impact onion production, causing bulb yield reduction by 40-80%. Uncontrolled weed growth reduced onion bulb yield by 49 to 86 percent (James and Harlen, 2010). The critical period for weed competition in onion is between 15 and 60 days after transplanting, and early weed management is crucial for higher yield. This is primarily due to weeds competing with onions for resources like water, nutrients, light, and space. Onions, being a relatively poor competitor with weeds due to their growth habit and shallow root system, are particularly vulnerable. The conventional methods of weed control, like hand weeding and hoeing, are ineffective for onion crops due to factors like closer planting geometry and shallow root systems. These methods are also laborious, expensive, and time-consuming, making them less effective, especially on a large scale. In situations where conventional weed control methods are ineffective in onion fields, herbicides

offer a viable solution. The research likely aimed to determine how different herbicides (pre- and post-emergence) affected weed control, plant growth parameters, bulb yield, and ultimately, the financial returns associated with onion cultivation.

### MATERIAL AND METHODS

A field experiment was conducted during spring months of (January-April) 2020-21 at All India Coordinated Research Project (AICRP) on Weed Management, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, India. The soil of experimental plot was medium deep black with fairly uniform and leveled topography with slightly alkaline in reaction with medium status of organic carbon content, available nitrogen and phosphorous and fairly rich status of available potassium.

The experiment was laid out in randomized block design (RBD) replicated thrice. The treatment comprises of pendimethalin 677 g ha<sup>-1</sup> before transplanting (T<sub>1</sub>), pendimethalin 750 g ha<sup>-1</sup> pre-emergence (PE) day after transplanting (DAT) (T<sub>2</sub>), oxyfluorfen 200 g ha<sup>-1</sup> PE (T<sub>3</sub>), pendimethalin + oxyfluorfen 541 + 92 g ha<sup>-1</sup> PE (T<sub>4</sub>), pendimethalin + oxyfluorfen 600+104 g ha<sup>-1</sup> PE (T<sub>5</sub>), propaquizafop + oxyfluorfen 84 g ha<sup>-1</sup> 20 DAT (T<sub>6</sub>), propaquizafop + oxyfluorfen 84 g ha<sup>-1</sup> 20 DAT (T<sub>7</sub>),

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farmer practice thrice hand weeding 20 days interval ( $T_0$ ) and weedy check ( $T_0$ ). All the pre-emergence herbicides were applied on the day after transplanting of onion seedling and post-emergence herbicides were applied at 2-3 leaf stage of weeds (20 DAS). The gross plot size of the main plot was 25 m<sup>2</sup>. Herbicides were mixed with water at a rate of 500 litres per hectare, thoroughly mixed, and applied using a battery operated knapsack sprayer with a flat fan nozzle.

The onion (*cv. Akola Safed*) was sown on last week of November with seed rate of 10 kg ha<sup>-1</sup> and transplanted on last week of January at 10 cm x 10 cm and harvested in April. The data recorded for different characters in this study were analyzed by following analysis of variance procedure as described by Gomez and Gomez (1984). All other agronomic and crop management practices were followed as per regional recommendations.

## RESULTS AND DISCUSSION

### Weed flora

The major weed flora during *kharif* season in onion crop in the selected area composed of following weed species. *Cynodon dactylon*, *Cyperus rotundus*, *Commelina benghalensis*, *Ischaemum pilosum*, *Dinebra retroflexa*, *Roem*. Dicot weeds were *Digera arvensis*, *Euphorbia geniculata*, *Parthenium hysterophorus*, *Portulaca oleraceae*, *Amaranthis viridis*, *Acalypha indica*, *Cardiospermum helicacabum*, *Ipomoea reniformis*, *Corchorus acutangulus*, *Phyllanthus niruri*, *Boerhavia diffusa*.

### Weed density (no/m<sup>2</sup>)

Data pertaining to the effect of various weed management treatment on number of total weeds found to be differed significantly (Table 1). At 30 DAS, farmers practice i.e., hand weeding thrice at 20 days interval recorded significantly lowest number of weeds. Among pre-emergence herbicidal treatments, minimum total weed count/m<sup>2</sup> was observed with application of pendimethalin + oxyfluorfen (600 + 102 g ha<sup>-1</sup>) followed by pendimethalin + oxyfluorfen (541 + 92 g ha<sup>-1</sup>) and oxyfluorfen 200 g ha<sup>-1</sup>. Shinde *et al.*, (2013) indicated that pendimethalin 38.7% CS at 1.75 litre ha<sup>-1</sup> exhibited the greatest grass weed control efficiency (90.19%),

whereas oxyfluorfen 23.5% EC at 1.0 litre ha<sup>-1</sup> showed the greatest broadleaved weed control efficacy (82.95%) in onion. Whereas former treatment was found phytotoxic with slight stunting, injury discolouration (phytotoxic rating:1).

Among post emergence herbicides application of propaquizafop + oxyfluorfen (43 + 105 g ha<sup>-1</sup>) at both the levels recorded minimum weed density due to broad-spectrum weed control over propaquizafop 100 g ha<sup>-1</sup> 20 DAT and fenoxaprop 78 g ha<sup>-1</sup>. However, maximum total weeds were observed in weedy check treatment. Total weed population was reduced significantly due to various weed control treatments at all the stages of crop growth. Application of pendimethalin + oxyfluorfen (541+92 g ha<sup>-1</sup>) followed by oxyfluorfen 200 g ha<sup>-1</sup> were found almost identical reduction in weed dry matter.

### Weed control efficiency and weed index:

The highest weed control efficiency (%) was recorded with farmers practice (3 HW at 20, 40 & 60 DAT) at all the growth stages this may be due to better control of weeds with timely intercultivation (Table 2). Among herbicides treatments higher weed efficiency was recorded with pendimethalin + oxyfluorfen (600+102 g ha<sup>-1</sup>) followed by pre-emergence herbicide of oxyfluorfen 200 g ha<sup>-1</sup>. While lowest weed index was noticed in pendimethalin + oxyfluorfen 541 + 92 g ha<sup>-1</sup> 3 DAT followed by oxyfluorfen 200 g ha<sup>-1</sup>. This might be due to effective weed control in treated plot which resulted increase in yield. Similar result was reported by Patel *et al.* (2011). Weed index is the indicator of losses in the yield due to presence of the weeds. Minimum reduction in bulb yield of onion was recorded with farmers practice, however, among herbicides treatments lower reduction in yield was noticed with pendimethalin + oxyfluorfen (541 + 92 g ha<sup>-1</sup>) followed by oxyfluorfen 200 g ha<sup>-1</sup> (PE). Maximum weed index was in weedy check plots due to prominent weed-crop competition. Higher weed index was recorded with herbicide treatment of propaquizafop 100 g ha<sup>-1</sup> and fenoxaprop 78 g ha<sup>-1</sup> followed by combine application of propaquizafop + oxyfluorfen at both the doses.

### Onion Yield hectare<sup>-1</sup>

The among the weed control treatments, pre-emergence application of pendimethalin+oxyfluorfen

**Table 1 : Total weed population and weed dry matter as influenced by different treatment**

| Treatment                                                                  | Weed population (no/m <sup>2</sup> ) |                |                | Weed biomass (g/m <sup>2</sup> ) |                  |                |
|----------------------------------------------------------------------------|--------------------------------------|----------------|----------------|----------------------------------|------------------|----------------|
|                                                                            | 30                                   | 60             | 90             | 30                               | 60               | 90             |
| T <sub>1</sub> : Pendimethalin 0.677 kg/ha BTP (2-3 Days)                  | 2.61<br>(6.3)                        | 3.71<br>(13.3) | 4.22<br>(17.3) | 4.36<br>(18.5)                   | 5.90<br>(34.3)   | 6.19<br>(37.8) |
| T <sub>2</sub> : Pendimethalin 0.750 kg/ha (0-5 DAT)                       | 2.37<br>(5.1)                        | 3.56<br>(12.2) | 3.99<br>(15.4) | 4.09<br>(16.2)                   | 5.87<br>(33.9)   | 6.10<br>(36.7) |
| T <sub>3</sub> : Oxyfluorfen 0.200 kg/ha (PE) (0-5 DAT)                    | 2.26<br>(4.6)                        | 3.73<br>(13.4) | 4.32<br>(18.2) | 3.70<br>(13.2)                   | 5.40<br>(28.7)   | 5.75<br>(32.6) |
| T <sub>4</sub> : Pendimethalin + oxyfluorfen 0.541 + 0.092 kg/ha (0-5 DAT) | 2.41<br>(5.3)                        | 3.86<br>(14.4) | 4.35<br>(18.4) | 3.65<br>(12.8)                   | 5.32<br>(27.8)   | 5.63<br>(31.2) |
| T <sub>5</sub> : Pendimethalin + oxyfluorfen 600 + 102 g/ha (0-5 DAT)      | 2.12<br>(4.0)                        | 3.48<br>(11.6) | 3.85<br>(14.3) | 3.62<br>(12.6)                   | 5.27<br>(27.3)   | 5.50<br>(29.8) |
| T <sub>6</sub> : Propaquizafop + oxyfluorfen 35 + 84 g/ha PoE 15-20 DAT    | 3.26<br>(10.1)                       | 4.79<br>(22.4) | 4.97<br>(24.2) | 5.28<br>(27.4)                   | 8.25<br>(67.5)   | 8.49<br>(71.5) |
| T <sub>7</sub> : Propaquizafop + oxyfluorfen 43 + 105 g/ha PoE 15-20 DAT   | 2.61<br>(6.3)                        | 4.39<br>(18.8) | 4.82<br>(22.7) | 5.18<br>(26.3)                   | 7.32<br>(53.1)   | 7.56<br>(56.6) |
| T <sub>8</sub> : Farmers Practice (HW at 20, 40 and 60 DAT)                | 1.76<br>(2.6)                        | 2.41<br>(5.3)  | 2.93<br>(8.1)  | 1.73<br>(2.5)                    | 2.19<br>(4.3)    | 2.47<br>(5.6)  |
| T <sub>9</sub> : Weedy check<br>(59.3)                                     | 7.73<br>(73.4)                       | 8.60<br>(79.6) | 8.95<br>(49.2) | 7.05<br>(102.8)                  | 10.16<br>(121.2) | 11.03          |
| CD at 5%                                                                   | 0.17                                 | 0.21           | 0.24           | 0.17                             | 0.21             | 0.24           |

**Table 2: Weed control efficiency and weed index as influenced by different treatments**

| Treatment                                                                  | Weed Control Efficiency (%) |        |        | Weed index (%) |
|----------------------------------------------------------------------------|-----------------------------|--------|--------|----------------|
|                                                                            | 30 DAS                      | 60 DAS | 90 DAS |                |
| T <sub>1</sub> : Pendimethalin 0.677 kg/ha BTP (2-3 Days)                  | 62.40                       | 66.63  | 68.81  | 27.66          |
| T <sub>2</sub> : Pendimethalin 0.750 kg/ha (0-5 DAT)                       | 67.07                       | 67.02  | 69.72  | 17.02          |
| T <sub>3</sub> : Oxyfluorfen 0.200 kg/ha (PE) (0-5 DAT)                    | 73.17                       | 72.08  | 73.10  | 5.32           |
| T <sub>4</sub> : Pendimethalin + oxyfluorfen 0.541 + 0.092 kg/ha (0-5 DAT) | 73.98                       | 72.96  | 74.26  | 4.26           |
| T <sub>5</sub> : Pendimethalin + oxyfluorfen 600 + 102 g/ha (0-5 DAT)      | 74.39                       | 73.44  | 75.41  | 11.70          |
| T <sub>6</sub> : Propaquizafop + oxyfluorfen 35 + 84 g/ha PoE 15-20 DAT    | 44.31                       | 34.34  | 41.01  | 32.45          |
| T <sub>7</sub> : Propaquizafop + oxyfluorfen 43 + 105 g/ha PoE 15-20 DAT   | 46.54                       | 48.35  | 53.30  | 27.66          |
| T <sub>8</sub> : Farmers Practice (HW at 20, 40 and 60 DAT)                | 94.92                       | 95.82  | 95.38  | 0.00           |
| T <sub>9</sub> : Weedy check                                               | 0.00                        | 0.00   | 0.00   | 41.49          |

(541+92 g ha<sup>-1</sup>) recorded significantly higher bulb yield excepting application of oxyfluorfen 200 g ha<sup>-1</sup> and pendimethalin 750 g ha<sup>-1</sup> due to better control of weeds at critical stages thus providing favourable environment for better growth and development leading to enhanced bulb yield (Table 3). These treatments were comparable with each other. However, at higher level of pendimethalin + oxyfluorfen (600 + 102 g ha<sup>-1</sup>) showed phytotoxic with

slight stunting, injury discolouration (phytotoxic rating: 1) resulting in reduction in yield. The pre-emergence herbicides offer the most practical, effective and economical method of weed control for increasing bulb yields of onion. Among post-emergence herbicides none of the treatments was found effective in obtaining better bulb yield than pre-emergence herbicides. Findings are

**Table 3: Economics of onion as influenced by different treatments**

| Treatment                                                                 | Onion<br>bulb<br>yield<br>(t ha <sup>-1</sup> ) | Cost of<br>production<br>(Rs ha <sup>-1</sup> ) | Gross<br>monetary<br>return<br>(Rs ha <sup>-1</sup> ) | Net<br>monetary<br>return<br>(Rs ha <sup>-1</sup> ) | BCR  |
|---------------------------------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------------|-----------------------------------------------------|------|
| T <sub>1</sub> :Pendimethalin 0.677 kg/ha BTP (2-3 Days)                  | 13.6                                            | 42153                                           | 68000                                                 | 25847                                               | 1.61 |
| T <sub>2</sub> :Pendimethalin 0.750 kg/ha (0-5 DAT)                       | 16.6                                            | 42853                                           | 83000                                                 | 40147                                               | 1.94 |
| T <sub>3</sub> :Oxyfluorfen 0.200 kg/ha (PE) (0-5 DAT)                    | 17.0                                            | 41438                                           | 85000                                                 | 43562                                               | 2.05 |
| T <sub>4</sub> :Pendimethalin + oxyfluorfen 0.541 + 0.092 kg/ha (0-5 DAT) | 18.0                                            | 42293                                           | 90000                                                 | 47707                                               | 2.13 |
| T <sub>5</sub> :Pendimethalin + oxyfluorfen 600 + 102 g/ha (0-5 DAT)      | 17.8                                            | 42493                                           | 89000                                                 | 46507                                               | 2.09 |
| T <sub>6</sub> :Propaquizafop + oxyfluorfen 35 + 84 g/ha PoE 15-20 DAT    | 11.5                                            | 43603                                           | 57500                                                 | 13897                                               | 1.32 |
| T <sub>7</sub> :Propaquizafop + oxyfluorfen 43 + 105 g/ha PoE 15-20 DAT   | 13.6                                            | 42303                                           | 68000                                                 | 25697                                               | 1.61 |
| T <sub>8</sub> :Farmers Practice (HW at 20, 40 and 60 DAT)                | 18.8                                            | 46253                                           | 94000                                                 | 47747                                               | 2.03 |
| T <sub>9</sub> :Weedy check                                               | 11.0                                            | 40253                                           | 55000                                                 | 14747                                               | 1.37 |
| CD at 5%                                                                  | 2.91                                            | —                                               | 15157                                                 | 15157                                               | —    |

closely vicinity of those reported by Kalhapure *et al.* (2013) and Gohil *et al.* (2024).

#### Economics

The data related to cost of cultivation, gross return, net return, benefit: cost ratio under various weed management practices is presented in Table 3. The highest net monetary return of Rs 47707/ha was obtained with application of pendimethalin + oxyfluorfen (600+102 g/ha PE) with benefit: cost ratio of 2.13 followed by oxyfluorfen 200 g ha<sup>-1</sup> (Rs.43562; BCR-2.05). Though weeds were controlled more efficiently and bulb yield production was highest in treatment of three hand weeding at 20, 40 and 60 DAT, its cost of cultivation was also higher (Rs 94000 ha) because of the higher human labour requirement and their higher wages. The cost of human labours for controlling weeds was reduced with application of pre-emergence herbicides, which was responsible for reduction in total cost of cultivation, resulting maximum B: C. The lowest monetary returns were obtained with weedy check treatment. The outcomes correspond with those of Tripathy *et al.* (2019) and Pramod and Rakesh (2021).

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## Studies of Soil Nutrient Status of Aundha Nagnath Block In Hingoli District of Maharashtra

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### ABSTRACT

The present study assessed the fertility status of soil from 19 villages in Aundha Nagnath block of Hingoli district in Maharashtra state, during the year of 2014-2015. Based on 619 composite soil samples, the soil reaction was uniformly alkaline across all locations of selected villages, with pH ranging from 7.69 to 8.39 (mean value 8.07), while electrical conductivity remained within normal limits (mean 0.34 dS m<sup>-1</sup>), indicating that soil was non saline categories. Organic carbon content in soil varied widely (0.12- 0.87%, mean 0.49), with the most of soil samples comes under low to medium classes. Available phosphorus showed considerable deficiency, ranging from 5.10 to 28.34 kg ha<sup>-1</sup> (mean 12.64 kg ha<sup>-1</sup>), with 65-85% of samples categorized as low. In contrast, available potassium was consistently very high in all samples (>300 kg ha<sup>-1</sup>), indicating strong K rich pedology. Micronutrients analysis revealed sufficient to high levels of Cu (mean 0.52 ppm), Fe (mean 5.95 ppm), Mn (mean 7.82 ppm) and Zn. Overall the soils of Aundha Nagnath are characterized by alkaline reaction, low organic matter, phosphorus deficiency, and very high potassium reserves.

Aundha Nagnath block is located in Hingoli district of Maharashtra. The annual precipitation was 500 to 700 mm. The most of the farmers practiced only rainfed farming but now irrigation facility through dam well available and some area is under protective irrigation. The soil fertility is the inherent capacity of a soil to supply the essential plant nutrients. It is primary division whose maintenance is a major concern in tropical parts of world like India where fast decomposition of organic matter lowers the soil organic carbon content. Lowering the organic carbon content in the soil deteriorates the fertility of the soil. In traditional farming system, soil fertility was naturally maintained due to traditional management practices such as used of crop residues, animal manures and leaving land fallow for few years.

Soil fertility is a function of several factors and processes like, soci-economic and some ecological, for instance, parent material natural inputs and outputs to and from the system and management practices. Soil testing program is beneficial to formulate specific fertilizer recommendations. Soil fertility maps are meant for highlighting the nutrient needs, based on fertility status of soil (adverse soil condition need improvement) to realized good crop yield. Obviously, a soil fertility map for a particular area can prove highly beneficial in guiding the farmers, manufacturers and planners (associated with fertilizer marketing and distribution ) in ascertaining the

requirement of various fertilizers in a season / year and making projections for increased requirement based on cropping pattern and intensity.

### MATERIAL AND METHODS

The present studied was undertaken in order to evaluation soil nutrient status of Aundha Nagnath block of Hingoli district. Randomly 19 villages selected form the Aundha block for collection of soil samples. Aundha Nagnath has dry and tropical climate with hot summer and mild winter season. The most of the farmer's soybean, red gram and cotton cultivated in kharif season, moreover sorghum, wheat and gram in rabi season under protective irrigation. Total soil sample 619 was collected for evaluation of fertility status in Aundha block. The soil samples were collected in the month of April to May from the concern farmers with the help of State Agriculture department of Hingoli. The soil pH was determined in soil water suspension (1:25 ratio) using digital pH meter (Jackson, 1973). The electrical conductivity was determined in 1:2.5 soil: water suspension using electrical conductivity meter and noted in dS m<sup>-1</sup> (Jackson, 1973). The soil organic carbon estimating by Walkely and Blacks method (Walkley and Black, 1934). Available nitrogen estimated using Alkaline and permanganate method (Subbiah and Asija, 1956). The determination of available phosphorus was done by using Olsens reagen (0.5 N

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sodium bicarbonate solution of pH 8.5) by (Olsen *et al.*, 1954). Available potassium was extracted by 1 N ammonium acetate of pH 7.0 using Flame photometer by (Jackson, 1973). The soil micronutrients viz., Fe, Mn, Zn, Cu (DTPA extractable) were determined by using extraction method by (Lindsay and Norvell, 1978). The nutrient indices of soil of selected villages in Aundha Nagnath block of Hingoli district will be worked out and soil fertility index will be assessed using rating suggested by Ramamurthy and Bajaj (1959). Statistical analysis was done by using excel format.

## RESULTS AND DISCUSSION

### Chemical properties of soil:

**Soil pH :** The soil pH from different 19 villages locations in Aundha Nagnath block ranged 7.69 and 8.79 with an overall mean of 8.07 presented in Table 1. According to the soil pH classification, 97-100% of soil samples observed in alkaline category (pH 7.5-8.5), with only a negligible parts in ASEN (2.44%) and AASO (4.76%) recorded neutral pH of soil, whereas higher pH 8.79 in AGOL was noted. Most soil samples were moderately alkaline condition, due to the continuously irrigated crop was grown on medium to deep black soils, which was promotes alkalinity. The variation in soil pH is closely associated with factors with as parent materials, leaching intensity, calcium carbonate and exchangeable sodium. These findings align with the observations of Kale *et al.* (2025).

### Electrical Conductivity (EC)

The data on the electrical conductivity and its categorized are presented in Table 1. The electrical conductivity value of soil samples varied from 0.12 to 0.64 dS/m, with an average of 0.34 dS m<sup>-1</sup>, indicating that soil are non –saline and suitable for most crops. All the soil samples found normal category (<0.8 dS m<sup>-1</sup>). Lower the electrical conductivity, suggests minimal salt stress, which is beneficial for crop growth in these soils conditions. Similar results were reported by Magare *et al.* (2019).

### Electrical Conductivity

The electrical conductivity of soil pare shown and all tested soil samples value were normal in their

electrical conductivities below <2dS m<sup>-1</sup>. The electrical conductivity ranges from 0.18 to 0.50 with an average 0.34 dS m<sup>-1</sup>. The minimum electrical conductivity 0.14 dS/m was observed in sample code No. AWAL33, ANAL21 and ARUP39 respectively, while maximum EC was recorded in sample code No. ARUP 39 that was 0.64 dS m<sup>-1</sup>. These soil samples from seceded villages are safe for agronomical and horticultural crops for growing in categorized. The lower the electrical conductivity values which is indicated that the infiltration rate of soil was good due to leaching the soluble salts from the soil surface layers are similar to findings of Waikar *et al.* (2014) who reported normal range of soluble salts concentration in Marathwada regions of soils.

### Organic Carbon

The organic carbon content in different location of Aundha Nagnath soil varied from 0.22 to 0.87% with a mean value of 0.49% presented in table 2. Across the various 19 villages, the majority of the sample low categories (0.20-0.40%) to medium (0.41-0.60%), accounting for more than 60% of the total soil samples. Very low (<0.20%) soil organic carbon was noticed only at AASO, ARUP, and ASON indicating localized depletion of organic residues. Moderately high soil organic carbon was (0.60-0.80%) at ASAN, AWAL, APOT and ASON, while none of the samples reached the high (>0.80%) class. The predominance of low to medium soil organic carbon is characteristic of semi-arid tropical regions, where high temperature and rapid mineralization reduce organic matter accumulations. Similar result findings were reported by Lal (2004) . In dryland soils of India, need for continuous organic matter addition through FYM, compost, green manuring or bio-organic inputs to improve soil productivity.

### Available Phosphorus

Available phosphorus ranged from 5.10 to 28.34 kg ha<sup>-1</sup> with a mean of 12.64 kg ha<sup>-1</sup>, indicating predominantly low to medium phosphorus availability (Table 3). Most locations were classified under low (7-14 kg ha<sup>-1</sup>) and medium (15-12 kg ha<sup>-1</sup>) categories, together comprising more than 85% of the soil samples. Very low phosphorus (< 7 kg ha<sup>-1</sup>) occurred at ASAN, ABRA, ADEV, AMAR and AASO, while moderately high levels

Table 1: Categorization of Aundha Nagnath soil on the basis of rating of soil pH and Electrical conductivity

| S.S.N.  | Code No. | No of Samples | pH   |       | EC (dS/m) |               | Categorized (%)  |                    |      |       |         |              |                          |                         |
|---------|----------|---------------|------|-------|-----------|---------------|------------------|--------------------|------|-------|---------|--------------|--------------------------|-------------------------|
|         |          |               | Min  | Max   | Average   | Acidic (<6.5) | Normal (6.5-7.5) | Alkaline (7.5-8.5) | Min  | Max   | Average | Normal (0.8) | Salt Sensitive (0.8-1.6) | Salt Tolerant (1.6-2.5) |
| 1       | ASAN     | 22            | 7.79 | 8.20  | 7.99      | -             | -                | 100                | 0.21 | 0.39  | 0.29    | 100          | -                        | -                       |
| 2       | AWAL     | 33            | 7.78 | 8.29  | 8.08      | -             | -                | 100                | 0.14 | 0.52  | 0.35    | 100          | -                        | -                       |
| 3       | ABRA     | 33            | 7.80 | 8.38  | 8.14      | -             | -                | 100                | 0.19 | 0.50  | 0.32    | 100          | -                        | -                       |
| 4       | AKAI     | 41            | 7.78 | 8.34  | 8.08      | -             | -                | 100                | 0.21 | 0.53  | 0.35    | 100          | -                        | -                       |
| 5       | AWAG     | 30            | 7.80 | 8.29  | 8.11      | -             | -                | 100                | 0.19 | 0.49  | 0.36    | 100          | -                        | -                       |
| 6       | ADEV     | 47            | 7.79 | 8.39  | 8.08      | -             | -                | 100                | 0.19 | 0.48  | 0.32    | 100          | -                        | -                       |
| 7       | ANAL     | 21            | 7.80 | 8.33  | 8.09      | -             | -                | 100                | 0.14 | 0.55  | 0.33    | 100          | -                        | -                       |
| 8       | ATAP     | 49            | 7.80 | 8.29  | 8.08      | -             | -                | 100                | 0.18 | 0.52  | 0.35    | 100          | -                        | -                       |
| 9       | AMAR     | 19            | 7.76 | 8.32  | 8.04      | -             | -                | 100                | 0.18 | 0.44  | 0.33    | 100          | -                        | -                       |
| 10      | ALAS     | 47            | 7.69 | 8.39  | 8.06      | -             | -                | 100                | 0.16 | 0.54  | 0.34    | 100          | -                        | -                       |
| 11      | ASEN     | 41            | 7.75 | 8.32  | 8.05      | -             | 2.44             | 97.56              | 0.19 | 0.44  | 0.33    | 100          | -                        | -                       |
| 12      | AJAD     | 52            | 7.80 | 8.38  | 8.05      | -             | -                | 100                | 0.19 | 0.44  | 0.30    | 100          | -                        | -                       |
| 13      | AASO     | 21            | 7.72 | 8.32  | 8.03      | -             | 4.76             | 95.24              | 0.16 | 0.39  | 0.26    | 100          | -                        | -                       |
| 14      | APOT     | 35            | 7.80 | 8.29  | 7.99      | -             | -                | 100                | 0.22 | 0.48  | 0.35    | 100          | -                        | -                       |
| 15      | ARUP     | 39            | 7.69 | 8.39  | 8.09      | -             | -                | 100                | 0.14 | 0.64  | 0.37    | 100          | -                        | -                       |
| 16      | ADHA     | 19            | 7.80 | 8.29  | 8.05      | -             | -                | 100                | 0.21 | 0.48  | 0.35    | 100          | -                        | -                       |
| 17      | ASUK     | 29            | 7.81 | 8.39  | 8.10      | -             | -                | 100                | 0.12 | 0.52  | 0.35    | 100          | -                        | -                       |
| 18      | ASON     | 21            | 7.82 | 8.38  | 8.05      | -             | -                | 100                | 0.25 | 0.55  | 0.36    | 100          | -                        | -                       |
| 19      | AGOL     | 41            | 7.79 | 8.79  | 8.16      | -             | -                | 100                | 0.21 | 0.61  | 0.38    | 100          | -                        | -                       |
| Average |          |               | 7.78 | 8.36  | 8.07      |               |                  |                    | 0.18 | 0.50  | 0.34    |              |                          |                         |
| SD      |          |               |      | 0.043 |           |               |                  |                    |      | 0.029 |         |              |                          |                         |
| CV%     |          |               |      | 0.54  |           |               |                  |                    |      | 8.65  |         |              |                          |                         |

**Table 2: Categorization of Aundha Nagnath soil on the basis of rating of soil Organic Carbon**

| S.S.N. | Code No. | No of<br>Samples | Organic carbon (%) |      |         |                     | Categorized        |                       |                                |                     |                     |
|--------|----------|------------------|--------------------|------|---------|---------------------|--------------------|-----------------------|--------------------------------|---------------------|---------------------|
|        |          |                  | Min                | Max  | Average |                     |                    |                       |                                |                     |                     |
|        |          |                  |                    |      |         | Very Low<br>(<0.20) | Low<br>(0.20-0.40) | Medium<br>(0.41-0.60) | Moderately<br>high (0.60-0.80) | high<br>(0.80-1.00) | Very high<br>(>1.0) |
| 1      | ASAN     | 22               | 0.36               | 0.77 | 0.57    | -                   | 13.64              | 54.55                 | 31.82                          | -                   | -                   |
| 2      | AWAL     | 33               | 0.23               | 0.83 | 0.54    | -                   | 18.18              | 54.55                 | 27.27                          | -                   | -                   |
| 3      | ABRA     | 33               | 0.20               | 0.65 | 0.42    | -                   | 51.52              | 39.39                 | 9.09                           | -                   | -                   |
| 4      | AKAI     | 41               | 0.30               | 0.72 | 0.50    | -                   | 24.39              | 63.41                 | 12.20                          | -                   | -                   |
| 5      | AWAG     | 30               | 0.22               | 0.78 | 0.49    | -                   | 33.33              | 56.67                 | 10.00                          | -                   | -                   |
| 6      | ADEV     | 47               | 0.24               | 0.67 | 0.49    | -                   | 23.40              | 63.83                 | 12.77                          | -                   | -                   |
| 7      | ANAL     | 21               | 0.33               | 0.60 | 0.47    | -                   | 28.57              | 71.43                 | 00.00                          | -                   | -                   |
| 8      | ATAP     | 49               | 0.29               | 0.70 | 0.49    | -                   | 20.41              | 71.43                 | 8.16                           | -                   | -                   |
| 9      | AMAR     | 19               | 0.22               | 0.63 | 0.43    | -                   | 42.11              | 52.63                 | 5.26                           | -                   | -                   |
| 10     | ALAS     | 47               | 0.21               | 0.79 | 0.55    | -                   | 10.64              | 53.19                 | 36.17                          | -                   | -                   |
| 11     | ASEN     | 41               | 0.24               | 0.68 | 0.46    | -                   | 34.15              | 60.98                 | 4.88                           | -                   | -                   |
| 12     | AJAD     | 52               | 0.23               | 0.73 | 0.48    | -                   | 32.69              | 53.85                 | 13.46                          | -                   | -                   |
| 13     | AASO     | 21               | 0.12               | 0.81 | 0.47    | 4.76                | 38.10              | 52.38                 | 9.52                           | -                   | -                   |
| 14     | APOT     | 35               | 0.23               | 0.80 | 0.52    | -                   | 20.00              | 54.29                 | 22.86                          | 2.86                | -                   |
| 15     | ARUP     | 39               | 0.15               | 0.75 | 0.45    | 5.13                | 33.33              | 38.46                 | 23.08                          | 0.00                | -                   |
| 16     | ADHA     | 19               | 0.28               | 0.69 | 0.44    | 0.00                | 36.84              | 57.89                 | 5.26                           | 0.00                | -                   |
| 17     | ASUK     | 29               | 0.26               | 0.73 | 0.48    | 0.00                | 31.03              | 48.28                 | 20.69                          | 0.00                | -                   |
| 18     | ASON     | 21               | 0.17               | 0.87 | 0.57    | 4.76                | 4.76               | 42.86                 | 42.86                          | 4.76                | -                   |
| 19     | AGOL     | 41               | 0.28               | 0.77 | 0.50    | 0.00                | 17.07              | 68.29                 | 14.63                          | 0.00                | -                   |
|        | Average  |                  | 0.24               | 0.74 | 0.49    |                     |                    |                       |                                |                     |                     |
|        | SD       |                  |                    |      | 0.044   |                     |                    |                       |                                |                     |                     |
|        | CV%      |                  |                    |      | 8.92    |                     |                    |                       |                                |                     |                     |

Table 3: Categorization of Aundha Nagnath soil on the basis of rating of soil Available Phosphorus (Kg ha<sup>-1</sup>)

| S.N.    | Code No. | No of Samples | Available Phosphorus kg/ha |       |         |               | Categorized (%) |                |                         |              |                 |
|---------|----------|---------------|----------------------------|-------|---------|---------------|-----------------|----------------|-------------------------|--------------|-----------------|
|         |          |               | Min                        | Max   | Average | Very Low (<7) | Low (7-14)      | Medium (15-21) | Moderately high (22-28) | High (29-35) | Very high (>35) |
| 1       | ASAN     | 22            | 6.20                       | 22.33 | 14.39   | 9.09          | 54.55           | 36.36          | -                       | -            | -               |
| 2       | AWAL     | 33            | 7.05                       | 20.64 | 12.52   | 12.12         | 54.55           | 33.33          | -                       | -            | -               |
| 3       | ABRA     | 33            | 6.71                       | 24.41 | 13.40   | 6.06          | 57.58           | 36.36          | -                       | -            | -               |
| 4       | AKAI     | 41            | 6.26                       | 23.39 | 13.48   | 9.76          | 56.10           | 34.15          | -                       | -            | -               |
| 5       | AWAG     | 30            | 6.33                       | 21.77 | 12.69   | 3.33          | 63.33           | 33.33          | -                       | -            | -               |
| 6       | ADEV     | 47            | 5.44                       | 27.84 | 13.77   | 17.02         | 46.81           | 36.17          | -                       | -            | -               |
| 7       | ANAL     | 21            | 6.33                       | 14.42 | 10.49   | 14.29         | 85.71           | 0.00           | -                       | -            | -               |
| 8       | ATAP     | 49            | 6.40                       | 19.68 | 10.99   | 10.20         | 83.67           | 6.12           | -                       | -            | -               |
| 9       | AMAR     | 19            | 5.15                       | 15.91 | 10.07   | 15.79         | 78.95           | 5.26           | -                       | -            | -               |
| 10      | ALAS     | 47            | 6.56                       | 23.97 | 12.77   | 8.51          | 70.21           | 21.28          | -                       | -            | -               |
| 11      | ASEN     | 41            | 7.34                       | 23.19 | 13.71   | 2.44          | 53.66           | 43.90          | -                       | -            | -               |
| 12      | AJAD     | 52            | 6.02                       | 20.28 | 12.14   | 3.85          | 80.77           | 15.38          | -                       | -            | -               |
| 13      | AASO     | 21            | 5.10                       | 28.34 | 13.98   | 9.52          | 57.14           | 33.33          | -                       | -            | -               |
| 14      | APOT     | 35            | 7.24                       | 20.64 | 12.52   | 11.43         | 62.86           | 25.71          | -                       | -            | -               |
| 15      | ARUP     | 39            | 6.31                       | 22.94 | 12.50   | 12.82         | 56.41           | 30.77          | -                       | -            | -               |
| 16      | ADHA     | 19            | 7.67                       | 18.42 | 12.22   | 0.00          | 78.95           | 21.05          | -                       | -            | -               |
| 17      | ASUK     | 29            | 8.10                       | 22.94 | 13.11   | 0.00          | 68.97           | 27.59          | 3.45                    | -            | -               |
| 18      | ASON     | 21            | 8.53                       | 19.00 | 11.64   | 0.00          | 90.48           | 9.52           | -                       | -            | -               |
| 19      | AGOL     | 41            | 7.88                       | 20.29 | 13.70   | 0.00          | 58.54           | 41.46          | -                       | -            | -               |
| Average |          |               | 6.66                       | 21.60 | 12.64   |               |                 |                |                         |              |                 |
| SD      |          |               |                            |       | 1.187   |               |                 |                |                         |              |                 |
| CV%     |          |               |                            |       | 9.39    |               |                 |                |                         |              |                 |

(22-28 kg ha<sup>-1</sup>) were rare (only ASUK). No soil sample reached the high (>29 kg ha<sup>-1</sup>) category.

The widespread deficiency of available P is common in soil of Maharashtra due to high calcium carbonate and clay content, which lead to fixation of phosphorus in unavailable form. Similar low P status has been reported by Waikar *et al.*, (2014) in Marathwada soils. This suggests a requirement for regular application of P fertilizer, integrated with organic amendments to reduce fixation losses.

#### Available Potassium

Available K level were exceptionally high across all soil samples, ranging from 308.11 to 792.96 kg/ha, with an average of 505.21 kg ha<sup>-1</sup> (Table 4). All soil samples belonged to the very high (>300 kg ha<sup>-1</sup>) category. High potassium supply is characteristic of block soil derived from K-rich minerals such as feldspars and micas present in Deccan basalt (Waikar *et al.*, 2014). This indicates that external K fertilizer application may be minimized under soil test based fertilizer recommendations. Excessive K can also antagonize Ca and Mg uptake, therefore, balanced fertilization should be emphasized.

#### Micronutrient status of Aundha Nagnath soil

##### Copper (Cu)

Copper content in soil samples of Aundha Nagnath range from 0.20 to 1.60 ppm presented in Table 4, with a mean value of 0.52 ppm. Based on the categorical distribution, none of the soil series fell into the Cu deficient class (<0.2-0.4. ppm) and high (>0.4ppm) categories, high proportions of samples in the high category were observed in soil series ASAN (77.27%), AWAL (72.73%), ATAP (75.51%) and AJAD (71.15%). The adequate Cu content may be attributed to the basaltic parent material of Vertisols enriched with Cu-bearing minerals (Waikar *et al.*, 2015). Similar ranges of Cu have been reported in other districts of Maharashtra, reflecting the natural enrichment of micronutrients in black soil (Magare *et al.*, 2019). Since none of the soil samples fell below the critical level, Cu unlikely to limit crop productivity in the region.

##### Iron (Fe)

Available Fe ranged between 2.85 and 12.50

ppm, with a mean value of 5.95 ppm (Table 4). The distribution indicated that Fe was low (<5 ppm) in 20-50% of samples across several series, including ASRA (33.33%), ADEV (44.68%), AJAD (34.62%) and ASEN (41.46%), Around 50-75% of soil belonged to the medium range (5-10 ppm), while high Fe (>10 ppm) was observed only in small proportions (2-10%) in ADEV, ALAS, ASEN, ASUK, ASON and AGOL.

Although Vertisols generally contain high reserves of Fe, the high soil pH (7.69-8.79) likely reduce Fe solubility, resulting in moderate Fe availability (Gaikwad *et al.*, 2016). Similar Fe deficiencies in alkaline soils have been reported in semi-arid regions of India (Magar *et al.*, 2017). This Suggests that Fe-sensitive crops may occasionally show chlorosis and may benefit from foliar Fe sprays.

##### Manganese (Mn)

Manganese concentration varied widely, ranging from 3.02 to 15.05 ppm with an average of 7.82 ppm (Table 5). Most soil samples found in the medium (5-10 ppm) category, ranging from 60-87% of samples in ABRA, ADEV, ALAS, ASEN and ASON. High Mn (>10 PPM) was recorded in 15-45% of samples in series such as ASAN, AWAG, AJAD and ANAL. Only isolated low Mn values (< 5ppm) were reported, notably in ASAN (18.18%) and AWAL (3.03%).

These results reflect generally adequate Mn availability, consistent with Mn behavior in alkaline black soil that retain sufficient Mn in exchangeable or oxide form (Patil *et al.*, 2019). The moderate to high levels indicate Mn deficiency is unlikely, though localized low values may require monitoring under intensive cropping systems.

##### Zinc (Zn)

Zinc concentration ranged from 0.26 to 1.84 ppm, with an average of 0.63 ppm (Table 6). Zn deficiency (<0.55 ppm) was observed in 19-43% of samples across many series including medium (5-10 ppm). The soil samples were analyzed for the Zn status 30.11% soil were observed in low, 63.14% medium and 6.74% high categories, respectively. The zinc availability was low due to the low organic matter content in soil which was

Table 4: Categorization of Aundha Nagnath soil on the basis of rating of soil Available Potassium (Kg/ha

| S.N.    | Code No. | No of Samples | Available Potassium (Kg/ha) |        |         |                    | Categorized (%)  |                     |                              |                               |
|---------|----------|---------------|-----------------------------|--------|---------|--------------------|------------------|---------------------|------------------------------|-------------------------------|
|         |          |               | Min                         | Max    | Average | Very Low<br>(<100) | Low<br>(100-150) | Medium<br>(150-200) | Moderately<br>high (201-250) | Very high<br>(251-300) (>300) |
| 1       | ASAN     | 22            | 410.26                      | 696.98 | 567.48  | -                  | -                | -                   | -                            | 100                           |
| 2       | AWAL     | 33            | 387.74                      | 694.98 | 573.41  | -                  | -                | -                   | -                            | 100                           |
| 3       | ABRA     | 33            | 308.11                      | 515.20 | 429.13  | -                  | -                | -                   | -                            | 100                           |
| 4       | AKAI     | 41            | 333.31                      | 738.08 | 518.34  | -                  | -                | -                   | -                            | 100                           |
| 5       | AWAG     | 30            | 410.37                      | 723.52 | 569.26  | -                  | -                | -                   | -                            | 100                           |
| 6       | ADEV     | 47            | 360.42                      | 670.10 | 497.60  | -                  | -                | -                   | -                            | 100                           |
| 7       | ANAL     | 21            | 387.74                      | 704.48 | 552.21  | -                  | -                | -                   | -                            | 100                           |
| 8       | ATAP     | 49            | 387.74                      | 675.36 | 551.79  | -                  | -                | -                   | -                            | 100                           |
| 9       | AMAR     | 19            | 356.61                      | 680.96 | 538.94  | -                  | -                | -                   | -                            | 100                           |
| 10      | ALAS     | 47            | 387.63                      | 792.96 | 553.15  | -                  | -                | -                   | -                            | 100                           |
| 11      | ASEN     | 41            | 304.86                      | 606.14 | 430.38  | -                  | -                | -                   | -                            | 100                           |
| 12      | AJAD     | 52            | 315.28                      | 574.78 | 439.25  | -                  | -                | -                   | -                            | 100                           |
| 13      | AASO     | 21            | 356.50                      | 732.48 | 567.66  | -                  | -                | -                   | -                            | 100                           |
| 14      | APOT     | 35            | 347.76                      | 624.96 | 484.26  | -                  | -                | -                   | -                            | 100                           |
| 15      | ARUP     | 39            | 323.68                      | 670.10 | 466.57  | -                  | -                | -                   | -                            | 100                           |
| 16      | ADHA     | 19            | 392.00                      | 574.78 | 466.99  | -                  | -                | -                   | -                            | 100                           |
| 17      | ASUK     | 29            | 354.03                      | 544.32 | 451.09  | -                  | -                | -                   | -                            | 100                           |
| 18      | ASON     | 21            | 338.24                      | 550.70 | 438.61  | -                  | -                | -                   | -                            | 100                           |
| 19      | AGOL     | 41            | 354.03                      | 614.54 | 502.87  | -                  | -                | -                   | -                            | 100                           |
| Average |          |               | 358.77                      | 651.86 | 505.21  |                    |                  |                     |                              |                               |
| SD      |          |               |                             |        | 53.269  |                    |                  |                     |                              |                               |
| CV%     |          |               |                             |        | 10.54   |                    |                  |                     |                              |                               |

**Table 5: Categorization of Aundha Nagnath soil on the basis of rating of soil Cu and Fe (ppm)**

| S.N. | Code No. | No ofSamples | Cu              |     |         |       | Fe      |          |     |     |         |       |        |          |  |  |
|------|----------|--------------|-----------------|-----|---------|-------|---------|----------|-----|-----|---------|-------|--------|----------|--|--|
|      |          |              | Categorized (%) |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              | Min             | Max | Average | I low | II Med. | III High | Min | Max | Average | I low | II Med | III High |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         |       |         |          |     |     |         |       |        |          |  |  |
|      |          |              |                 |     |         | </    |         |          |     |     |         |       |        |          |  |  |

**Table 6: Categorization of Aundha Nagnath soil on the basis of rating of soil Cu and Fe (ppm)**

| S.N.    | Code No. | No of Samples | Mn              |       |         |       |        | Zn       |       |         |         |       |        |          |
|---------|----------|---------------|-----------------|-------|---------|-------|--------|----------|-------|---------|---------|-------|--------|----------|
|         |          |               | Categorized (%) |       |         |       |        |          |       |         |         |       |        |          |
|         |          |               | Min             | Max   | Average | I low | II Med | III High | Min   | Max     | Average | I low | II Med | III High |
|         |          |               | <5              | 5-10  | >10     |       |        |          | <0.55 | 0.5-1.0 | >1.0    |       |        |          |
| 1       | ASAN     | 22            | 4.77            | 13.70 | 9.30    | 18.18 | 36.36  | 45.45    | 0.30  | 1.30    | 0.66    | 36.36 | 54.55  | 9.09     |
| 2       | AWAL     | 33            | 4.24            | 12.32 | 8.01    | 3.03  | 75.76  | 21.21    | 0.30  | 0.90    | 0.65    | 24.24 | 57.58  | 18.18    |
| 3       | ABRA     | 33            | 5.12            | 12.36 | 7.79    | 3.03  | 87.88  | 9.09     | 0.29  | 1.04    | 0.61    | 33.33 | 63.64  | 3.03     |
| 4       | AKAI     | 41            | 4.27            | 12.20 | 7.09    | 9.76  | 82.93  | 7.32     | 0.28  | 2.11    | 0.66    | 31.71 | 63.41  | 4.88     |
| 5       | AWAG     | 30            | 4.37            | 13.20 | 8.07    | 13.33 | 63.33  | 23.33    | 0.30  | 1.04    | 0.65    | 26.67 | 66.67  | 6.67     |
| 6       | ADEV     | 47            | 4.22            | 12.20 | 7.40    | 12.77 | 80.85  | 6.38     | 0.28  | 0.90    | 0.63    | 29.79 | 70.21  | 0.00     |
| 7       | ANAL     | 21            | 5.32            | 12.26 | 8.67    | 0.00  | 80.95  | 19.05    | 0.32  | .84     | 0.59    | 38.10 | 61.90  | 0.00     |
| 8       | ATAP     | 49            | 3.72            | 12.37 | 7.98    | 16.33 | 63.27  | 20.41    | 0.30  | 0.88    | 0.60    | 38.78 | 61.22  | 0.00     |
| 9       | AMAR     | 19            | 4.42            | 12.28 | 7.47    | 10.53 | 68.42  | 21.05    | 0.26  | 1.00    | 0.60    | 36.84 | 57.89  | 5.26     |
| 10      | ALAS     | 47            | 4.25            | 13.20 | 8.26    | 4.26  | 80.85  | 14.89    | 0.30  | 1.23    | 0.64    | 34.04 | 61.70  | 4.26     |
| 11      | ASEN     | 41            | 4.27            | 12.02 | 7.48    | 12.20 | 80.49  | 7.32     | 0.29  | 1.57    | 0.69    | 31.71 | 58.54  | 9.76     |
| 12      | AJAD     | 52            | 3.02            | 15.05 | 7.70    | 15.38 | 67.31  | 17.31    | 0.40  | 1.06    | 0.70    | 19.23 | 78.85  | 1.92     |
| 13      | AASO     | 21            | 4.40            | 11.08 | 7.83    | 14.29 | 80.95  | 4.76     | 0.26  | 1.51    | 0.70    | 42.86 | 42.86  | 14.29    |
| 14      | APOT     | 35            | 4.28            | 12.20 | 7.48    | 0.00  | 85.71  | 14.29    | 0.26  | 0.96    | 0.61    | 34.29 | 62.86  | 2.86     |
| 15      | ARUP     | 39            | 4.20            | 11.30 | 7.67    | 12.82 | 79.49  | 7.69     | 0.30  | 1.37    | 0.69    | 23.08 | 69.23  | 7.69     |
| 16      | ADHA     | 19            | 3.23            | 12.50 | 7.89    | 15.79 | 68.42  | 15.79    | 0.38  | 1.32    | 0.67    | 21.05 | 73.68  | 5.26     |
| 17      | ASUK     | 29            | 4.22            | 11.41 | 7.42    | 10.34 | 34.48  | 55.17    | 0.29  | 1.84    | 0.60    | 24.14 | 72.41  | 3.45     |
| 18      | ASON     | 21            | 4.28            | 12.20 | 7.63    | 4.76  | 85.71  | 9.52     | 0.30  | 1.33    | 0.30    | 19.05 | 71.43  | 9.52     |
| 19      | AGOL     | 41            | 5.22            | 11.20 | 7.44    | 7.332 | 82.93  | 9.76     | 0.30  | 1.30    | 0.66    | 26.83 | 51.22  | 21.95    |
| Average |          |               | 4.31            | 12.37 | 7.82    |       |        |          | 0.30  | 1.24    | 0.63    |       |        |          |
| SD      |          |               | 0.510           |       |         |       |        |          |       |         |         |       |        |          |
| CV%     |          |               | 6.52            |       |         |       |        |          |       |         |         |       |        |          |
|         |          |               | 13.87           |       |         |       |        |          |       |         |         |       |        |          |



acts as natural chelating agent. Similar results were noted by Waikar *et al.* (2017).

### CONCLUSION

The comprehensive evaluation of soils from Aundha Nagnath indicates that the region is dominated by alkaline, non saline, potassium rich Vertisols with low organic carbon and widespread phosphorus deficiency. Micronutrient status was generally adequate. Though localized deficiencies of Mn and Zn warrant attention. To enhance soil productivity and maintain long term fertility, integrated nutrient management strategies focusing on organic carbon buildup and phosphorus supplementation are essential.

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## Effect of Foliar Nutrition on Growth, Productivity and Economics of Rainfed Rabi Sorghum (*Sorghum bicolor* L. Moench) under Nitrogen Stress Conditions

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### ABSTRACT

Rabi sorghum (*Sorghum bicolor* L. Moench) is one of the most important post-rainy season cereals cultivated under rainfed conditions in the semi-arid regions of India. Its productivity is frequently constrained by inadequate nitrogen availability during the reproductive phase because top dressing is often impractical under receding soil moisture conditions. Foliar nutrient application has emerged as a promising strategy to supplement crop nutrient demand during critical growth stages while improving nutrient use efficiency. A field experiment was conducted during the rabi season of 2024–25 at the Sorghum Research Station, Vasant Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, to evaluate different foliar nutrition schedules for enhancing the productivity of rainfed rabi sorghum. Twelve treatments comprising recommended basal fertilization, nano urea, diammonium phosphate (DAP), potassium chloride (KCl), zinc sulphate, ferrous sulphate and sodium borate sprays, along with nitrogen top dressing and an unfertilized control, were evaluated. The experiment was conducted using the recommended package of practices with a spacing of 45 × 15 cm and a recommended fertilizer dose of 40:20:20 kg N:P:K<sub>2</sub>O ha<sup>-1</sup>. Growth characters, grain yield, fodder yield and economic returns were recorded. The treatment receiving basal fertilization supplemented with foliar potassium recorded the highest numerical grain yield (3195 kg ha<sup>-1</sup>), whereas the combined application of DAP, potassium and zinc recorded the highest fodder yield (9465 kg ha<sup>-1</sup>) and gross monetary return. However, treatment differences for yield and economic parameters were statistically non-significant. Nevertheless, foliar nutrient application generally improved crop performance compared with the unfertilized control and demonstrated its potential to enhance nutrient availability during reproductive growth. The study indicates that balanced foliar nutrition can serve as an effective supplementary nutrient management strategy for sustaining rabi sorghum productivity under rainfed environments where nitrogen top dressing is often restricted by limited soil moisture.

Sorghum (*Sorghum bicolor* L. Moench) is one of the most important cereal crops cultivated in the semi-arid tropics because of its adaptability to drought, high temperature, and low-input production systems. In India, rabi sorghum occupies a unique position owing to its superior grain quality, fodder value, and contribution to the livelihood of dryland farmers. However, its productivity remains below potential due to nutrient deficiencies, particularly nitrogen, during the reproductive stage when declining soil moisture limits nutrient uptake from the soil. Nitrogen plays a vital role in chlorophyll synthesis, photosynthetic activity, and grain development, and inadequate nitrogen supply during grain filling substantially reduces yield and quality (Patel *et al.*, 2026).

Foliar nutrition has emerged as an effective supplementary nutrient management strategy under rainfed agriculture because nutrients supplied through leaves are rapidly absorbed and efficiently utilized during

critical crop growth stages. Foliar application reduces nutrient losses through volatilization, leaching, and fixation, thereby improving nutrient use efficiency under moisture-stressed environments. Nano urea, in particular, has gained considerable attention because of its higher nitrogen use efficiency, controlled nutrient release, and environmental advantages over conventional urea (Patel *et al.*, 2026).

Potassium is another essential nutrient that regulates stomatal conductance, osmotic adjustment, enzyme activation, and carbohydrate translocation. Foliar potassium application enhances drought tolerance by maintaining cell turgor and improving water-use efficiency. Similarly, phosphorus applied through DAP sprays supports energy transfer, root activity, and reproductive development during grain formation (Sawane *et al.*, 2025).

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Micronutrients such as zinc, iron, and boron also play indispensable roles in sorghum physiology. Zinc activates numerous enzymes involved in protein synthesis and auxin metabolism, iron is essential for chlorophyll synthesis and electron transport, while boron facilitates pollen viability, carbohydrate transport, and grain setting. Foliar supplementation of these nutrients during reproductive growth has been reported to improve crop productivity and nutrient use efficiency under rainfed conditions (Gautam *et al.*, 2025).

Recent studies conducted under semi-arid environments have demonstrated that foliar application of major nutrients significantly improves growth, grain yield, fodder yield, and economic returns of rabi sorghum compared with conventional fertilization alone (Sawane *et al.*, 2024; Sawane *et al.*, 2025). Similarly, Giri *et al.* (2025) reported that balanced foliar nutrition improved water-use efficiency and productivity of rabi sorghum under moisture-limited conditions, highlighting its potential as a climate-resilient nutrient management strategy.

## MATERIAL AND METHODS

A field experiment entitled “Foliar Nutrition for Boosting Productivity of Rabi Sorghum” was conducted during the rabi season of 2024–25 at the Sorghum Research Station, Vasantrao Naik Marathwada Krishi Vidyapeeth (VNMKV), Parbhani, Maharashtra, India. The objective of the investigation was to evaluate the effectiveness of different foliar nutrient management strategies in improving the productivity and profitability of rainfed *rabi* sorghum and to assess the yield penalty resulting from the non-application of nitrogen top dressing under moisture-limited conditions. The experiment was laid out in a Randomized Block Design (RBD) comprising twelve treatments. The crop was sown on 17 October 2024 using a spacing of 45 cm × 15 cm and harvested on 22 February 2025, resulting in a crop duration of approximately 128 days. Each experimental plot measured 4.50 m × 5.10 m (22.95 m<sup>2</sup>), while the net plot size for recording observations was 2.70 m × 4.50 m (12.15 m<sup>2</sup>). The recommended fertilizer dose of 40:20:20 kg N:P:K, ha<sup>-1</sup>, along with the recommended basal application of zinc (Zn), iron (Fe) and boron (B), was applied according

to the treatment schedule. Foliar nutrient applications, including nano urea, diammonium phosphate (DAP), potassium chloride (KCl), zinc sulphate, ferrous sulphate and sodium borate, were imposed at panicle initiation and/or flowering stages as specified for each treatment. The crop was grown under rainfed conditions using conserved soil moisture, and all agronomic and plant protection practices recommended for rabi sorghum were followed uniformly across treatments to ensure unbiased comparison. The region is characterized by a semi-arid tropical climate with hot summers, mild winters and erratic rainfall. *Rabi* sorghum is grown exclusively on stored soil moisture after the cessation of the southwest monsoon. Consequently, moisture stress during the reproductive phase frequently restricts nutrient uptake, particularly nitrogen, thereby limiting grain development and overall productivity.

## Soil Characteristics

The experimental field was representative of the medium to deep black cotton soils (Vertisols) of the Marathwada region. These soils are generally clayey in texture with good moisture-holding capacity but exhibit reduced nutrient diffusion under receding soil moisture during the *rabi* season. The soil fertility status was considered adequate for conducting the experiment, and the recommended package of practices for *rabi* sorghum cultivation was followed throughout the crop growth period.

Growth parameters, yield attributes, grain yield, dry fodder yield and economic returns were recorded following standard agronomic procedures. The experimental data were subjected to analysis of variance (ANOVA), and treatment means were compared using the appropriate statistical tests at the 5% level of significance. The details of treatments are as follows.

- T<sub>1</sub> Recommended dose of NPK + Zn + Fe + B fertilizers (Basal)
- T<sub>2</sub> T<sub>1</sub> + Nano urea @ 4 ml L<sup>-1</sup> water spray at panicle initiation (PI)
- T<sub>3</sub> T<sub>1</sub> + Nano urea @ 4 ml L<sup>-1</sup> water spray at flowering (FL)
- T<sub>4</sub> T<sub>1</sub> + Nano urea @ 4 ml L<sup>-1</sup> at PI and FL

|                 |                                                                     |
|-----------------|---------------------------------------------------------------------|
| T <sub>5</sub>  | T <sub>1</sub> + 2% DAP spray at PI                                 |
| T <sub>6</sub>  | T <sub>1</sub> + 2% KCl spray at PI                                 |
| T <sub>7</sub>  | T <sub>5</sub> + 2% KCl spray at PI                                 |
| T <sub>8</sub>  | T <sub>7</sub> + 0.5% Zinc sulphate spray at PI                     |
| T <sub>9</sub>  | T <sub>8</sub> + 0.5% Ferrous sulphate spray at PI                  |
| T <sub>10</sub> | T <sub>9</sub> + 0.1 ppm Sodium borate spray at PI                  |
| T <sub>11</sub> | T <sub>1</sub> + 50% nitrogen top dressing under rainfed conditions |
| T <sub>12</sub> | Unfertilized control                                                |

## RESULTS AND DISCUSSION

The results obtained from the field investigation are presented in Tables 1 and 2. The influence of different foliar nutrient management treatments on growth parameters, grain yield, fodder yield and economics of *rabi* sorghum is discussed below.

### Plant Stand at Harvest

Plant stand at harvest was not significantly influenced by different foliar nutrient treatments (Table 2). The number of plants at harvest varied from 156 to 169 plants per net plot. Numerically, the highest plant stand (169 plants) was recorded under T<sub>9</sub> (T<sub>8</sub> + 0.5% ferrous sulphate spray), followed by T<sub>8</sub> (168 plants), T<sub>4</sub> (167 plants) and T<sub>11</sub> (167 plants), whereas the lowest plant stand (156 plants) was observed under T<sub>3</sub>. The absence of significant variation indicates that foliar nutrient application at panicle initiation or flowering did not affect crop establishment or plant survival, as these characteristics are primarily determined during germination and the early vegetative growth stages. Since foliar nutrient sprays were imposed after crop establishment, they were not expected to influence final plant population.

These findings are consistent with those of Sawane *et al.* (2025), who reported that foliar application of major nutrients had no significant effect on plant population in rainfed *rabi* sorghum. Likewise, Gautam *et al.* (2025) observed that nano-nitrogen fertilization improved physiological traits without significantly altering plant stand. Similar observations have also been reported in sorghum and maize by Fageria *et al.* (2009), who concluded that post-emergence foliar nutrient application generally exerts little influence on plant establishment

because stand density is mainly governed by seed quality, sowing conditions, and environmental factors.

### Days to 50% Flowering

Days required for 50% flowering remained statistically unaffected by the foliar nutrient treatments and ranged from 70.5 to 71.5 days. The earliest flowering (70.5 days) was observed under T<sub>5</sub>, T<sub>7</sub>, T<sub>8</sub> and T<sub>10</sub>, whereas the latest flowering (71.5 days) was recorded under T<sub>1</sub>. However, these differences were statistically non-significant.

Flowering is largely under genetic control and is influenced primarily by temperature, photoperiod, and moisture availability. Foliar nutrient application during reproductive development generally improves physiological activity rather than altering crop phenology. Similar findings were reported by Sawane *et al.* (2025), who observed that foliar application of nitrogen, potassium, and micronutrients did not significantly influence flowering duration in *rabi* sorghum. Taiz *et al.* (2018) also emphasized that flowering time in cereals is primarily regulated by genetic and environmental interactions, with nutrient management playing only a minor role under normal field conditions.

### Plant Height

Plant height varied numerically from 203 to 230 cm without significant differences among treatments. The tallest plants (230 cm) were recorded under T<sub>11</sub> (recommended basal fertilizer + 50% nitrogen top dressing), followed by T<sub>2</sub> and T<sub>8</sub> (228 cm), whereas the shortest plants (203 cm) were recorded in the unfertilized control.

Although treatment effects were statistically non-significant, numerically greater plant height under balanced nutrient supply may be attributed to improved nitrogen availability, enhanced chlorophyll synthesis, increased photosynthetic activity, and greater cell elongation. Nitrogen plays a key role in protein synthesis and vegetative growth, while potassium improves enzyme activation and water relations, thereby supporting biomass production under rainfed conditions.

Comparable trends have been reported by Patel *et al.* (2026), who observed slight improvements in plant

height following foliar application of nano urea in *rabi* sorghum. Sawane *et al.* (2024) also reported numerical increases in plant height following foliar application of potassium and balanced nutrients. Similar observations were documented by Marschner (2012), who highlighted the role of balanced nutrition in promoting vegetative growth through improved metabolic activity.

### Test Weight

Test weight ranged from 25.75 to 32.95 g and did not differ significantly among treatments. Numerically, the highest test weight (32.95 g) was recorded under T<sub>7</sub> (DAP + KCl spray), followed by T<sub>3</sub> (32.75 g) and T<sub>11</sub> (31.45 g), whereas the lowest value (25.75 g) was observed under T<sub>2</sub>.

Higher test weight under balanced foliar nutrition may be associated with improved assimilate production and efficient translocation of carbohydrates from source to sink during grain filling. Foliar potassium enhances phloem loading and transport of photosynthates, while phosphorus improves energy metabolism required for grain development.

These findings corroborate those of Giri *et al.* (2025), who reported improved grain development and

test weight following foliar nutrient application in *rabi* sorghum. Similarly, Fageria *et al.* (2009) emphasized that foliar fertilization can improve grain filling by supplementing nutrient availability during reproductive growth, particularly under moisture-deficit conditions.

### Leaf Area Index (LAI)

Leaf Area Index (LAI) at flowering ranged from 1.99 to 2.87 and did not differ significantly among treatments. The highest LAI (2.87) was recorded under T<sub>2</sub>, (nano urea spray at panicle initiation), followed by T<sub>4</sub> (2.79) and T<sub>9</sub> (2.65), whereas the lowest LAI (1.99) was recorded in the unfertilized control.

The higher LAI observed under nano urea treatments may indicate improved nitrogen availability, leading to enhanced leaf expansion and delayed leaf senescence. Maintenance of green leaf area during reproductive growth contributes to sustained photosynthetic activity and dry matter accumulation.

Similar findings were reported by Gautam *et al.* (2025), who observed improved canopy development following nano-nitrogen fertilization. Patel *et al.* (2026) also reported that nano urea increased leaf area and chlorophyll content in *rabi* sorghum by improving

**Table 1. Effect of foliar nutrition on growth parameters of *rabi* sorghum**

| Treatments      | Plant stand | 50% flowering<br>(days) | Plant height<br>(cm) | Test<br>weight (g) | LAI  | SPAD  |
|-----------------|-------------|-------------------------|----------------------|--------------------|------|-------|
| T <sub>1</sub>  | 160         | 71.5                    | 225                  | 28.65              | 2.12 | 44.75 |
| T <sub>2</sub>  | 163         | 71.0                    | 228                  | 25.75              | 2.87 | 46.00 |
| T <sub>3</sub>  | 156         | 71.0                    | 215                  | 32.75              | 2.48 | 43.50 |
| T <sub>4</sub>  | 167         | 71.0                    | 223                  | 29.10              | 2.79 | 44.20 |
| T <sub>5</sub>  | 166         | 70.5                    | 218                  | 30.15              | 2.64 | 43.35 |
| T <sub>6</sub>  | 158         | 71.0                    | 220                  | 27.55              | 2.49 | 44.65 |
| T <sub>7</sub>  | 165         | 70.5                    | 223                  | 32.95              | 2.28 | 45.75 |
| T <sub>8</sub>  | 168         | 70.5                    | 228                  | 31.20              | 2.38 | 44.35 |
| T <sub>9</sub>  | 169         | 71.0                    | 225                  | 29.95              | 2.65 | 45.50 |
| T <sub>10</sub> | 165         | 70.5                    | 215                  | 28.55              | 2.15 | 46.60 |
| T <sub>11</sub> | 167         | 71.0                    | 230                  | 31.45              | 2.53 | 47.35 |
| T <sub>12</sub> | 162         | 71.0                    | 203                  | 27.70              | 1.99 | 43.45 |
| SE(m)±          | 2.40        | 0.48                    | 9.20                 | 3.88               | 0.27 | 1.09  |
| CD at 5%        | -           | -                       | -                    | -                  | -    | -     |
| Grand Mean      | 164         | 71                      | 221                  | 29.64              | 2.44 | 45.00 |

nitrogen use efficiency. According to Marschner (2012), nitrogen nutrition directly influences leaf expansion, chlorophyll biosynthesis, and canopy development.

#### SPAD Chlorophyll Value

SPAD chlorophyll values ranged from 43.35 to 47.35 without significant differences among treatments. Numerically, the highest SPAD value (47.35) was recorded under  $T_{11}$ , followed by  $T_{10}$  (46.60) and  $T_2$  (46.00), whereas the lowest value (43.35) was observed under  $T_5$ .

Higher SPAD values under nitrogen top dressing and nano urea treatments indicate improved chlorophyll concentration and nitrogen status of leaves. Nitrogen is an integral component of chlorophyll molecules and plays a fundamental role in photosynthetic efficiency. Foliar nitrogen application may therefore help maintain chlorophyll content during reproductive growth, especially under declining soil moisture.

These findings agree with those of Gautam *et al.* (2025) and Patel *et al.* (2026), who reported enhanced SPAD values following foliar application of nano nitrogen in sorghum. Likewise, Sawane *et al.* (2025) observed higher chlorophyll content under integrated foliar nutrient

management. According to Taiz *et al.* (2018), chlorophyll concentration is closely associated with leaf nitrogen content and photosynthetic efficiency.

#### Grain Yield

Grain yield constitutes the most important indicator of treatment effectiveness under rainfed conditions.

The grain yield varied from 1621 to 3195 kg ha<sup>-1</sup> (Table 3). Numerically, the highest grain yield (3195 kg ha<sup>-1</sup>) was recorded under  $T_6$  (Recommended fertilizer + 2% KCl spray at panicle initiation), followed closely by  $T_8$  (3155 kg ha<sup>-1</sup>),  $T_7$  (3139 kg ha<sup>-1</sup>) and  $T_3$  (3008 kg ha<sup>-1</sup>).

The unfertilized control ( $T_{12}$ ) produced the lowest grain yield (1621 kg ha<sup>-1</sup>), indicating the importance of balanced nutrient management in rainfed sorghum.

Although the differences among treatments were statistically non-significant, numerical improvements in grain yield under potassium- and nutrient-based foliar applications suggest enhanced physiological activity during grain filling. Potassium is known to regulate stomatal conductance, enzyme activation, carbohydrate

**Table 2. Effect of foliar nutrition on grain yield, fodder yield and economics of *rabi* sorghum**

| Treatments | Grain yield (kg ha <sup>-1</sup> ) | Fodder yield (kg ha <sup>-1</sup> ) | GMR (Rs ha <sup>-1</sup> ) | NMR (Rs ha <sup>-1</sup> ) | B:C  |
|------------|------------------------------------|-------------------------------------|----------------------------|----------------------------|------|
| $T_1$      | 2230                               | 6790                                | 9431                       | 62633                      | 2.75 |
| $T_2$      | 2461                               | 6173                                | 104645                     | 68097                      | 2.86 |
| $T_3$      | 2745                               | 6996                                | 117052                     | 80504                      | 3.20 |
| $T_4$      | 2428                               | 8642                                | 110900                     | 73852                      | 2.99 |
| $T_5$      | 3008                               | 9053                                | 132442                     | 95894                      | 3.62 |
| $T_6$      | 3195                               | 8230                                | 136526                     | 99603                      | 3.70 |
| $T_7$      | 3139                               | 8230                                | 134538                     | 97490                      | 3.63 |
| $T_8$      | 3155                               | 9465                                | 138803                     | 101255                     | 3.70 |
| $T_9$      | 2271                               | 7078                                | 100736                     | 62688                      | 2.65 |
| $T_{10}$   | 2753                               | 9465                                | 124747                     | 86199                      | 3.24 |
| $T_{11}$   | 2662                               | 7819                                | 116640                     | 80592                      | 3.24 |
| $T_{12}$   | 1621                               | 4527                                | 70326                      | 37650                      | 2.15 |
| SE(m)±     | 336                                | 2084                                | 12549                      | 12521                      | -    |
| CD at 5%   | -                                  | -                                   | -                          | -                          | -    |
| CV (%)     | 17                                 | 12                                  | 15                         | 22                         | -    |
| Grand Mean | 2514                               | 8127                                | 112360                     | 75750                      | 3.06 |

translocation and osmotic adjustment, all of which contribute to improved grain development under moisture stress. Foliar nutrient application during the reproductive stage may also improve nitrogen utilization efficiency by directly supplying nutrients through the foliage, thereby minimizing dependence on soil moisture for nutrient uptake.

### Dry Fodder Yield

Dry fodder yield ranged from 4527 to 9465 kg ha<sup>-1</sup>. The highest fodder yield (9465 kg ha<sup>-1</sup>) was recorded under T<sub>8</sub> and T<sub>10</sub>, followed by T<sub>5</sub> (9053 kg ha<sup>-1</sup>) and T<sub>4</sub> (8642 kg ha<sup>-1</sup>). The lowest fodder production was recorded under the unfertilized control. Higher biomass production under integrated foliar nutrient application may be attributed to sustained leaf area, improved chlorophyll concentration and efficient photosynthesis during vegetative and reproductive growth. However, since treatment differences were statistically non-significant, these numerical differences should be interpreted cautiously.

### Economics

Economic analysis provides an important basis for evaluating the practical feasibility of nutrient management technologies.

Gross monetary return varied from Rs. 70,326 to Rs. 138,803 ha<sup>-1</sup>, whereas net monetary return ranged from Rs. 37,650 to Rs. 101,255 ha<sup>-1</sup>. Numerically, the highest gross monetary return (Rs. 138,803 ha<sup>-1</sup>) and net monetary return (Rs. 101,255 ha<sup>-1</sup>) were recorded under T<sub>8</sub>, followed by T<sub>6</sub> and T<sub>7</sub>. The benefit:cost ratio varied from 2.15 to 3.70. Treatments T<sub>6</sub> and T<sub>8</sub> recorded the highest B:C ratio (3.70), suggesting better economic efficiency of potassium- and micronutrient-based foliar nutrition.

The present findings are in close agreement with Sawane *et al.* (2024), who reported that foliar application of potassium and balanced nutrients improved grain yield of rainfed rabi sorghum. Giri *et al.* (2025) also observed higher grain yield and improved water-use efficiency following foliar nutrient application under semi-arid conditions. Patel *et al.* (2026) reported that nano urea enhanced nitrogen use efficiency and maintained grain

productivity comparable with conventional nitrogen management. Similar responses of foliar nutrition in cereals have been documented by Fageria *et al.* (2009) and Marschner (2012), who concluded that foliar nutrient application is particularly effective during reproductive growth when root nutrient uptake is restricted by declining soil moisture.

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## Sustainable Cellulase Production From De-Oiled Lemongrass Residue By Solid-State Fermentation: A Comparative Study of Different Microorganisms

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### ABSTRACT

Agricultural waste can be converted into valuable industrial enzymes through solid-state fermentation (SSF), providing an eco-friendly and cost-effective approach to waste utilization. In this study, de-oiled lemongrass residue was evaluated as a substrate for cellulase production using *Trichoderma viride*, *Aspergillus niger*, *Pleurotus florida* and a microbial consortium. Among the tested microorganisms, *Trichoderma viride* produced the highest cellulase activity (22.93 U/ml) on the 10<sup>th</sup> day of incubation under optimized fermentation conditions. The results showed that both the microorganism and incubation period significantly influenced enzyme production. Overall, the study demonstrates that de-oiled lemongrass residue is a promising substrate for sustainable and economical cellulase production through solid-state fermentation.

Global agricultural activities generate approximately 5 billion metric tons of agricultural waste annually. Transforming this agricultural waste into eco-friendly products, such as industrial enzymes, through bioconversion can help address sustainability challenges. (Bhattacharya *et al.*, 2024). Agro-industrial wastes and byproducts can be converted into raw materials for value-added products using biotechnology. In this regard, solid-state fermentation (SSF) is a low-cost, sustainable biotechnology method that can directly utilize agro-industrial byproducts without the need for pretreatments (Leite *et al.*, 2021). The world market of enzymes could reach \$7.0 billion. Lignocellulolytic enzymes represent more than 20% of worldwide sales of commercially available enzymes. (Toushik *et al.*, 2017).

Over the past three centuries, microorganisms have played a major role in the production of food and beverages. Many industries, including food, brewing, textiles, pharmaceuticals, and confections, rely heavily on a variety of products, particularly extracellular enzymes. Extracellular enzymatic activity in various microorganisms has been the subject of renewed study in recent years due to the use of microbes as biotechnological sources as industrially relevant enzymes. (Dharani and Kumaran 2012).

Solid-state fermentation (SSF) can more effectively transform low-value agricultural and sideline products into high-value products through microbial growth on solid or semi-solid substrates compared to liquid-phase fermentation (Wang *et al.*, 2023). Solid-state

fermentation (SSF) is considered an efficient approach for enzyme production due to its numerous operational and economic benefits. The technique utilizes inexpensive agro-industrial residues as substrates, which significantly lowers production costs while requiring only simple processing facilities and minimal labour. In addition, the limited availability of free water during fermentation reduces both water and energy consumption, leading to the production of highly concentrated enzyme preparations (Astolfi *et al.*, 2019).

Enzymatic hydrolysis plays a crucial role in converting agricultural residues into valuable bioproducts. Agro-industrial wastes serve as abundant and cost-effective natural carbon sources for the production of commercially important enzymes. Their utilization not only provides an efficient means of waste valorization but also has significant potential to reduce enzyme production costs and enhance their large-scale industrial applications. (Bharathiraja *et al.*, 2017). Enzymes are biological catalysts (also known as biocatalysts) that speed up biochemical reactions in living organisms and which can be extracted from cells and then used to catalyse a wide range of commercially important processes (Robinson, 2015).

The present study aimed to evaluate cellulase production by different microorganisms under solid-state fermentation and to optimize the cultural conditions, including substrate type, pH, temperature, moisture content, and the concentrations of carbon and nitrogen sources, for enhanced enzyme production.

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## MATERIAL AND METHODS

### Preparation of substrate

The de-oiled lemongrass residue was initially sun-dried for 24 h to remove residual moisture and reduce the risk of microbial contamination during the year 2024. The dried material was subsequently ground into uniform particles of approximately 2-3 mm in diameter to ensure homogeneity of the substrate and facilitate efficient microbial growth and enzyme production during solid-state fermentation.

### Preparation of inoculum

Fungal cultures (*Trichoderma viride*, and *Aspergillus niger*) were grown on PDA medium for 7 days at 30°C in an incubator. The spores were collected in sterile solution (1% of Tween 80). The inoculum contained  $1 \times 10^7$  spores/ml. *Pleurotus florida* was procured from M/s Krishizone Pvt Ltd. The prepared spawn was used as the inoculum for solid-state fermentation. The microbial consortia were procured from the Center for Organic Agriculture Research and Training, Dr. PDKV, Akola. The microbial consortia were directly inoculated into the sterilized substrate. The microbial consortium contains *Rhizobium*, *Azotobacter*, phosphate-solubilizing bacteria (PSB) and potassium-mobilizing bacteria (KMB).

### Production of crude enzyme through SSF

A 2000 ml Erlenmeyer flask containing 100 g of substrate (de-oiled lemongrass residue) was used for solid-state fermentation. During solid-state fermentation, the ideal moisture content of the solid substrate was established and maintained using a moistening agent (72.5% w/w), adjusted to pH 6.0. The substrate was aseptically inoculated with 7.5% (w/w) inoculum in a laminar airflow cabinet, and it was then incubated for 15 days at 30°C in static conditions. On the 3<sup>rd</sup>, 5<sup>th</sup>, 10<sup>th</sup>, 12<sup>th</sup>, and 15<sup>th</sup> days of fermentation, five grams of wet fermented biomass were then aseptically collected using a sterile spatula.

### Composition of moistening agent (g/l)

The moistening agent was used as described by Tein and Krick, 1988. The moistening agent contained (g L<sup>-1</sup>): Glucose; 10, Yeast extract; 5, KH<sub>2</sub>PO<sub>4</sub>; 0.6, MgSO<sub>4</sub>; 0.5, K<sub>2</sub>HPO<sub>4</sub>; 0.4, CuSO<sub>4</sub>.5 H<sub>2</sub>O; 0.25, FeSO<sub>4</sub>.7H<sub>2</sub>O; 0.05, MnSO<sub>4</sub> and ZnSO<sub>4</sub>; 0.001.

### Preparation of sodium phosphate buffer

**Stock solution A:** 27.6 g of sodium dihydrogen phosphate (NaH<sub>2</sub>PO<sub>4</sub> · H<sub>2</sub>O) was dissolved in 1000 ml of distilled water.

**Stock solution B:** 35.61 g of disodium hydrogen phosphate (Na<sub>2</sub>HPO<sub>4</sub>) was dissolved in 1000 ml of distilled water.

A sodium phosphate buffer (pH 6.0) was prepared by mixing 770 ml of stock solution B with 230 ml of stock solution A to obtain a final volume of 1000 ml.

### Enzyme extraction

The crude enzyme was extracted by homogenizing the fermented biomass in 50 ml of sodium phosphate buffer (pH 6.0). The suspension was subsequently filtered through filter paper to separate the solid residues. The clear filtrate obtained after filtration served as the crude enzyme extract and was used for subsequent enzyme activity assays.

### Analytical Method

#### Procedure for determination of cellulase enzyme activity

The filter paper unit (FPU) assay is a standard method recommended by IUPAC for estimating total cellulase activity. This method measures the ability of cellulase enzymes to hydrolyze filter paper (pure cellulose) into soluble sugars, mainly glucose. The reducing sugars released during hydrolysis are quantified using the DNS (3,5-Dinitrosalicylic acid) method.

One filter paper strip (50 mg) was placed vertically in each tube. 1.0 ml of citrate buffer (0.05 M, pH 4.8) was added. 0.5 ml of the enzyme sample (appropriate dilution) was added. The mixture was mixed gently by swirling. The tubes were incubated at 50°C for exactly 60 minutes. 3.0 ml of DNS reagent was added immediately after incubation. The mixture was mixed thoroughly. The absorbance was measured at 540 nm. A glucose standard was prepared from the stock solution (10 mg 10 ml<sup>-1</sup>).

## RESULTS AND DISCUSSION

### Solid state fermentation

The prepared sterile substrate was separately inoculated with *Trichoderma viride*, *Pleurotus florida*,

*Aspergillus niger*, and a microbial consortium consisting of *Azotobacter*, *Rhizobium*, PSB, and KMB, and incubated at 26°C for 15 days.

For the solid-state fermentation, de-oiled lemongrass was used as substrate. All the organisms were found to exhibit good amylase activity, when deoiled lemongrass was used as the substrate. Enzyme activity was determined on the 3<sup>rd</sup>, 5<sup>th</sup>, 10<sup>th</sup>, 12<sup>th</sup> and 15<sup>th</sup> days of incubation.

#### Amylase production from different organisms

Cellulase enzyme activity (U ml<sup>-1</sup>) differed significantly across fungal treatments. The amyalse enzyme activity produced by different fungal treatments, namely *T. viride*, *P. florida*, microbial consortia and *A. niger*, was evaluated at various incubation periods (3, 5, 10, 12 and 15 days). The enzyme activity was expressed in U ml<sup>-1</sup>, with each treatment replicated four times. The results demonstrating the enzyme activity produced during solid-state fermentation under optimized process conditions are shown in Table No. 1.1 and graphically represented in Fig. 1.2

The cellulase production by different microorganisms grown on de-oiled lemongrass residue under solid-state fermentation varied significantly with the incubation period. Among all the microorganisms tested, *Trichoderma viride* exhibited the highest cellulase activity throughout the experiment. The enzyme activity increased from 5.27 U ml<sup>-1</sup> on the 3<sup>rd</sup> day to a maximum of 22.93 U/ml on the 10<sup>th</sup> day of incubation, followed by a gradual decline to 21.42 U ml<sup>-1</sup> on the 12<sup>th</sup> day and 19.93 U ml<sup>-1</sup> on the 15<sup>th</sup> day. The decrease after the 10<sup>th</sup> day may be attributed to nutrient depletion, accumulation of inhibitory metabolites, or reduced fungal metabolic activity during the later stages of fermentation.

In the present study, the cellulase enzyme activity increased during the initial days of incubation and reached its optimum level around the 10<sup>th</sup> day of fermentation, after which a gradual decline in enzyme activity was observed. This decrease may be attributed to the depletion of available nutrients, accumulation of metabolic by-products and reduced metabolic activity of the fungus during prolonged incubation. Similar findings were reported by Nathan *et al.*, (2014), who observed that the

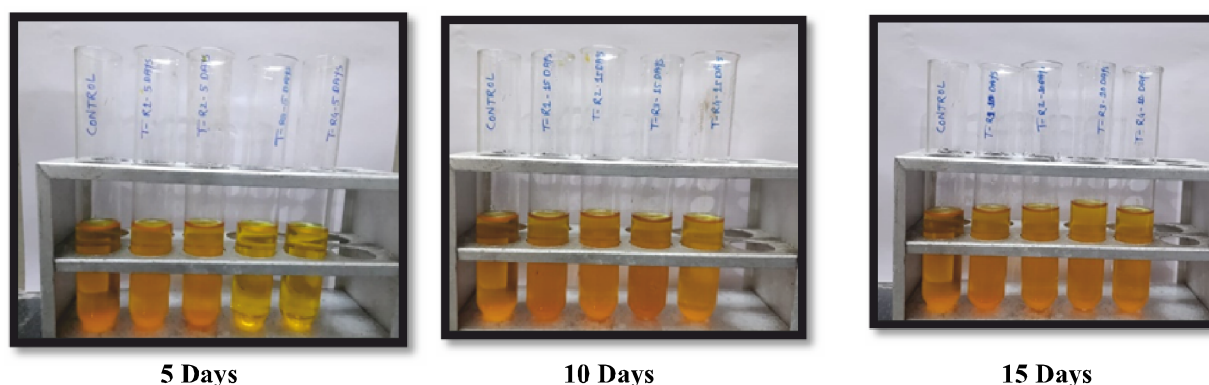
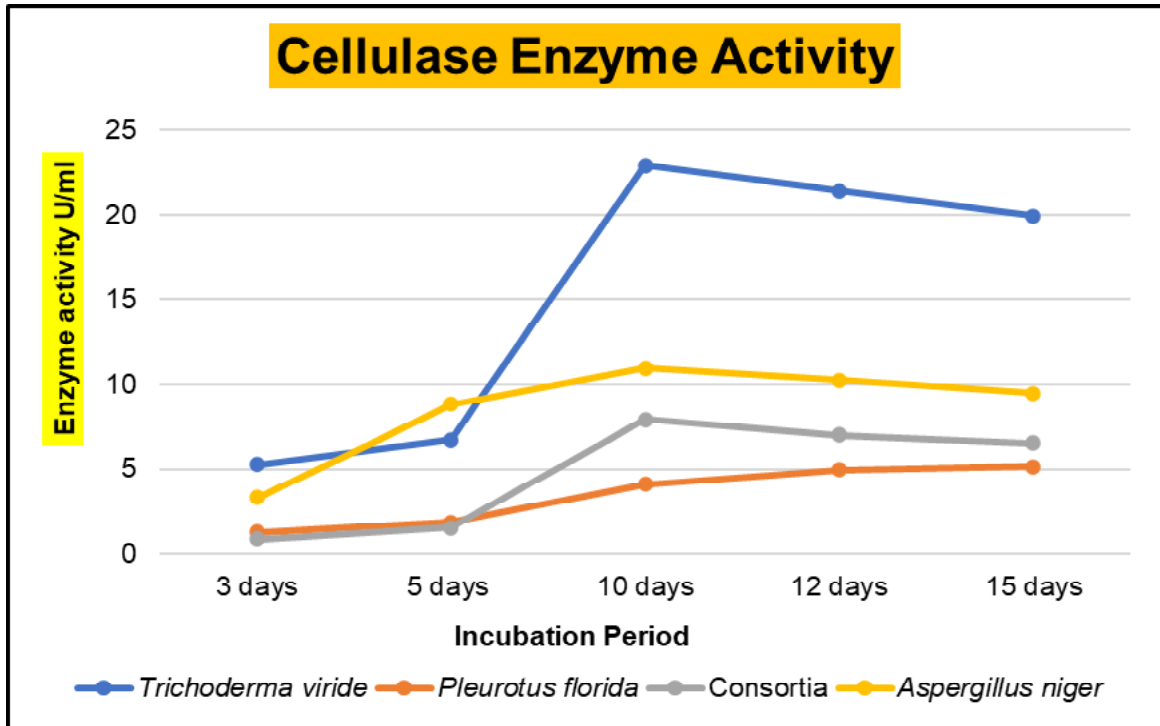


Fig. 1.1 The highest production of cellulase enzyme by *Trichoderma viride* using deoiled lemongrass residue under solid-state fermentation

Table 1.1 Cellulase enzyme production by different microorganisms using de-oiled lemongrass under solid-state fermentation

| Organisms                 | 3 D.A.I. | 5 D.A.I. | 10 D.A.I. | 12 D.A.I. | 15 D.A.I. |
|---------------------------|----------|----------|-----------|-----------|-----------|
| <i>Trichoderma viride</i> | 5.27     | 6.71     | 22.93     | 21.42     | 19.93     |
| <i>Pleurotus florida</i>  | 1.26     | 1.84     | 4.07      | 4.95      | 5.13      |
| Consortia                 | 0.86     | 1.53     | 7.91      | 6.97      | 6.52      |
| <i>Aspergillus niger</i>  | 3.29     | 8.8      | 10.94     | 10.27     | 9.48      |

(Note: DAI = Days after incubation)



**Fig.1.2 Graphical representation of cellulase enzyme activity produced by different microorganisms at different incubation intervals.**

optimum enzyme recovery period occurred between the 5<sup>th</sup> and 9<sup>th</sup> days of incubation, beyond which the enzyme activity decreased.

The findings are in agreement with Adetiloye *et al.* (2025), indicating that incubation period significantly influences amylase production. Enzyme activity increases during the lag and logarithmic phases and reaches its maximum during the stationary phase due to active microbial metabolism.

### CONCLUSION

The study demonstrated that solid-state fermentation using de-oiled lemongrass residue is an efficient method for amylase production. Among the tested organisms, *Trichoderma viride* showed the highest enzyme activity (22.93 U ml<sup>-1</sup>) under optimized conditions. Enzyme production was significantly influenced by incubation period and fermentation parameters. Overall, the process offers a cost-effective and sustainable approach for industrial enzyme production.

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## Influence of Biopesticides on Parasitization and Adult Emergence of *Trichogramma* spp.

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### ABSTRACT

The egg parasitoids *Trichogramma* spp. is widely used biological control agent against lepidopteran pests; however, their effectiveness can be influenced by concurrent use of biopesticides in integrated pest management (IPM) programmes. In view of this laboratory experiment was conducted during 2021–2022 in a Factorial Completely Randomized Design on 'Safety Assessment of Biopesticides on *Trichogramma*'. The study was conducted using three *Trichogramma* species, viz., *Trichogramma chilonis*, *Trichogramma pretiosum* and *Trichogramma batrae*. The biopesticides assessed were viz., *Metarhizium anisopliae*, *Nomuraea rileyi*, *Beauveria bassiana*, *Lecanicillium lecanii* and NBAIR BtG4 along with untreated control. The results revealed that *T. batrae* recorded the highest egg parasitization, minimum reduction in parasitism and maximum adult emergence, indicating superior tolerance to biopesticide exposure. Among the biopesticides, NBAIR BtG4 proved to be the most compatible, followed by *M. anisopliae*, *B. bassiana* and *N. rileyi*, all of which were categorized as harmless to slightly harmful. In contrast, *L. lecanii* caused comparatively higher reduction in parasitism and lower adult emergence, suggesting reduced compatibility with *Trichogramma* spp. The findings clearly indicate that selective use of compatible biopesticides, particularly NBAIR BtG4 in combination with *T. batrae*, can enhance the efficiency of biological control while conserving beneficial parasitoids. This study supports the strategic integration of biopesticides and egg parasitoids for sustainable and eco-friendly pest management.

*Trichogramma* is among the most widely used parasitoid species worldwide (Parreira *et al.*, 2019). *Trichogramma* (Hymenoptera: Trichogrammatidae) is a genus of egg parasitoids that has been reported by several researchers to be efficient in comparison to several other parasitoids. Use of *Trichogrammatoida* spp. in different pest control program proves satisfactory as it gives high level of pest suppression in the field (Krishnamoorthy, 2012 and Mohamed *et al.*, 2016). A large number of species, sub-species and strains of *Trichogramma* spp. are distributed throughout the world in diverse habitats and parasitizing eggs of over 200 insect species belonging to 70 families and 8 orders (Flanders and Quednau, 1960). Attempts to suppress insect-pest populations by biological control measures have often failed because of deleterious effects of chemicals on the beneficial insects. The contact toxicity and impact of pesticide residues on *Trichogrammatids* have been examined in numerous studies using protocols developed by International Organisation for Biological Control of Noxious Plants and Animals (IOBC) and West Palaearctic Region Section (WPRS) working group. The use of entomopathogenic

fungi in the biological control may generate immediate effects, not only in particular pest, but also on species that occupy the same habitat and on related species, such as parasitoids, predators and decomposers (Sosa-Gomez *et al.*, 1998). Additionally, entomopathogenic fungi may not be selective, and may directly infect key non-targeted organisms. Thus, the parasitoids may be susceptible to diseases caused by entomopathogenic fungi. Knowledge on which species has relatively impacted more or less by the treatments and which biopesticides causes more hinderance in the effectiveness of *Trichogramma* and if the interaction of bioagents and biopesticides is being strategized then to know whether they enhance or reduce the effectiveness of *Trichogramma* specifically is important. Considering all above points, the present study was framed to evaluate the influence of biopesticides on the biological parameters of *Trichogramma* spp.

### MATERIAL AND METHODS

The present investigation was conducted in the Biocontrol Laboratory, Department of Agril. Entomology, Post Graduate Institute, Dr. Panjabrao Deshmukh Krishi

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Vidyapeeth, Akola during the year 2021-2022. The experiment was laid out in a Factorial Completely Randomized Design (FCRD) with 18 treatments and three replications. Three strains of *Trichogramma* viz., *Trichogramma chilonis*, *Trichogramma pretiosum*, *Trichogrammatoidea bactrae* were considered as Factor “A”. Whereas, Factor B included five biopesticide viz., *Metarhizium anisopliae*  $1 \times 10^8$  CFU  $g^{-1}$  @ 5ml  $lit^{-1}$ , *Nomuraea rileyi*  $1 \times 10^8$  CFU  $g^{-1}$  @ 5g  $lit^{-1}$ , *Beauveria bassiana*  $1 \times 10^8$  CFU  $g^{-1}$  @ 5ml  $lit^{-1}$ , *Lecanicillium lecanii*  $1 \times 10^8$  CFU  $g^{-1}$  @ 5ml  $lit^{-1}$ , NBAIR BtG4 2% @ 2 ml  $lit^{-1}$  and distilled water as untreated control. The nucleus culture of *C. cephalonica* in the form of eggs was procured from NBAIR, Bangalore and was mass reared on sterilized crushed sorghum grains supplemented with yeast, groundnut powder and streptomycin sulphate under laboratory conditions. The nucleus cultures of *Trichogramma chilonis*, *Trichogrammatoidea bactrae* and *Trichogramma pretiosum* were obtained from NBAIR, Bangalore and maintained on the eggs of *Corcyra cephalonica* at ambient temperature  $28 \pm 2^\circ C$  and relative humidity  $70 \pm 10\%$  R.H. for further studies.

### Effect of biopesticides on parasitization and fecundity

U.V. irradiated fresh eggs of *Corcyra cephalonica* were glued to the egg cards separately (@ 50 eggs per card strip). The cards were then cut into small strips of 5.0 x 2.0 cm. The treatment was given by card dip bioassay method. The strips along with pasted *Corcyra* eggs were dipped in different biopesticide treatments for 5 seconds. The untreated control was maintained by treating the egg card strip with distilled water. The treated egg cards were shade dried. The card strips containing treated U.V. exposed eggs were kept in plastic vials (2.5 x 6 cm size). The treated egg cards were exposed to 5 gravid females of *Trichogramma*. Parasitized eggs were assessed by counting the blackened eggs (Singh and Jalali, 1998). Per cent reduction in parasitism was calculated following Hassan *et al.* (2000).

As per the method described by Miura and Kobayashi (1998) the number of eggs parasitized by a single female  $day^{-1}$  was used to express fecundity of *Trichogramma*.

$$\% \text{ egg parasitization} = \frac{\text{Number of parasitized eggs}}{\text{Total no. of eggs exposed}} \times 100$$

$$\text{Reduction in parasitism (\%)} = (1 - f/t) \times 100$$

Where,

f = average number of parasitized eggs in the biopesticides treatment

t = average number of parasitized eggs in the control treatment.

On the basis of Per cent reduction in parasitism, biopesticides were classified in different categories as suggested by Sterk *et al.*, (1999).

| Toxicity Class | Categorization     | % reduction in parasitization |
|----------------|--------------------|-------------------------------|
| Class 1        | Harmless           | <30                           |
| Class 2        | Slightly harmful   | 30-79                         |
| Class 3        | Moderately harmful | 80-99                         |
| Class 4        | Harmful            | >99                           |

## RESULTS AND DISCUSSION

The data presented in Table 1 and depicted in Fig. 1 revealed that egg parasitization differed significantly among *Trichogramma* species, biopesticide treatments and their interactions. Among the different parasitoid species (Factor A), *T. bactrae* had significantly parasitized maximum *Corcyra* eggs (80.44%) as compared to rest of the species. This was followed by *T. chilonis* which parasitized 77.99 per cent *Corcyra* eggs and was found at par with *T. pretiosum* (77.66%). With respect to biopesticide treatments (Factor B), significantly highest egg parasitization (90.66%) was recorded in control. Amongst the biopesticides NBAIR BtG4 recorded maximum parasitization (78.22%) and was found to be at par with *M. anisopliae*, *B. bassiana* and *N. rileyi* which recorded 77.10, 76.44 and 75.33 per cent egg parasitization, respectively. Whereas significantly least parasitization (74.88%) was observed in treatment with *L. lecanii*.

While considering the interaction effects (A × B), significantly highest egg parasitization was recorded in the untreated control (distilled water) with *T. chilonis*

(92.00%), *T. pretiosum* (90.00%) and *T. batrae* (90.00%), which were statistically at par with each other. This was followed by *T. batrae* on the eggs sprayed with BtG4 (82.00%) which was found at par with interaction treatments i.e., *M. anisopliae* with *T. batrae* (80.66%), *N. rileyi* with *T. batrae* (80.00), *M. anisopliae* with *T. pretiosum* (78.66%), *B. bassiana* with *T. batrae* (78.00%) and *N. rileyi* with *T. chilonis* (78.00%). The remaining treatments showed moderate per cent egg parasitization. Whereas, the interaction of *L. lecanii* with *T. batrae* (72.00%), *M. anisopliae* with *T. chilonis* (72.00%) and *N. rileyi* with *T. pretiosum* (68.00%) showed minimum per cent egg parasitization. The interaction indicated moderate to high compatibility of most biopesticides with

*Trichogramma* spp., except *L. lecanii*. Thus from the above study NBAIR BtG4, *Metarhizium anisopliae*, *Beauveria bassiana* and *Nomuraea rileyi* can be categorized as harmless, indicating their high compatibility with *Trichogramma* spp. supporting their safe integration with biological control agents. Whereas *Lecanicillium lecanii* exhibited relatively higher adverse effects and was classified as slightly harmful, reflecting reduced compatibility with the parasitoids and thus should be used cautiously to avoid adverse effects on parasitoid activity.

Similar findings were recorded by earlier worker like Reddy and Manjunatha (2000) recorded 75.60 per

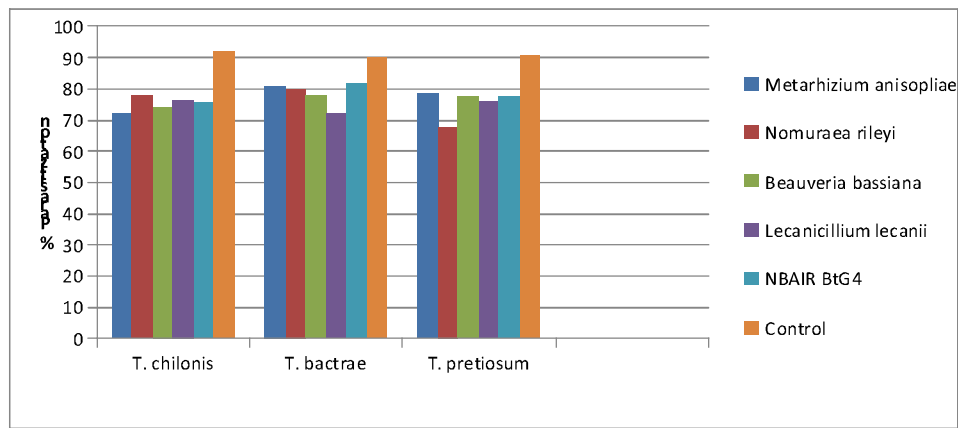


Fig 1. Compatibility of biopesticides with *Trichogramma* species based on egg parasitization

Table 1. Influence of biopesticides on egg parasitization by different *Trichogramma* species

| Treatments                         | Egg Parasitization (%) Interaction 'AxB' |                            |                               |                                  |                  |                  | Mean<br>Factor 'A'<br>(Species) |
|------------------------------------|------------------------------------------|----------------------------|-------------------------------|----------------------------------|------------------|------------------|---------------------------------|
|                                    | <i>Metarhizium<br/>anisopliae</i>        | <i>Nomuraea<br/>rileyi</i> | <i>Beauveria<br/>bassiana</i> | <i>Lecanicillium<br/>Lecanii</i> | NBAIR<br>BtG4    | Control          |                                 |
| <i>T. chilonis</i>                 | 72.00<br>(58.03)                         | 78.00<br>(62.01)           | 74.00<br>(59.33)              | 76.66<br>(61.12)                 | 75.33<br>(60.22) | 92.00<br>(73.62) | 77.99<br>(62.39)                |
| <i>T. batrae</i>                   | 80.66<br>(63.93)                         | 80.00<br>(63.42)           | 78.00<br>(62.01)              | 72.00<br>(58.05)                 | 82.00<br>(64.89) | 90.00<br>(71.59) | 80.44<br>(63.98)                |
| <i>T. pretiosum</i>                | 78.66<br>(62.47)                         | 68.00<br>(55.53)           | 77.33<br>(61.54)              | 76.00<br>(60.69)                 | 77.33<br>(60.65) | 90.00<br>(71.77) | 77.66<br>(62.11)                |
| Mean Factor 'B'<br>(Biopesticides) | 77.10<br>(61.48)                         | 75.33<br>(60.32)           | 76.44<br>(60.96)              | 74.88<br>(59.95)                 | 78.22<br>(61.92) | 90.66<br>(72.33) |                                 |
|                                    | Factor 'A'                               |                            | Factor 'B'                    |                                  | Interaction AxB  |                  |                                 |
| SE(m)±                             | 0.44                                     |                            | 0.63                          |                                  | 1.01             |                  |                                 |
| CD at 5%                           | 1.29                                     |                            | 1.83                          |                                  | 3.16             |                  |                                 |

# Influence of Biopesticides on Parasitization and Adult Emergence of *Trichogramma* spp.

cent *H. armigera* egg parasitization by *T. chilonis*. Further concluded that Bt formulation (Dipel) had no effects on the parasitoid *T. chilonis* which supports present study. Whereas, Potrich *et al.* (2009) reported that *M. anisopliae* resulted decrease in adult emergence and parasitism of *T. pretiosum*. Moreover, Derakhshan *et al.* (2007) reported that *L. lecanii* negatively affects the parasitism. This indicates that these biopesticides exert minimal adverse effects on the host-finding and oviposition behavior of *Trichogramma* spp. In contrast, *Lecanicillium lecanii* caused a comparatively greater reduction in parasitization, suggesting a relatively higher negative influence on parasitoid activity. The reduced parasitization observed with *L. lecanii* may be due to contact toxicity, sublethal effects, or fungal contamination on treated host eggs, which could interfere with parasitoid acceptance and oviposition.

The data presented in Table 2 and depicted in Fig.2 indicated that among the *Trichogramma* species tested, *T. bactrae* recorded minimum reduction in parasitism (12.73%) and it was significantly superior to other two species. This was followed by *T. pretiosum* and *T. chilonis* in which reduction in parasitism recorded was 15.95 and 18.24 per cent, respectively. Among biopesticides it was observed that NBAIR BtG4 was most effective treatment with minimum per cent reduction in

egg parasitism (13.67 %). This was found at par with treatment of *M. anisopliae* in which 14.85 per cent reduction was recorded. Maximum per cent reduction in egg parasitism was recorded with treatment of *L. lecanii* i.e., 17.15 per cent. However, this treatment was found to be at par with treatment *N. rileyi* (16.89 %) and *B. bassiana* (15.61 %).

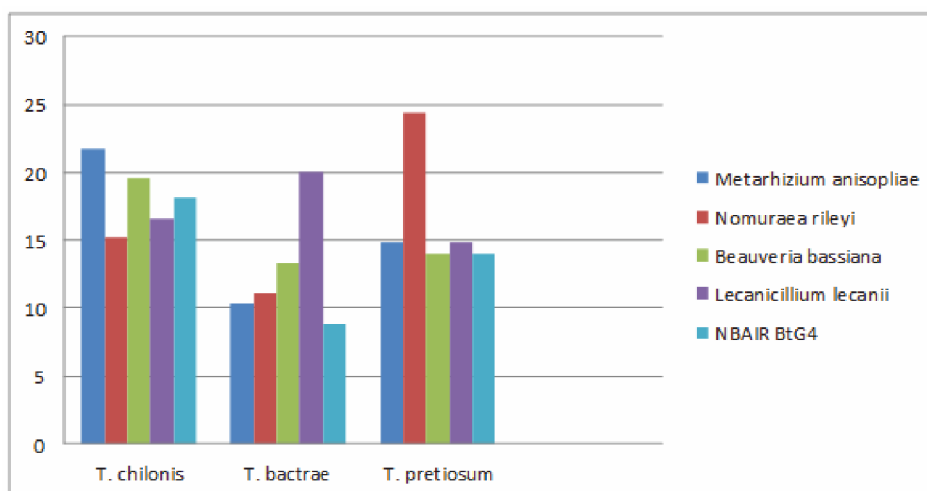
The interaction between *Trichogramma* species and biopesticides (A × B) was found to be significant, indicating that the response of each parasitoid species varied depending on the biopesticide used. Minimum per cent reduction in parasitism (8.87 %) was observed in interaction effect of *T. bactrae* with NBAIR BtG4 and emerged as best treatment. However, this treatment was found at par with interaction treatments i.e., *M. anisopliae* with *T. bactrae*, *N. rileyi* with *T. bactrae*, *M. anisopliae* with *T. pretiosum* which recorded 10.35, 11.09, 12.50 per cent reduction in egg parasitism, respectively. The remaining treatments showed moderate effect in this regard. Among *Trichogramma* species, *T. bactrae* was the most tolerant, recording the lowest overall reduction in egg parasitism across biopesticide treatments. Treatments involving *Lecanicillium lecanii* resulted in comparatively higher reductions in parasitism, indicating lower compatibility with *Trichogramma* spp.

**Table 2. Effect of biopesticides on per cent reduction in parasitism by *Trichogramma* spp.**

| TREATMENTS                      | Reduction in Parasitism (per cent) |                        |                           | Interaction 'AxB'            |                  | Mean Factor 'A' (Species) |
|---------------------------------|------------------------------------|------------------------|---------------------------|------------------------------|------------------|---------------------------|
|                                 | <i>Metarhizium anisopliae</i>      | <i>Nomuraea rileyi</i> | <i>Beauveria bassiana</i> | <i>Lecanicillium lecanii</i> | NBAIR BtG4       |                           |
| <i>T. chilonis</i>              | 21.72<br>(27.75)                   | 15.20<br>(22.91)       | 19.55<br>(26.21)          | 16.65<br>(24.00)             | 18.10<br>(25.11) | 18.24<br>(25.20)          |
| <i>T. bactrae</i>               | 10.35<br>(18.59)                   | 11.09<br>(19.39)       | 13.31<br>(21.35)          | 20.02<br>(26.54)             | 8.87<br>(17.24)  | 12.73<br>(20.62)          |
| <i>T. pretiosum</i>             | 12.50<br>(20.61)                   | 24.40<br>(29.59)       | 13.99<br>(21.89)          | 14.80<br>(22.53)             | 14.05<br>(22.00) | 15.95<br>(23.32)          |
| Mean Factor 'B' (Biopesticides) | 14.85<br>(22.32)                   | 16.89<br>(23.96)       | 15.61<br>(23.15)          | 17.15<br>(24.36)             | 13.67<br>(21.45) |                           |
|                                 | Factor 'A'                         |                        | Factor 'B'                | Interaction AxB              |                  |                           |
| SE(m) ±                         | 0.53                               |                        | 0.69                      | 1.19                         |                  |                           |
| CD at 5%                        | 1.54                               |                        | 1.99                      | 3.45                         |                  |                           |

Note: Figures in parentheses are corresponding arc sin transformed values.





**Fig 2. Percent reduction in parasitism of *Trichogramma* spp against different biopesticides**

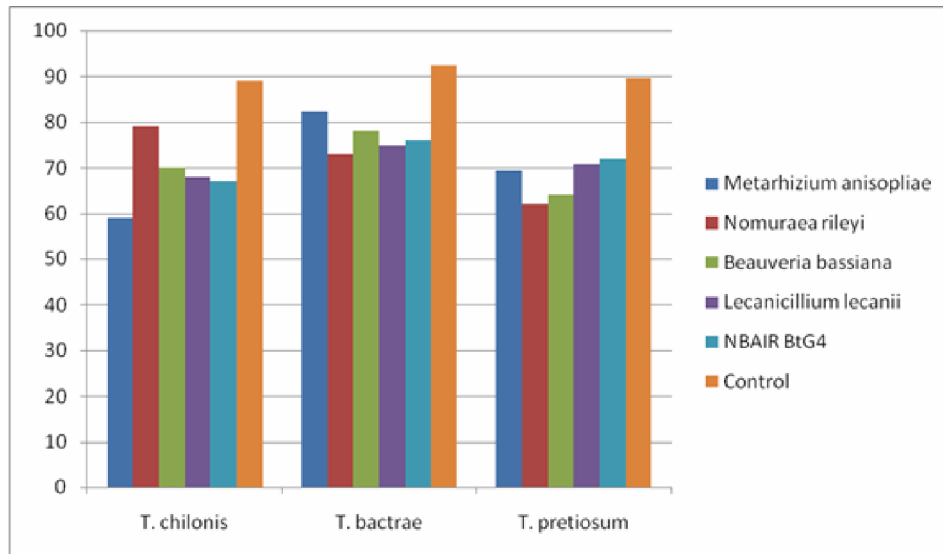
The result of the present study finds support in the work carried out by earlier workers like Sharma and Aggarwal (2019) concluded that the biopesticides viz., Dipel WP and Myco-Jaal 10% SC tested at varied doses against adult emergence of *Trichogramma* spp. proved harmless to slightly harmful. Similarly, Singh *et al.* (2015) in his studies concluded that *B. thuringiensis* 5 per cent WP (0.2%) was a safer microbial insecticide to the parasitoid. Less than 30 per cent reduction in parasitism was observed by Araujo *et al.* (2020) while working with *T. pretiosum* and *T. atopovirilia* treated with *B. bassiana*.

The data presented in Table 3 and depicted in Fig. 3 indicates that *T. bactrae* recorded significantly maximum adult emergence (79.72 %) followed by *T. chilonis* (72.11%) and *T. pretiosum* (71.49%). While considering the factor B (effect of biopesticides) it was observed that significantly highest adult emergence (90.33 %) was recorded from untreated control parasitized *Corcyra* eggs. Amongst the biopesticide parasitized *Corcyra* eggs treated with NBAIR BtG4 recorded maximum adult emergence (71.66 %). However, this treatment was found at par with *N. rileyi*, *L. lecanii*, *B.*

**Table 3. Effect of biopesticides on adult emergence of *Trichogramma* spp. from treated *Corcyra* eggs**

| Treatments                      | Adult Emergence (%) Interaction 'AxB' |                        |                           |                              |                   | Control          | Mean Factor 'A' (Species) |
|---------------------------------|---------------------------------------|------------------------|---------------------------|------------------------------|-------------------|------------------|---------------------------|
|                                 | <i>Metarhizium anisopliae</i>         | <i>Nomuraea rileyi</i> | <i>Beauveria bassiana</i> | <i>Lecanicillium lecanii</i> | NBAIR BtG4        |                  |                           |
| <i>T. chilonis</i>              | 59.00<br>(50.17)                      | 79.00<br>(62.75)       | 69.66<br>(56.57)          | 68.00<br>(55.94)             | 67.00<br>(54.93)  | 89.00<br>(71.07) | 72.11<br>(58.57)          |
| <i>T. bactrae</i>               | 82.33<br>(65.14)                      | 73.00<br>(59.13)       | 78.00<br>(62.28)          | 75.00<br>(60.01)             | 76.00<br>(61.09)  | 92.33<br>(74.09) | 79.72<br>(63.62)          |
| <i>T. pretiosum</i>             | 69.33<br>(56.35)                      | 62.00<br>(52.32)       | 64.00<br>(53.11)          | 70.66<br>(57.19)             | 72.00<br>(58.49)  | 89.66<br>(71.22) | 71.49<br>(58.12)          |
| Mean Factor 'B' (Biopesticides) | 70.22<br>(57.22)                      | 71.33<br>(58.07)       | 70.55<br>(57.32)          | 71.22<br>(57.72)             | 71.66<br>(58.17)  | 90.33<br>(72.13) |                           |
|                                 | Factor 'A'                            |                        | Factor 'B'                |                              | Interaction 'AxB' |                  |                           |
| SE(m) ±                         | 0.49                                  |                        | 0.70                      |                              | 1.21              |                  |                           |
| CD at 5%                        | 1.42                                  |                        | 2.01                      |                              | 3.49              |                  |                           |

### Influence of Biopesticides on Parasitization and Adult Emergence of *Trichogramma* spp.



**Fig 3. Effect of different biopesticides on per cent adult emergence against *Trichogramma* spp**

*bassiana* and *M. anisopliae* which recorded 71.33, 71.22, 70.55 and 70.22 per cent adult emergence, respectively. While studying Factor A x B, significantly maximum adult emergence of *Trichogramma* spp. were observed in untreated control group with distilled water i.e., *T. bactrae* (92.33 %), *T. pretiosum* (89.66 %) and *T. chilonis* (89.00 %) were found at par with each other. This was followed by interaction of *M. anisopliae* with *T. bactrae* (82.33 %) found at par with interaction treatments i.e., *N. rileyi* with *T. chilonis* (79.00 %) and *B. bassiana* with *T. bactrae* (78.00 %). Whereas, the interaction of *B. bassiana* with *T. pretiosum* (64.00 %), *N. rileyi* with *T. pretiosum* (62.00 %) and *M. anisopliae* with *T. chilonis* (59.00 %) recorded minimum per cent adult emergence.

Among the *Trichogramma* species evaluated, *T. bactrae* consistently recorded the highest adult emergence from biopesticide-treated Corcyra eggs, indicating its comparatively better tolerance and compatibility with the tested biopesticides. Among the biopesticides, NBAIR BtG4 supported relatively higher adult emergence followed by entomopathogenic fungi *N. rileyi*, *L. lecanii*, *B. bassiana*, and *M. anisopliae*, suggesting that these biopesticides are comparatively safer to *Trichogramma* spp. Interaction effects revealed that combinations involving *T. bactrae*, particularly with *M. anisopliae*, *N. rileyi*, *B. bassiana*, *L. lecanii*, and NBAIR BtG4, resulted in higher adult emergence, highlighting their better compatibility. *B. bassiana* and *N. rileyi* with *T. pretiosum*,

and *M. anisopliae* with *T. chilonis*, recorded the lowest adult emergence, indicating relatively higher negative impact on parasitoid survival.

The present results finds support from the work carried out by earlier worker Amaro *et al.* (2015) who stated that entomopathogens viz., *B. thuringiensis* var. *kurstaki*, *B. bassiana* and *M. anisopliae* had no side effects on biological parameters and were classified as harmless to *T. pretiosum*. Similarly, Sharma and Aggarwal (2019) studied the influence of biopesticides viz., Dipel WP (*B. thuringiensis* var. *kurstaki*), Myco-Jaal 10% SC (*B. bassiana*), entomopathogenic nematode (EPN) on adult emergence and parasitization efficiency of *Trichogramma* spp. gives conformity to present findings. Moreover, Kaur and Joshi (2017) reported maximum adult emergence (82.25%) of *T. chilonis* in tricho cards treated with Bt Delfin@WG which was at par with NBAIR BtG4 isolate (82.05%), PAU Bt isolate (81.54%) and PDBC BT1 isolate (76.67%) at higher dose at 20 g lit<sup>-1</sup> concluding Bt formulations were more compatible with *T. chilonis* adults. Moreover, Kumar *et al.* (2016) recorded maximum parasitization and emergence of *T. chilonis* from combination of HaNPV (1 x 10<sup>9</sup> PIB ml<sup>-1</sup>) @ 0.2% + Btk (0.1%) proved less toxic to *T. chilonis* and is in conformity with present study. The interaction effects highlighted those combinations involving *T. bactrae* with most biopesticides resulted in higher adult emergence, reinforcing its suitability for integration with microbial

pesticides. In contrast, reduced emergence in certain species indicates the need for species specific compatibility evaluation before large scale field application.

## CONCLUSION

The present investigation clearly demonstrates that the compatibility between biopesticides and *Trichogramma spp.* varies significantly with the species of parasitoid and the biopesticide used. Among the three parasitoids evaluated, *Trichogrammatoidea bactrae* consistently exhibited superior performance, reflected by higher egg parasitization, lower reduction in parasitism, and maximum adult emergence across most treatments, indicating its greater tolerance and adaptability to biopesticide exposure. Among the biopesticides, NBAIR BtG4 proved to be the most compatible, recording high parasitization, minimum reduction in parasitism, and comparatively higher adult emergence, followed closely by *Metarhizium anisopliae*, *Beauveria bassiana*, and *Nomuraea rileyi*. These biopesticides were categorized as harmless and thus can be safely integrated with *Trichogramma spp.* in biological control programmes. In contrast, *Lecanicillium lecanii* showed relatively higher adverse effects on parasitization and adult emergence and was thus classified as slightly harmful, warranting cautious use when combined with egg parasitoids.

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## Management of Sucking and Lepidopteran Insect Pests Infesting Sunflower

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### ABSTRACT

Field experiment was conducted at Oilseeds Research Unit, Dr.Panjabrao Deshmukh Krushi Vidhyapeeth, Akola with an objective to find out the effective insecticides against the Sucking and Lepidopteran Insect pests in Sunflower. Imidacloprid 48% FS @ 5 ml kg<sup>-1</sup> seed and Thiamethoxam 30FS @ 3 ml kg<sup>-1</sup> seed were evaluated as seed treatment, while Neem seed extract 5 per cent and cypermethrin 10 % EC @ 1.5ml lit<sup>-1</sup> were tried as foliar spray, alternatively at starbud and flowering stage of the crop. Seed treatment with Imidacloprid 48% FS @ 5 ml kg<sup>-1</sup> seed, spraying of cypermethrin 10 % EC @ 1.5ml lit<sup>-1</sup> at starbud and flowering stage of crop found effect against sucking and lepidopteran pests of sunflower followed by seed treatment with Thiamethoxam 30% FS @ 3 ml kg<sup>-1</sup> seed, spraying of cypermethrin 10 % EC @ 1.5ml lit<sup>-1</sup> at starbud and NSE 5 % at flowering stage of crop. Non significant difference was noticed in treated and untreated plots against lady bird beetle. Seed treatment with Imidacloprid 48% FS @ 5 ml kg<sup>-1</sup> seed, spraying of cypermethrin 10 % EC @ 1.5ml lit<sup>-1</sup> at starbud and flowering stage of crop found cost effective treatment.

Sunflower is an important oilseed crop. Among the several factors responsible for the low productivity of sunflowers, the damage caused by insect pests is a major one. The major insect pests which drew the attention of both farmers and scientists are sucking pests like leafhopper (*Amrasca biguttula biguttula* Ishida) and Thrips (*Thrips palmi*), defoliators such as *Spodoptera litura* (Fabricius) and capitulum or head borer, *Helicoverpa armigera* (Hubner). Infestation by sucking insect pests is becoming a major concern in obtaining the expected yield from sunflower crops because its incidence starts at the seedling stage and prevails throughout the entire plant life. Both nymphs and adults of the leafhopper desap the plant and show symptoms like stunted growth, burning of leaf margins, cupped and crinkled leaves. In severe cases, characteristic “hopper burn” symptoms are noticed. Several species of thrips are associated with the crop, which does not cause direct damage but enormous losses indirectly as vectors of viral diseases, especially the sunflower necrosis virus (Chander Rao, 2002). Defoliators like *Spodoptera litura* causes nearly 70 per cent yield loss and 90 per cent defoliation in crops such as sunflower, soybean, blackgram and cotton. Head borer is serious pests that, cause damage by boring the head of sunflower, feed on the developing seeds and cause heavy yield losses. The damage caused by the borer also invites secondary saprophytic fungi, which results in the development of head rot (Ravi *et al.* 2007). The capitulum

borer directly inflicts damage to sunflowers by depriving the plant of ovaries and developing seeds (Bhat and Virupakshappa, 1993). As crop producers are able to have the support of natural enemies as predators or parasitoids for insect pest management, it is clearly important not to destroy these natural enemies. The effects of pesticides on the natural enemies of pests are well documented. So today, it is increasingly desirable to intervene with insecticidal compounds that can act in harmony with predators and parasitoids, or at least reduce the effects against natural enemies. Hence, an attempt has been made to study the evaluation of insecticides against major insect pests of sunflowers through seed treatment and foliar application at critical stages of crop.

### MATERIAL AND METHODS

Field experiment was conducted at Oilseeds Research Unit, Dr.Panjabrao Deshmukh Krishi Vidyapeeth, Akola during the *kharif* season of 2021-22 to 2023-24. Sunflower hybrid KBSH 44 was used for sowing and followed the recommended package of practices except plant protection. The KBSH-44 variety of Sunflower was cultivated using a randomised block design with a plot size of 4.5 x 4.2 m<sup>2</sup> and a spacing of 60 x 30 cm between rows and plants. This was done in accordance with the package of practices advised by Dr.PDKV, Akola. The treaments comprised the seed treatment with Imidacloprid 48% FS @ 5 ml kg<sup>-1</sup> seed &

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Thiamethoxam 30% FS @ 3 ml kg<sup>-1</sup> seed and foliar application of insecticides viz Neem seed extract 5 %, cypermethrin 10 % EC @ 1.5 ml lit<sup>-1</sup> at starbud and flowering stage of the crop. Observation on *Thrips palmi* (Nymphs/6L/Plant), leafhopper (*Amrasca biguttula biguttula* Ishida) and per cent necrosis was recorded at 30 days after germination. *Spodoptera litura* (Fabricius) and *Helicoverpa armigera* (Hubner) was recorded ten days after application of insecticides at starbud and flowering stage of crop, respectively. The population of Coccinelids (adults plant<sup>-1</sup>) was recorded at starbud and at flowering stage of crop. Yield was recorded from net plot and calculated the incremental cost benefit ratio. The data was subjected to suitable statistical analysis by using appropriate analytical methods (R software and OPSTAT) and on the basis of critical difference results were compared.

## RESULTS AND DISCUSSION

Seed treatment with Imidacloprid 48% FS @ 5 ml/kg seed, application of Yellow sticky trap 1/18.9 m<sup>2</sup> at 15 days after germination of crop found effective, recording minimum thrips i.e 6.2 nymphs/6L/plant followed by spraying of Imidacloprid 17.8 SL 0.2 ml/lit of water at 15 days after germination recording 8.8 nymphs 6L<sup>-1</sup> plant<sup>-1</sup> found at par with each other. The minimum infestation of leafhoppers i.e 4.2 nymphs<sup>-1</sup> 6L<sup>-1</sup> plant was observed due to spraying of Imidacloprid 17.8 SL 0.2 ml lit<sup>-1</sup> of water at 15 days after germination followed by seed treatment with Imidacloprid 48% FS @ 5 ml kg<sup>-1</sup> seed, application of yellow sticky trap 1/18.9 m<sup>2</sup> at 15 days after germination of crop and spraying of NSE 5% at 15 days after germination of crop recording 4.5 and 6.5 nymphs 6L<sup>-1</sup> plant<sup>-1</sup>, respectively. Minimum incidence of necrosis 2.2 per cent was noticed from seed treatment with Imidacloprid 48% FS @ 5 ml kg<sup>-1</sup> seed, application of yellow sticky trap 1/18.9 m<sup>2</sup> at 15 days after germination of crop, followed by Spraying of Imidacloprid 17.8 SL 0.2 ml lit<sup>-1</sup> of water at 15 days germination, spraying of NSE 5 % at starbud stage and cypermethrin 10 % EC @ 1.5 ml/lit at flowering stage of crop (3.2 %) (Table 1). Significant difference was found in spraying of NSE 5 % & Cypermethrin 10% EC over untreated control against *Spodoptera litura*. The treatments comprising spraying of cypermethrin 10 % EC @ 1.5 ml

lit<sup>-1</sup> at starbud found effective against *Spodoptera litura*, recording 0.57, 0.57 and 0.60 larvae per plant as compare to spraying of NSE 5 % at star bud, recording 0.69, 0.70 and 0.79 larvae plant<sup>-1</sup>, found significantly superior over untreated control and at par with each other. Spraying of cypermethrin 10 % EC @ 1.5 ml lit<sup>-1</sup> and NSE 5 % at flowering stage of crop found significantly superior over untreated control against *Helicoverpa armigera*. Among the insecticide treatment spraying of cypermethrin 10 EC at flowering stage of crop found most effective recording 0.44, 0.56 and 0.58 larvae plant<sup>-1</sup> as compare to spraying of NSE 5% at flowering, recording 0.63 and 0.74 larvae plant<sup>-1</sup> (Table 2). Data given on lady bird beetles in table 3 revealed non significant difference was observed in between the spraying of cypermethrin 10 % EC @ 1.5 ml lit<sup>-1</sup>, spraying of NSE 5 % at star bud & flowering stage and untreated control. Maximum yield 1443 kg ha<sup>-1</sup> was obtained from spraying of NSE 5 % at 15 days after germination of crop and spraying of cypermethrin 10 % EC at starbud and flowering stage of crop followed by Seed treatment with Thiamethoxam 30% FS @ 3 ml kg<sup>-1</sup> seed, spraying of cypermethrin 10 % EC @ 1.5 ml lit<sup>-1</sup> at starbud and NSE 5 % at flowering stage of crop (1406 kg ha<sup>-1</sup>) (Table 4). Seed treatment with Imidacloprid 48% FS @ 5 ml kg<sup>-1</sup> seed, spraying of cypermethrin 10 % EC at star bud and flowering stage of the crop found economical having 5.62 ICBR (Table 4).

These findings corroborated those of Ingale *et al.* (2019), El-Naggar and Zidan (2013) and Ding *et al.* (2018) with seed treatment of imidacloprid and thiamethoxam, revealed in reducing the population of leafhoppers and thrips. Imidacloprid is a systemic insecticide which acts on the central nervous system of insect's works by interfering with the transmission of stimuli in the insect nervous system. Specifically, it causes a blockage of the nicotinic neuronal pathway. By blocking nicotinic acetylcholine receptors, imidacloprid prevents acetylcholine from transmitting impulses between nerves, resulting in the insect's paralysis and eventual death. Thiamethoxam is a broad-spectrum, systemic insecticide, which means it is absorbed quickly by plants and transported to all of its parts, including through direct contact, including through its stomach after feeding, or through direct contact, including through direct

Table 1. Effect of different treatments against sucking pests

| Treatment                                                                                                                                                                                                         | At 30 days after sowing |            |            |            |                             |            |            |            |             |            |           |            |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|------------|------------|------------|-----------------------------|------------|------------|------------|-------------|------------|-----------|------------|
|                                                                                                                                                                                                                   | Thrips Nymphs/6L/Plant  |            |            |            | Leafhoppers nymphs/6L/Plant |            |            |            | Necrosis(%) |            |           |            |
|                                                                                                                                                                                                                   | 21-22                   | 22-23      | 23-24      | Pooled     | 21-22                       | 22-23      | 23-24      | Pooled     | 21-22       | 22-23      | 23-24     | Pooled     |
| T1 Seed treatment with Imidacloprid 48% FS @ 5 ml/kg seed, application of Yellow sticky trap 1/18.9 m <sup>2</sup> at 15 days after germination of crop, spraying of NSE 5% at star bud initiation stage of crop. | 7.0 (2.6)               | 6.1 (2.4)  | 5.5 (2.3)  | 6.2 (2.5)  | 4.0 (2.0)                   | 3.8 (1.9)  | 5.7 (2.3)  | 4.5 (2.1)  | 1.9 (1.4)   | 1.9 (1.4)  | 2.8 (1.6) | 2.2 (1.5)  |
| T2 Spraying of NSE 5% at 15 days after germination of crop, spraying of cypermethrin 10 % EC @ 1.5ml/lit at starbud and flowering stage of crop                                                                   | 10.8 (3.3)              | 10.7 (3.2) | 10.0 (3.1) | 10.5 (3.2) | 7.6 (2.7)                   | 5.6 (2.3)  | 6.3 (2.5)  | 6.5 (2.5)  | 4.8 (2.2)   | 4.3 (2.0)  | 3.3 (1.8) | 4.1 (2.0)  |
| T3 Seed treatment with Imidacloprid 48% FS @ 5 ml/kg seed, spraying of NSE 5 % at starbud and flowering stage of crop                                                                                             | 16.0 (4.0)              | 13.5 (3.7) | 11.7 (3.4) | 13.7 (3.7) | 11.8 (3.4)                  | 9.0 (3.0)  | 9.5 (3.1)  | 10.1 (3.2) | 6.7 (2.6)   | 5.8 (2.4)  | 2.7 (1.6) | 5.1 (2.3)  |
| T4 Seed treatment with Imidacloprid 48% FS @ 5 ml/kg seed, spraying of cypermethrin 10 % EC @ 1.5ml/lit at starbud and flowering stage of crop                                                                    | 16.7 (4.1)              | 15.1 (3.9) | 14.3 (3.8) | 15.4 (3.9) | 16.5 (4.1)                  | 13.5 (3.7) | 14.1 (3.7) | 14.7 (3.8) | 6.7 (2.6)   | 5.8 (2.4)  | 4.1 (2.0) | 5.5 (2.4)  |
| T5 Spraying of Imidacloprid 17.8 SL 0.2 ml/lit of water at 15 days germination, spraying of NSE 5 % at starbud stage and cypermethrin 10 % EC @ 1.5ml/lit at flowering stage of crop                              | 9.5 (3.1)               | 8.5 (2.9)  | 8.3 (2.9)  | 8.8 (2.9)  | 4.9 (2.2)                   | 3.2 (1.8)  | 4.5 (2.1)  | 4.2 (2.0)  | 3.8 (1.9)   | 3.9 (2.0)  | 3.1 (1.7) | 3.6 (1.9)  |
| T6 Seed treatment with Thiamethoxam 30% FS @ 3ml/kg seed, spraying of cypermethrin 10 % EC @ 1.5ml/lit at starbud and NSE 5 % at flowering stage of crop.                                                         | 11.2 (3.0)              | 12.3 (3.5) | 11.7 (3.4) | 11.7 (3.4) | 10.6 (3.0)                  | 9.6 (3.1)  | 9.5 (3.1)  | 9.9 (3.1)  | 6.3 (2.5)   | 4.9 (2.2)  | 4.7 (2.1) | 5.3 (2.3)  |
| T7 Untreated control                                                                                                                                                                                              | 26.5 (5.1)              | 23.3 (4.8) | 22.6 (4.7) | 24.1 (4.9) | 30.9 (5.5)                  | 24.0 (4.9) | 21.1 (4.6) | 25.3 (5.0) | 14.8 (3.8)  | 12.6 (3.5) | 9.0 (3.0) | 12.2 (3.5) |
| SE (m)±                                                                                                                                                                                                           | 0.30                    | 0.19       | 0.18       | 0.16       | 0.32                        | 0.31       | 0.25       | 0.23       | 0.22        | 0.20       | 0.21      | 0.18       |
| CD at 5 %                                                                                                                                                                                                         | 0.94                    | 0.59       | 0.57       | 0.50       | 0.97                        | 0.67       | 0.76       | 0.7        | 0.67        | 0.61       | 0.66      | 0.56       |
| CV (%)                                                                                                                                                                                                            | 14.6                    | 9.45       | 9.35       | 8.03       | 16.7                        | 12.7       | 13.9       | 12.69      | 15.5        | 15.0       | 18.5      | 13.94      |

\* Figures given in the parenthesis are square root transformed values

Table 2. Effect of different treatments against lepidopteran pests

| Treatment |                                                                                                                                                                                                                | <i>Spodoptera litura</i> at star bud stage Larvae/plant |                |                |                | <i>Helicoverpa armigera</i> at flowering stage Larvae/plant |                |                |                |
|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|----------------|----------------|----------------|-------------------------------------------------------------|----------------|----------------|----------------|
|           |                                                                                                                                                                                                                | 21-22                                                   | 22-23          | 23-24          | Pooled         | 21-22                                                       | 22-23          | 23-24          | Pooled         |
| T1        | Seed treatment with Imidacloprid 48% FS @ 5 ml/kg seed, application of Yellow sticky trap 1/18.9 m <sup>2</sup> at 15 days after germination of crop, spraying of NSE 5% at star bud initiation stage of crop. | 0.67<br>(0.82)                                          | 0.77<br>(0.88) | 0.93<br>(0.97) | 0.79<br>(0.89) | 0.77<br>(0.87)                                              | 0.73<br>(0.84) | 0.80<br>(0.89) | 0.77<br>(0.86) |
| T2        | Spraying of NSE 5% at 15 days after germination of crop, spraying of cypermethrin 10 % EC @ 1.5ml/lit at starbud and flowering stage of crop                                                                   | 0.40<br>(0.63)                                          | 0.50<br>(0.70) | 0.80<br>(0.89) | 0.57<br>(0.75) | 0.30<br>(0.54)                                              | 0.40<br>(0.63) | 0.63<br>(0.79) | 0.44<br>(0.66) |
| T3        | Seed treatment with Imidacloprid 48% FS @ 5 ml/kg seed, spraying of NSE 5 % at starbud and flowering stage of crop                                                                                             | 0.60<br>(0.77)                                          | 0.70<br>(0.84) | 0.80<br>(0.89) | 0.70<br>(0.83) | 0.73<br>(0.85)                                              | 0.50<br>(0.70) | 0.67<br>(0.81) | 0.63<br>(0.79) |
| T4        | Seed treatment with Imidacloprid 48% FS @ 5 ml/kg seed, spraying of cypermethrin 10 % EC @ 1.5ml/lit at starbud and flowering stage of crop                                                                    | 0.37<br>(0.60)                                          | 0.47<br>(0.68) | 0.77<br>(0.86) | 0.57<br>(0.74) | 0.40<br>(0.63)                                              | 0.60<br>(0.77) | 0.73<br>(0.86) | 0.58<br>(0.76) |
| T5        | Spraying of Imidacloprid 17.8 SL 0.2 ml/lit of water at 15 days germination, spraying of NSE 5 % at starbud stage and cypermethrin 10 % EC @ 1.5ml/lit at flowering stage of crop                              | 0.63<br>(0.79)                                          | 0.67<br>(0.81) | 0.87<br>(0.90) | 0.69<br>(0.82) | 0.43<br>(0.66)                                              | 0.53<br>(0.73) | 0.70<br>(0.84) | 0.56<br>(0.74) |
| T6        | Seed treatment with Thiamethoxam 30FS @ 3 ml/kg seed, spraying of cypermethrin 10 % EC @ 1.5ml/lit at starbud and NSE 5 % at flowering stage of crop.                                                          | 0.43<br>(0.65)                                          | 0.57<br>(0.75) | 0.80<br>(0.89) | 0.60<br>(0.77) | 0.63<br>(0.79)                                              | 0.70<br>(0.84) | 0.90<br>(0.95) | 0.74<br>(0.86) |
| T7        | Untreated control                                                                                                                                                                                              | 1.57<br>(1.25)                                          | 1.83<br>(1.35) | 1.43<br>(1.19) | 1.64<br>(1.23) | 1.93<br>(1.39)                                              | 1.17<br>(1.07) | 1.30<br>(1.14) | 1.47<br>(1.21) |
|           | SE (m)+                                                                                                                                                                                                        | 0.05                                                    | 0.04           | 0.08           | 0.05           | 0.24                                                        | 0.07           | 0.05           | 0.05           |
|           | CD at 5 %                                                                                                                                                                                                      | 0.15                                                    | 0.13           | 0.24           | 0.16           | 0.73                                                        | 0.21           | 0.17           | 0.16           |
|           | CV (%)                                                                                                                                                                                                         | 10.87                                                   | 8.71           | 15.26          | 10.54          | 10.68                                                       | 15.23          | 10.53          | 10.19          |

\* Figures given in the parenthesis are square root transformed values



Table 3. Effect of different treatments against ladybird beetle

| Treatment                                                                                                                                                                                                         | Ladybird beetle at starbud stage |               |               |              |  | Ladybird beetle at flowering stage |               |               |              |  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|---------------|---------------|--------------|--|------------------------------------|---------------|---------------|--------------|--|
|                                                                                                                                                                                                                   | Adult/plant                      |               |               |              |  | Adult/plant                        |               |               |              |  |
|                                                                                                                                                                                                                   | 21-22                            | 22-23         | 23-24         | Pooled       |  | 21-22                              | 22-23         | 23-24         | Pooled       |  |
| T1 Seed treatment with Imidacloprid 48% FS @ 5 ml/kg seed, application of Yellow sticky trap 1/18.9 m <sup>2</sup> at 15 days after germination of crop, spraying of NSE 5% at star bud initiation stage of crop. | 1.2<br>(1.11)                    | 1.1<br>(1.03) | 1.0<br>(1.00) | 1.1<br>(1.0) |  | 1.4<br>(1.18)                      | 1.5<br>(1.21) | 1.4<br>(1.19) | 1.4<br>(1.2) |  |
| T2 Spraying of NSE 5% at 15 days after germination of crop, spraying of cypermethrin 10 % EC @1.5ml/lit at starbud and flowering stage of crop                                                                    | 1.0<br>(1.00)                    | 0.9<br>(0.93) | 0.9<br>(0.93) | 0.9<br>(1.0) |  | 1.1<br>(1.03)                      | 1.0<br>(1.00) | 1.1<br>(1.06) | 1.1<br>(1.0) |  |
| T3 Seed treatment with Imidacloprid 48% FS @ 5 ml/kg seed, spraying of NSE 5 % at starbud and flowering stage of crop                                                                                             | 1.5<br>(1.24)                    | 1.3<br>(1.12) | 1.2<br>(1.09) | 1.3<br>(1.2) |  | 1.7<br>(1.29)                      | 1.5<br>(1.21) | 1.4<br>(1.18) | 1.5<br>(1.2) |  |
| T4 Seed treatment with Imidacloprid 48% FS @ 5 ml/kg seed, spraying of cypermethrin 10 % EC @ 1.5ml/lit at starbud and flowering stage of crop                                                                    | 1.0<br>(1.00)                    | 0.9<br>(0.93) | 1.0<br>(1.00) | 1.0<br>(1.0) |  | 1.0<br>(0.98)                      | 0.9<br>(0.96) | 1.0<br>(1.01) | 1.0<br>(1.0) |  |
| T5 Spraying of Imidacloprid 17.8 SL 0.2 ml/lit of water at 15 days germination, spraying of NSE 5 % at starbud stage and cypermethrin 10 % EC @ 1.5ml/lit at flowering stage of crop                              | 1.4<br>(1.16)                    | 1.1<br>(1.05) | 1.1<br>(1.04) | 1.2<br>(1.1) |  | 1.0<br>(1.01)                      | 1.0<br>(0.98) | 1.0<br>(1.02) | 1.0<br>(1.0) |  |
| T6 Seed treatment with Thiamethoxam 30FS @ 3 ml/kg seed, spraying of cypermethrin 10 % EC @ 1.5ml/lit at starbud and NSE 5 % at flowering stage of crop.                                                          | 1.0<br>(0.98)                    | 1.0<br>(1.00) | 1.1<br>(1.05) | 1.0<br>(1.0) |  | 1.5<br>(1.20)                      | 1.4<br>(1.16) | 1.3<br>(1.14) | 1.4<br>(1.2) |  |
| T7 Untreated control                                                                                                                                                                                              | 1.4<br>(1.19)                    | 1.3<br>(1.14) | 1.2<br>(1.11) | 1.3<br>(1.1) |  | 1.7<br>(1.30)                      | 1.6<br>(1.26) | 1.6<br>(1.25) | 1.6<br>(1.3) |  |
| SE (m)+                                                                                                                                                                                                           | 0.10                             | 0.05          | 0.04          | 0.06         |  | 0.07                               | 0.06          | 0.05          | 0.06         |  |
| CD at 5 %                                                                                                                                                                                                         | 0.33                             | 0.15          | -             | -            |  | 0.20                               | 0.19          | -             | -            |  |
| CV (%)                                                                                                                                                                                                            | 15.10                            | 8.11          | -             | -            |  | 10.00                              | 9.83          | -             | -            |  |

\* Figures given in the parenthesis are square root transformed values

**Table 4. Effect of different treatments on seed yield and ICBR**

| Treatment                                                                                                                                                                                                         | Yield kg ha <sup>-1</sup> |       |        |        | ICBR |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|-------|--------|--------|------|
|                                                                                                                                                                                                                   | 21-22                     | 22-23 | 23-24  | Pooled |      |
| T1 Seed treatment with Imidacloprid 48% FS @ 5 ml/kg seed, application of Yellow sticky trap 1/18.9 m <sup>2</sup> at 15 days after germination of crop, spraying of NSE 5% at star bud initiation stage of crop. | 1481                      | 1083  | 1368   | 1311   | 4.06 |
| T2 Spraying of NSE 5% at 15 days after germination of crop, spraying of cypermethrin 10 % EC @ 1.5ml/lit at starbud and flowering stage of crop                                                                   | 1595                      | 1254  | 1481   | 1443   | 3.91 |
| T3 Seed treatment with Imidacloprid 48% FS @ 5 ml/kg seed, spraying of NSE 5 % at starbud and flowering stage of crop                                                                                             | 1510                      | 1197  | 1311   | 1339   | 3.01 |
| T4 Seed treatment with Imidacloprid 48% FS @ 5 ml/kg seed, spraying of cypermethrin 10 % EC @ 1.5ml/lit at starbud and flowering stage of crop                                                                    | 1567                      | 1254  | 1339   | 1377   | 5.62 |
| T5 Spraying of Imidacloprid 17.8 SL 0.2 ml/lit of water at 15 days germination, spraying of NSE 5 % at starbud stage and cypermethrin 10 % EC @ 1.5ml/lit at flowering stage of crop                              | 1538                      | 1168  | 1453   | 1387   | 3.41 |
| T6 Seed treatment with Thiamethoxam 30FS @ 3 ml/kg seed, spraying of cypermethrin 10 % EC @ 1.5ml/lit at starbud and NSE 5 % at flowering stage of crop.                                                          | 1567                      | 1225  | 1425   | 1406   | 4.72 |
| T7 Untreated control                                                                                                                                                                                              | 1197                      | 997   | 969    | 1054   | 0.00 |
| SE (m)+                                                                                                                                                                                                           | 121.40                    | 86.0  | 102.25 | 85.36  |      |
| CD at 5 %                                                                                                                                                                                                         | 374.20                    | 265.0 | 315.07 | 263.01 |      |
| CV (%)                                                                                                                                                                                                            | 14.08                     | 12.76 | 13.27  | 11.10  | -    |

contact, including through its tracheal system. The compound gets in the way of information transfer between nerve cells by interfering with nicotinic acetylcholine receptors in the central nervous system and eventually paralyzing the muscles of the insects. In this way, both insecticides provide protection to crop from sucking pests. Through observation, it is concluded that, both insecticides as a seed treatment provide protection to crop from sucking pests up to 30 days after germination.

Bharat Singh *et al.* (2019) reported that, Quinalphos 25% EC showed maximum efficacy in terms of larval population reduction (62.37% and 63.90%) against *S. litura* on cauliflowe followed by neem oil (58.26% and 57.89%), neem seed kernel extract (54.83%

and 55.24%), neem leaf extract (50.70% and 51.42%). Among the neem biopesticides, neem oil showed maximum reduction in larval population of *S. litura* under field condition. Neem seed kernel and leaf extract showed results at par. Usama Saleem *et al.* (2024) evaluated the toxicity potential of native plant extracts (*Azadirachta indica*, *Eucalyptus globulus*, *Parthenium hysterophorus*, *Cannabis sativa*, *Citrullus colocynthis*, *Nicotiana tabacum*) against *S. frugiperda*. Results showed that all plant extracts were found to be effective against *S. frugiperda*. The key compounds identified in neem leaf extract and kortuma fruit extract are predominantly biologically active molecules. Many of them were volatile compounds that belonged to different chemical categories,

such as fatty acids, hydrocarbons, esters, terpenoids, phenolic compounds, and amines. Terpenes exhibited a wide range of different biological activities, such as serving as insecticides and antifeedant. Cypermethrin, a synthetic pyrethroid insecticide, has demonstrated significant efficacy against *Helicoverpa armigera*, in sunflower crops. Jadhav *et al.* (2020) studied the bio-efficacy of indoxacarb 0.019 percent, emamectin benzoate 0.006 per cent, quinalphos 0.03 percent, chlorantraniliprole 0.024 per cent, cypermethrin 0.03 per cent and profenophos 0.06 percent against head borer, *Helicoverpa armigera* on sunflower, Emamectin benzoate 0.006 per cent found to be cost effective followed by cypermethrin 0.03 percent. Zereabruk Gebretsadkan *et al.* (2019) studied the efficacy of insecticides and crop critical stage for the management of chickpea pod borer (*Helicoverpa armigera*) they identified the podding stage of the chickpea is best application time. Cypermethrin 10 EC @ 300 and 450 ml acre<sup>-1</sup> was effective in controlling Bihar hairy and it provided the maximum benefit: cost ratio and recommended for the management of Bihar hairy caterpillar in sunflower (Sarwan Kumar and Rakesh Kumar Sharma, 2021).

Through this study it is proved that, the protecting the crop at critical stage through seed treatment at the time of sowing and application of insecticides at starbud and flowering stages in sunflower found economical and effective.

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## Pathogenic Variation and Fungitoxic Efficiency of Essential Oils against *Colletotrichum gloeosporioides*, causing Twig Blight and Stem End Rot of Nagpur Mandarin

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### ABSTRACT

Nagpur mandarin (Santra), predominantly cultivated in the Vidarbha region of Maharashtra, is affected by various biotic and abiotic stresses, including fungal infections at different stages of orchard growth. Diseases such as anthracnose, twig blight, and stem-end rot, leading to fruit drop, are primarily caused by *Colletotrichum* species. Samples showing typical symptoms of twig blight and stem-end rot were collected, and the pathogen was isolated from the infected twigs and fruits using the hyphal tip method. Based on symptomology, cultural, morphological, and microscopic observations, as well as the pathogenicity test the pathogen was identified as *Colletotrichum gloeosporioides*. The pathogen isolated from twig blight and stem end rot of fruits was capable of producing symptoms on Nagpur mandarin leaves and twigs and varied in cultural characteristics and aggressiveness. Isolates showed cultural, morphological, and pathological variability. Furthermore, the *in vitro* effectiveness of different essential oils against *Colletotrichum gloeosporioides* at 0.5 and 1.0% doses was investigated. The essential oils Citronella, Lemongrass, Tea tree, and Garlic were found to be the most effective at completely inhibiting the growth of the tested pathogen.

Nagpur Santra (Mandarin) is grown predominantly in Central India's Satpura hills (Vidarbha region), Darjeeling (West Bengal) and Coorg (Karnataka). Nagpur mandarin is considered as one of the best in the world. The yield of this fruit crop in India's central and western areas is increasing year after year. *Colletotrichum gloeosporioides* infects about 470 different host genera but some economic important crops such as: avocado, mango, citrus, papaya, cashews, pepper, beans, cassava, cotton, cow-pea, cucumber, eggplant, green gram, onion, pumpkin, sorghum, soybean, tomato, watermelon, wheat, yam, cucurbit, and spinach (Sharma and Kulshrestha 2015). Amongst them mango anthracnose and citrus pre-harvest fruit drop is very important from Indian prospective. Twenty-four per cent of the losses have been observed by pre-harvest quiescent infection of *Colletotrichum gloeosporioides* and *Botryodiplodia theobromae* in the form of stem end rot and anthracnose in citrus (Naqvi, 1993). The pre-harvest fruit drop in Kinnow mandarin result in direct economic losses. This drop has been estimated to be 30-76 per cent of the crop load (Arora et al. 2008). Understanding the nature of the pathogen is greatly aided by research on the morphological, pathological, and cultural variations of the pathogen.

There is growing interest in the use of non-toxic alternative antimicrobial agents. One such alternative is to use natural plant products with antifungal activity, which are more environmentally friendly and widely accepted by the general public. Essential oils are commonly used among plant extracts due to their broad spectrum antimicrobial activity, low toxicity and low resistance effects in target microorganisms. Essential oils from aromatic plants with antimicrobial activity to control plant pathogens and toxin-producing moulds are of great interest (Soliman and Badeea 2002).

The current study aimed to investigate the fungicide inhibition and antifungal potential of selected essential oils against pathogen, *Colletotrichum gloeosporioides*, isolated from mandarin showing twig blight disease symptoms, *in vitro*, with the view of using the selected novel combi fungicides and essential *in vivo* for the control of related diseases in the future.

### MATERIAL AND METHODS

#### Collection of disease sample

Infected plant samples of mandarin were collected from the field of AICRP on Fruits scheme, field of Department of Fruit Science, Dr. PDKV campus and Anbhora village Tq. Murtijapur Dist. Akola (Table 1).

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**Table 1. Collection of disease sample**

| SN | Place                                      | Location                                                  | Crop            | Isolate Designated |
|----|--------------------------------------------|-----------------------------------------------------------|-----------------|--------------------|
| 1  | AICRP on Fruits scheme field               | Lat.20.70298 <sup>0</sup><br>Long.77.06613 <sup>0</sup>   | Nagpur Mandarin | SERCg1             |
| 2  | Department of Fruit Science field          | Lat.20.70497 <sup>0</sup><br>Long.77.02434 <sup>0</sup>   | Nagpur Mandarin | TblCg2             |
| 3  | Anbhora village Tq. Murtijapur Dist. Akola | Lat.20.710208 <sup>0</sup><br>Long.77.322287 <sup>0</sup> | Nagpur Mandarin | TblCg3             |

The infected samples of twigs and fruits were brought to the laboratory and thoroughly washed with sterile distilled water. To confirm the presence of pathogen, microscopic slides were performed from different samples of mandarin and also subjected for tissue isolation.

Culture was purified by following the hyphal tip method, and the cultures obtained were maintained on PDA medium slants by adopting subsequent sub-culturing at regular intervals as and when required. The detection of fungal pathogen involved in causing respective infected samples was resolute by conducting studies on its morphological and cultural features.

*Colletotrichum gloeosporioides* was identified by its hyaline and septate mycelium, conidia with rounded ends and an oil globule in the center, and the presence of acervuli with erect setae. Observations recorded during present investigations were matched with opinion of earlier report of Thaung (2008); Hyde *et al.* (2009) and Gautam (2014).

#### Pathogenicity test

A seven-day-old culture of *Colletotrichum gloeosporioides* isolates was used to prove the pathogenicity by applying Koch's postulates. Healthy-growing graft of Nagpur mandarin (eleven months old) were maintained, watered regularly, and kept in the shade net for further development. The healthy leaves and twigs of Nagpur mandarin grafts were washed with sterile distilled water and small wounds were made on the leaves and twigs by using a sterile needle. The inoculations were made by spraying a spore suspension ( $1 \times 10^6$  spores per ml) on the pricked leaves and twigs of Nagpur mandarin seedlings.

Un-inoculated graft sprayed with sterilized water served as a control. After inoculation, the seedlings polybags (both inoculated and un-inoculated) were incubated in the shed net. Inoculated plants were sprayed twice a day with distilled water to maintain humidity. Observations were recorded every day for the appearance and development of symptoms. Observation on the incidence leaf spots and twig drying symptoms were noticed from 10<sup>th</sup>-15<sup>th</sup> days after inoculation. Pathogenic variation was observed during the experimentation. When artificially inoculated leaves expressed symptoms, re-isolation of the pathogen was done and compared with the original culture. Artificially infected leaves of Nagpur mandarin were used for re-isolation of the test pathogens. The cultures obtained were compared for growth with original cultures obtained from naturally diseased specimens to confirm their identity and pathogenicity. Cultural variation in isolated culture was observed on PDA medium as basal medium.

#### Evaluation of plant essential oils

Eight plant essential oils with different concentrations were evaluated by employing a poisoned food technique (Nene and Thapliyal, 1993 and Samithri *et al.* 2020) against *Colletotrichum gloeosporioides*.

The test pathogens were grown on a PDA medium in Petri plates for ten days before setting the experiment. Potato dextrose agar was prepared and distributed at the rate of 100 ml in a 250 ml conical flask; autoclaved at 1.05 kg/cm<sup>2</sup> for 15 minutes. The pure-grade essential oil in the selected concentrations was individually dispersed as an emulsion using Tween 80 (0.05%) and added to autoclaved potato dextrose agar immediately before pouring it into Petri dishes. A flask containing

poisoned medium was shaken well to have even and uniform distribution of essential oil. Twenty ml of poisoned medium was poured into each of the sterilized Petri plates and was allowed to solidify. These Petri plates were inoculated by pathogen separately. A 6 mm disc of test pathogen covered with germinated active fungal growth was placed at the center of the medium with the help of a sterilized cork borer. For this, a ten-day-old culture of test pathogens in Petri dishes on a sterilized PDA medium was used. To prevent test oils from leaking, Petri dishes were sealed with parafilm. Three replications for test pathogens and control i.e. without the addition of any essential oil were maintained. Petri plates were incubated at  $25 \pm 2^\circ\text{C}$  temperature in an inverted position. The whole procedure was carried out under aseptic conditions. The fungal colony's linear diameter (2 pairs, each pair at right angles to the other) was measured daily until the mycelium in the control completely filled the Petri plate. The experiment was conducted in Completely Randomized Design (CRD) with three replications. Percent inhibition of the test pathogen was calculated by applying the formula given by Vincent (1947) as follows.

$$\text{Percent mycelial growth inhibition} = (C - T) / C \times 100$$

Where,

C - mean colony diameter of the control sets and

T - mean colony diameter of treatment sets.

## RESULTS AND DISCUSSION

Naturally occurring disease specimens were collected from different locations and brought to the laboratory to identify the cause and subjected to standard tissue isolation method.

Diseased fruit samples of Nagpur mandarin with typical symptoms at the joint region in the form of light brown to brownish black colour lesion around fruit pedicel were collected from AICRP on Fruits scheme citrus

**Table 2. Collection of disease sample and pathogen association**

| SN | Place                             | Crop            | No. of bits<br>used for<br>isolation | No. of bits<br>yielded<br>fungi | Frequency<br>% | Designated<br>as |
|----|-----------------------------------|-----------------|--------------------------------------|---------------------------------|----------------|------------------|
| 1  | AICRP on Fruits scheme field      | Nagpur Mandarin | 10                                   | 08                              | 80.0           | SERCg1           |
| 2  | Department of Fruit Science field |                 | 10                                   | 07                              | 70.0           | TblCg2           |
| 3  | AnbhoraTq. Murtijapur Dist. Akola |                 | 10                                   | 07                              | 70.0           | TblCg3           |

orchards. Symptoms of same stem end rot have previously been documented by Anonymous (2004), Kumar and Garg (2012), and Pandey *et al.* (2019).

Furthermore, Singh (1971); Naqvi (1993); Anonymous (2004) and Mahiout *et al.* (2018) observed typical twig withering from the top and middle regions of the tree with silvery grey white colour symptoms of twig blight. *C. gloeosporioides* has been identified as a pathogen responsible for the diseases twig blight, anthracnose, stem end rot, fruit drop, and post-harvest spoiling on citrus by Naqvi (1999) and Riolo *et al.* (2021).

Using the tissue isolation method on a PDA medium, pathogens are isolated from respective diseased affected plants parts. Fungi were found to be associated with the diseased samples. *Colletotrichum gloeosporioides* were predominantly recovered from tissue isolation methods in collected specimens. It is seen that the majority of bits yielded the fungus *C. gloeosporioides* in the range of 70.0 to 80.0% (Table 2). The isolated fungi were brought in pure culture (SERCg1, TblCg2, and TblCg3) using the hyphal tip method and their cultural and microscopic characteristics were observed.

Morphological differences between isolates were investigated in a seven-day-old culture. Colony colour, mycelial growth, and the size and shape of conidia and acervuli were all studied using a light microscope at 45X magnification.

Under laboratory conditions, the diversity of culture characteristics of *C. gloeosporioides* isolated from three different places was seen on PDA solid media. The data are presented in Table 3.

On PDA medium, maximum radial mycelial growth (90 mm) was obtained in seven days. There were notable differences in colony and shape amongst *C.*

**Table 3. Growth characteristics of *C. gloeosporioides* isolates on PDA media**

| SN | Isolate | Colony growth characters                                                                                                                          | Mycelium                      | Conidia                                                                                                      | Setae   |
|----|---------|---------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|--------------------------------------------------------------------------------------------------------------|---------|
| 1  | SERCg1  | Superior growth, consistently felty with grayish white mycelium growth, diurnal zonations                                                         | Hyaline, septate and branched | Hyaline, cylindrical to oblong, one celled, having oil globules at center, with size 7.72 x 3.50 µm          | Present |
| 2  | TblCg2  | Creamy white, circular, slightly, and raised                                                                                                      | Hyaline, septate and branched | Hyaline, one celled, straight, cylindrical and obtuse at apices, with size 8.22 x 3.58 µm                    | Present |
| 3  | TblCg3  | Aerial mycelium even, felted mat with salmon pink conidial pustules evident at the center with white circular and entire margin, diurnal zonation | Hyaline, septate and branched | Hyaline, cylindrical or dumbbell shaped, one celled, having oil globules at center, with size 8.30 x 3.10 µm | Present |

*gloeosporioides* isolates. The coloration of the colonies varied among the isolates as well. All isolates' mycelium was initially hyaline, creamy white to light grey, and then changed light brown to black in the center, with red salmon round and creamy white with dark grey edges. Mycelial unique traits were originally thin, filamentous, and extensively branching until thickening to be observed in compact colonies with thick whole edges. This shows that there is significant variance among the isolates under study. This shows that there is significant variance among the isolates under study. TblCg2 was creamy white, round, slightly elevated, and felty, while SERCg1 was constantly felty with greyish white mycelium development with diurnal zonations. TblCg3 isolates had an even, felted mat with salmon pink conidial pustules in the center and a white circular and whole edge, as well as diurnal zonations. Within the isolates, conidial variation was also detected (Table 3).

In present investigations the isolation frequency was recorded in the range of 70 to 80% in Nagpur mandarin disease samples collected from different locations. In the same way, Ingle et al. (2008) found a *C. gloeosporioides* isolation frequency of 40 to 65 per cent from the diseased fruits of ambia bahar in Nagpur mandarin. Singh and Kapoor (1971) obtained six isolates of *C. gloeosporioides* as the predominant pathogen from disease twigs from three citrus hosts. *C. gloeosporioides*

has been associated with stem end rot dropped fruits of citrus and twig blight, according to Kale and Raut (1995), Naqvi (1999) and Ramos *et al.* (2016) and Mahiout *et al.* (2018). These reports corroborate the finding of present investigation.

The characteristics of *Colletotrichum gloeosporioides* matched with those reported by Carrington et al. (2002); Thaung (2008); Hyde *et al.* (2009) and Gautam (2014). Carrington *et al.* (2002) investigated the colony characteristics and conidial morphology of *C. gloeosporioides*, a citrus pathogen that causes premature fruit drop. On PDA, they reported that the majority of the isolates exhibited dense and white-grayish colony with aerial mycelium and dark brown to black conidial masses. Conidial lengths and breadths ranged from 7.5 to 17.5 x 2.5 to 3.75 µm, with hyaline, straight and rounded conidia at both ends. The isolated fungi (*Colletotrichum gloeosporioides*) were brought in pure culture by hyphal tip method and the pathogenic potential of the isolated fungi was tested against Nagpur mandarin in pot culture method.

Observations on symptoms produced by respective isolates in Nagpur mandarin seedlings were recorded and presented Table 4 during the pathogenicity test. After ten days of incubation, the wounded leaves began to show symptoms of infection, including chlorosis, necrotic blotches on the leaves, blight, twigs blight, shoot,

and branch dieback in Nagpur mandarin which exhibited symptoms similar to the symptoms of twig blight collected from field.

Initially, wounded leaves revealed only small brown necrotic lesions with a chlorotic halo, extending to the underside of the leaf and enlarge spots irregularly. SERCg1 isolates produced 2.20 cm lesions (spread faster and created greater lesions) in wounded leaves compared to the other two isolates (Table 4). Controls had no symptoms noted. Koch's postulates were fulfilled by the successful isolation of *C. gloeosporioides* and isolates identical to the inoculated ones from all of the inoculated symptomatic Nagpur mandarin branches and leaves.

**Table 4. Pathogenicity test of respective isolates**

| SN | Isolate name | Days to produce symptoms | Lesion size on leaves (cm) |
|----|--------------|--------------------------|----------------------------|
| 1  | SERCg1       | 10-12                    | 2.20                       |
| 2  | TblCg2       | 12-15                    | 1.80                       |
| 3  | TblCg3       | 11-14                    | 1.10                       |
| 4  | Control      | —                        | —                          |

The fungal identity was confirmed based on morphological features and published literature and it is evident that the *C. gloeosporioides* was found pathogenic to Nagpur mandarin causing twig blight, leaf spot and stem end rot fruit drop.

The current pathogenicity test revealed variation in lesion size. Similarly, Figueiredo *et al.* (2012) investigated the pathogenicity of *C. gloeosporioides* in detached cashew leaves and found that Cg2 and Cg3 isolates were the most aggressive. In addition, Rattanakreetakul *et al.* (2023) observed variation and aggressiveness in *Colletotrichum* isolates during a pathogenicity test mango leaves. During the pathogenicity test, Agostini *et al.* (1992) indicated that pathogen *C. gloeosporioides* derived from citrus wither tip, post bloom fruit drop, and anthracnose exhibited symptoms on leaves and petals as necrotic patches. This investigation confirmed that *C. gloeosporioides* isolates derived from distinct disease-affected plant parts samples were capable of producing all of the disease's symptoms observed in the field.

Under greenhouse conditions, Goes and Kimati (1997) investigated the pathogenicity of *C. acutatum* and *C. gloeosporioides* on citrus and reported the typical symptoms in the form of orange necrotic lesions on a twig, leaves, and post-bloom fruit drop of citrus. Similar symptoms were noticed in the present investigation of the pathogenicity test. Due to the aggressiveness of isolate SERCg1, the same isolate was used for the sensitivity test and essential oil efficacy.

#### Evaluation of plant essential oils

Plant essential oils were tested *in vitro* against *C. gloeosporioides*, using the poisoned food technique. Results presented in Table 5 revealed that the eight tested plant essential oils had excellent broad-spectrum antifungal activity against the tested pathogen, which was found to reduce with increased doses of the essential oils examined. Among the essential oils at 0.5% concentration, Eucalyptus oil, Citronella oil, Lemongrass oil, Tea tree oil, and Garlic oil showed no growth (0.00 mm) of *C. gloeosporioides*, proving to be greatly superior. Eucalyptus oil (56.83 mm) and neem oil (72.50 mm) came next in order of merit. The essential oils Karanj and Lime exhibited no inhibiting impact.

Essential oils suppressed *C. gloeosporioides* growth at 1 per cent concentration, with radial mycelial growth ranging from 00.00 mm (Citronella oil, Lemongrass oil, Tea tree oil, and Garlic oil) to 90.0 mm (Karanj oil and Lime oil), compared to 90.00 mm in the untreated control. Citronella oil, Lemongrass oil, Tea tree oil, and Garlic oil, were shown to be the most efficient in preventing the pathogen with the least mycelial growth (00.00 mm). Following this, Eucalyptus oil (45.83 mm) and Neem oil (53.33 mm) were applied. Both Karanj oil and Lime oil were shown to be ineffective, with maximum mycelial growth of 90.00 mm observed in both oils (Table 5). The antifungal properties of essential oils were dose-dependent, with larger dosages demonstrating stronger antifungal activity.

*Colletotrichum gloeosporioides* mycelial growth suppression ranged from 19.44% (Neem oil) to 100% (Citronella oil, Lemongrass oil, Tea tree oil, and Garlic oil) at 0.5% concentration. Citronella oil, Lemongrass oil, Tea tree oil, and Garlic oil totally inhibited pathogen



**Table 5. Effect of essential oils on radial mycelial growth of *C. gloeosporioides* 10 DAI**

| S.N. | Essential Oil  | Concn. 0.5 (%)             |                     | Concn. 1 (%)               |                     |
|------|----------------|----------------------------|---------------------|----------------------------|---------------------|
|      |                | Radial mycelial growth(mm) | % Growth inhibition | Radial mycelial growth(mm) | % Growth inhibition |
| 1.   | Eucalyptus oil | 56.83                      | 36.85               | 45.83                      | 49.07               |
| 2.   | Citronella oil | 0.00                       | 100.0               | 0.00                       | 100.0               |
| 3.   | Neem oil       | 72.50                      | 19.44               | 53.33                      | 40.74               |
| 4.   | Karanj oil     | 90.00                      | 00.00               | 90.00                      | 00.00               |
| 5.   | Lemongrass oil | 0.00                       | 100.0               | 0.00                       | 100.0               |
| 6.   | Tea tree oil   | 0.00                       | 100.0               | 0.00                       | 100.0               |
| 7.   | Lime oil       | 90.00                      | 00.00               | 90.00                      | 00.00               |
| 8.   | Garlic oil     | 0.00                       | 100.0               | 0.00                       | 100.0               |
| 9.   | Control        | 90.00                      | -                   | 90.00                      | -                   |
|      | Test           | Sig.                       |                     | Sig.                       |                     |
|      | SE (m) ±       | 0.03                       |                     | 0.42                       |                     |
|      | CD at 5%       | 1.26                       |                     | 1.73                       |                     |

mycelial development, with Eucalyptus oil ranking second (36.85%). Karanj and Lime oils were shown to be ineffective, with 0.0% mycelial inhibition of pathogens observed. At 1.0% concentrations, the essential oils Eucalyptus oil and Neem oil inhibited less than 50% of *C. gloeosporioides* mycelial development, however Karanj and Lime oil did not affect the growth of the test pathogen even at 1% concentrations and their effect was found not significant.

Citronella oil, Lemongrass oil, Tea tree oil, and Garlic oil were the most effective at inhibiting growth, followed by Eucalyptus oil. This investigation shows that essential oils like as Citronella oil, Lemongrass oil, Tea tree oil, and Garlic oil may possess a strong toxic component that directly impacts the growth of *C. gloeosporioides*, the causal agent of Nagpur mandarin twig blight and stem end rot fruit drop.

According to the literature, the mechanisms of action of essential oils against pathogenic fungus are diverse. Wijesekara *et al.* (1997) revealed that antifungal essential oils inhibit hyphal development while also causing lysis and cytoplasmic evacuation in fungus. According to Lagrouh *et al.* (2017), essential oils and plant extracts have six distinct antifungal mechanisms, which are as follows: i) interfering with the formation of

fungal cell walls; ii) disrupting the cell membrane by inhibiting ergosterol synthesis; iii) affecting fungal mitochondria by inhibiting mitochondrial electron transport; iv) inhibiting cell division; v) interfering with RNA or DNA synthesis and/or inhibiting protein synthesis; and vi) inhibiting efflux pumps. Essential oils often inhibit fungal growth by preventing hyphal growth and sporulation, interfering with nutrient uptake and metabolism, disrupting plasma membranes, disorganizing mitochondrial structure, and interfering with respiratory enzymatic reactions of the mitochondrial membrane (Patel and Jasrai, 2011).

Previously, researchers reported on the impact of several essential oils on *Colletotrichum gloeosporioides*. Pol *et al.* (2023) observed that essential oils Citronella, Lemongrass, and Garlic oil at concentrations of 0.1, 0.5, and 1% were the most effective against *C. gloeosporioides*, an incitant of citrus twig blight, producing 100% inhibition at the tested concentrations.

In the current study, we found that the suppression of growth was dosage dependent on the concentration of essential oils. In almost all cases, the inhibitory effects of essential oils increase with increasing concentration, supporting recent findings by Palhano *et*

al. (2004) who indicated that mycelial development of the tested fungi was more sensitive to high citral concentrations. The essential oil concentrations inhibited *C. gloeosporioides* mycelial development differently. Variations in essential oil potency may be influenced by the chemical composition of the oil, oil concentrations, isolate variability, and experimental circumstances.

### CONCLUSION

By confirming Koch's postulates, the pathogen was identified as *Colletotrichum gloeosporioides*, which was isolated from Nagpur mandarin twig blight and stem end rot fruit samples. Isolates showed cultural, morphological, and pathological variability. When different essential oils were examined *in vitro* for their ability to prevent the growth of *C. gloeosporioides*, it was found that Citronella, Lemongrass, Tea Tree, and Garlic essential oils were the most effective. These oils can be used in place of chemical fungicides or in the absence of them because they are natural and non-toxic to humans. However, *in vivo* studies should be conducted to determine the technique of application.

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## Holistic Approach To Restore The Growth and Yield of Declining Mandarin Orchards Through INM

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### ABSTRACT

Nagpur mandarin is the major crop of Vidarbha region. Old aged senile orchard is one of the causes for low productivity. To find out an effective Integrated Nutrient Management technology for restoring yield and growth of old and senile mandarin orchards, an experiment was conducted during 2020-21 and 2021-22 at the ICAR-AICRP (F) Akola. The experiment was laid out in RBD comprised four treatments, where in a holistic approach for nutrition management was made to rejuvenate senile orchard and 'was replicated four times. The observations on growth, yield and fruit quality attributes were recorded. The results obtained were consistent over the two years and pooled data investigation revealed that soil application of 25 kg FYM + 5 kg Neem cake + multiple microbial cultures of NRCC (*T. harzianum*, *Pseudomonas fluorescens* and *Azotobacter/ Azospirillum*) + 50 per cent RDF including FeSO<sub>4</sub>, MnSO<sub>4</sub> and ZnSO<sub>4</sub> (200 g plant<sup>-1</sup> each) as foliar application showed better vegetative growth, yield and quality attributes of Nagpur mandarin

Citrus constitutes one of the foremost global fruit crops. Globally, India contributes an annual production of 14.58 million metric tonnes of citrus fruits cultivated across an area of 1,114.45 thousand hectares, reflecting a mean productivity rate of 13.09 tonnes per hectare (Ministry of Agriculture and Farmers Welfare, Government of India, 2025). Within the citrus taxa, mandarin oranges - specifically the Kinnow variant in northern regions, Nagpur mandarin in western zones, and Khasi mandarin in the northeast - occupy the largest cultivation area, followed sequentially by sweet orange varieties.

However, "mandarin decline" presents a critical impediment across the majority of Indian orchards. Following a decade to twelve years of optimal vegetative growth, affected trees exhibit progressive degeneration characterized by reduced vigor and diminished productivity. Consequently, agricultural producers incur substantial economic losses. This decline is multifactorial, driven by an array of biotic and abiotic constraints. Among these, low soil nutrient availability and plant malnutrition are identified as primary drivers of citrus decline and suppressed yields.

Historically, citrus cultivation has relied heavily on synthetic chemical fertilizers. However, these inputs exert deleterious effects on fruit quality and impose

adverse environmental impacts on soil and aquatic ecosystems. To mitigate these issues, the integrated application of organic manures, biofertilizers, and chemical fertilizers offers a strategic approach to rejuvenating senescent mandarin orchards, thereby enhancing fruit yield and quality metrics. Prior research demonstrates that combining organic manures with inorganic NPK treatments significantly enhances the leaf nutrient status of Khasi mandarin, subsequently optimizing fruit dimensions, weight, and overall yield (Prasad & Singhania, 1989; Mukherjee *et al.*, 1991). Given the escalating cost of synthetic fertilizers, periodic supply deficits, and the critical need for agricultural sustainability, minimizing reliance on exclusive chemical inputs is imperative. Consequently, optimizing a suitable integration of diverse plant nutrient sources—namely chemical fertilizers, organic manures, and biofertilizers—remains essential.

Based on these considerations, the present investigation was initiated to evaluate integrated nutrient management protocols for mandarin (*Citrus reticulata*). The primary objective was to identify an optimal combination of nutrient sources capable of restoring productivity and vegetative growth in senescent and declining orchards.

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## MATERIAL AND METHODS

Field trials were carried out during two successive seasons (2020–21 and 2021–22) at the AICRP on Fruits, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, under the ICAR-AICRP(Fruits), IIHR, Bengaluru. The experimental field consisted of clay loam soil (pH 7.6) containing 202.00, 44.65, and 578.00 kg ha<sup>-1</sup> of available N, P and K, respectively. The experiment was laid out in a randomized block design (RBD) with four treatments and five replications. Evaluations were performed on 20-year-old Nagpur mandarin trees budded on Jamberi rootstock and planted at a spacing of 6 m × 6 m. Initially the trees were pruned as per the level of occurrence of die-back followed by the cut ends were applied with Bordeaux paste. As a nutrient management strategist following treatments were tried. The treatments were

- T<sub>1</sub> Soil application of 25 kg FYM+ 5kg Neem cake +100% RDF along with FeSO<sub>4</sub>, MnSO<sub>4</sub> and ZnSO<sub>4</sub> 200g /plant/year in three equal splits at the time of flower emergence.
- T<sub>2</sub> Soil application of 25 Kg FYM + 5 kg Neem cake + multiple microbial culture of NRCC (*T. harzianum*, *Pseudomonas fluroscens* and *Azotobacter/ Azospirillum*) + 50% RDF along with FeSO<sub>4</sub>, MnSO<sub>4</sub> and ZnSO<sub>4</sub> 100g each as soil application applied in two equal splits as pre and post-monsoon application and 50% RDF along with FeSO<sub>4</sub>, MnSO<sub>4</sub> and ZnSO<sub>4</sub> 100g each as foliar application applied in four equal splits (two each as pre and post-monsoon application).
- T<sub>3</sub> Soil application of 25 Kg FYM + 5 kg Neem cake + multiple microbial culture of NRCC (*T. harzianum*, *Pseudomonas fluroscens* and *Azotobacter/ Azospirillum*) + 50 % RDF along with FeSO<sub>4</sub>, MnSO<sub>4</sub> and ZnSO<sub>4</sub> 100g each as soil application applied in two equal splits as pre and post-monsoon application and 50 % RDF along with FeSO<sub>4</sub>, MnSO<sub>4</sub> and ZnSO<sub>4</sub> 100g each as foliar application applied in four equal splits two each as pre and post-monsoon application,
- T<sub>4</sub> Control: As per package of practice

Growth-attributing characteristics, specifically plant height and tree spread, were recorded and expressed as canopy volume  $CV = \pi r^2 h$  where h and r stand for tree height and canopy radius, respectively. Fruit samples were collected from plants across different treatments at maturity to analyze various physio- chemical characteristics. The weight of the selected fruits was recorded using a physical balance. Fruit yield data were then generated by multiplying the average fruit weight by the total number of fruits to determine the overall fruit yield (kg tree<sup>-1</sup>). Various fruit quality parameters - including juice content, total soluble solids (TSS), acidity, reducing sugars, total sugars, and ascorbic acid were determined according to standard AOAC (1990) methods.

## RESULTS AND DISCUSSION

The results remained consistent across experimental years and treatments, indicating that the integrated application of organic manure, inorganic fertilizers, micronutrients, and biofertilizers on declining mandarin trees significantly enhanced vegetative growth, fruit yield, yield attributes, juice content, and chemical composition compared to alternative treatments.

The pooled data (Table 1) revealed that treatment T<sub>2</sub> exhibited superior growth attributes, specifically a plant height of 3.99 m, an East-West (E-W) spread of 4.04 m, a North-South (N-S) spread of 4.18 m, and a canopy volume of 25.24 m<sup>3</sup>. Conversely, the lowest values for plant height and spread—resulting in the minimum canopy volume—were recorded in treatment T<sub>4</sub> (11.15 m<sup>3</sup>). This enhancement under T<sub>2</sub> may be attributed to the high nutrient and mineral density provided by combining inorganic and organic fertilizers with micronutrients, alongside the symbiotic effects of biofertilizers. Beyond supplying essential nutrients, organic manures improve the water- and nutrient-holding capacity of the soil. Furthermore, biofertilizers and associated microbes fix atmospheric nitrogen and convert complex phosphatic and nitrogenous compounds into plant-available forms. This synergy ultimately improves nutrient use efficiency through the balanced application of organic and inorganic sources. These observations align with previous findings by Yadav *et al.* (2012) in guava, Lal and Dayal (2014) in acid lime, and Lenka *et al.* (2016) in banana.

Table 1. Effect of INM on growth characters of rejuvenated mandarins spaced at normal spacing

| Tr. No.        | Height(m) |         |             | Spread E-W (m) |         |             | Spread N-S (m) |         |             | Canopy volume (m <sup>3</sup> ) |         |             |
|----------------|-----------|---------|-------------|----------------|---------|-------------|----------------|---------|-------------|---------------------------------|---------|-------------|
|                | 2020-21   | 2021-22 | Pooled mean | 2020-21        | 2021-22 | Pooled mean | 2020-21        | 2021-22 | Pooled mean | 2020-21                         | 2021-22 | Pooled mean |
| T <sub>1</sub> | 3.63      | 3.70    | 3.67        | 3.54           | 3.75    | 3.64        | 3.67           | 3.89    | 3.78        | 17.58                           | 20.14   | 18.86       |
| T <sub>2</sub> | 3.95      | 4.03    | 3.99        | 3.92           | 4.16    | 4.04        | 4.06           | 4.30    | 4.18        | 23.70                           | 26.79   | 25.24       |
| T <sub>3</sub> | 3.86      | 3.94    | 3.90        | 3.67           | 3.89    | 3.78        | 3.86           | 4.09    | 3.98        | 20.88                           | 23.59   | 22.23       |
| T <sub>4</sub> | 3.05      | 3.11    | 3.08        | 3.02           | 3.20    | 3.11        | 3.01           | 3.19    | 3.10        | 10.39                           | 11.91   | 11.15       |
| SE (m) ±       | 0.14      | 0.12    | 0.11        | 0.07           | 0.08    | 0.07        | 0.07           | 0.08    | 0.07        | 1.47                            | 1.25    | 1.22        |
| CD at 5 %      | 0.42      | 0.39    | 0.37        | 0.21           | 0.26    | 0.21        | 0.22           | 0.24    | 0.21        | 4.52                            | 3.80    | 3.74        |
| CV %           | 8.31      | 7.73    | 7.22        | 4.32           | 4.96    | 4.18        | 4.29           | 4.45    | 3.93        | 18.08                           | 13.37   | 14.15       |

**Table 2. Effect of INM on yield characters of rejuvenated mandarins spaced at normal spacing**

| Treatment no   | No. of fruits |         |             | Av. Weight of fruit (g) |         |             | Weight of fruit (kg) |         |             |
|----------------|---------------|---------|-------------|-------------------------|---------|-------------|----------------------|---------|-------------|
|                | 2020-21       | 2021-22 | Pooled mean | 2020-21                 | 2021-22 | Pooled mean | 2020-21              | 2021-22 | Pooled mean |
| T <sub>1</sub> | 255.45        | 329.90  | 292.68      | 157.81                  | 143.92  | 150.87      | 40.28                | 44.54   | 42.41       |
| T <sub>2</sub> | 300.19        | 387.40  | 343.80      | 164.29                  | 141.95  | 153.12      | 49.45                | 51.81   | 50.63       |
| T <sub>3</sub> | 285.18        | 356.40  | 320.79      | 160.40                  | 146.29  | 153.34      | 46.24                | 48.92   | 47.58       |
| T <sub>4</sub> | 135.26        | 175.10  | 155.18      | 153.36                  | 139.86  | 146.61      | 20.76                | 22.96   | 21.86       |
| SE (m) ±       | 19.94         | 24.10   | 19.82       | 2.45                    | 2.10    | 1.10        | 3.56                 | 3.01    | 2.96        |
| CD at 5        | 61.45         | 74.31   | 61.09       | -                       | -       | -           | 10.96                | 9.22    | 9.08        |
| CV %           | 18.27         | 17.27   | 15.99       | 3.45                    | 4.83    | 1.55        | 20.29                | 15.91   | 16.29       |

**Table 3. Effect of INM on quality parameters of rejuvenated mandarins spaced at normal spacing**

| Treatment no   | Ave. vol. of fruit (ml) |         |             | Juice (%) |         |             | TSS (°B) |         |             |
|----------------|-------------------------|---------|-------------|-----------|---------|-------------|----------|---------|-------------|
|                | 2020-21                 | 2021-22 | Pooled mean | 2020-21   | 2021-22 | Pooled mean | 2020-21  | 2021-22 | Pooled mean |
| T <sub>1</sub> | 191.39                  | 174.19  | 182.79      | 45.10     | 43.29   | 44.20       | 11.42    | 11.31   | 11.36       |
| T <sub>2</sub> | 199.22                  | 171.78  | 185.50      | 48.73     | 46.78   | 47.76       | 10.61    | 10.50   | 10.56       |
| T <sub>3</sub> | 194.58                  | 177.01  | 185.79      | 46.99     | 45.11   | 46.05       | 10.81    | 10.70   | 10.76       |
| T <sub>4</sub> | 185.92                  | 169.24  | 177.58      | 40.52     | 40.12   | 40.32       | 11.50    | 11.85   | 11.67       |
| SE (m) ±       | 2.97                    | 3.74    | 3.02        | 1.26      | 0.52    | 0.80        | 0.03     | 0.03    | 0.03        |
| CD at 5        | -                       | -       | -           | 3.88      | 1.61    | 2.47        | -        | -       | -           |
| CV %           | 3.45                    | 4.84    | 3.73        | 6.21      | 2.67    | 3.99        | 2.00     | 2.23    | 1.91        |

The pooled data regarding yield attributes (Table 2) indicated that the number of fruits per tree (343.80) and total yield per tree (50.63 kg) peaked under T<sub>2</sub>, whereas the lowest values were observed in T<sub>4</sub> (155.18 fruits and 21.86 kg, respectively), followed sequentially by treatment T<sub>3</sub>. The increase in yield and associated traits is likely driven by the optimal supply of essential plant nutrients and growth hormones throughout the fruit-development period. This adequate supply facilitates the accumulation of photosynthates, thereby increasing fruit weight and overall yield within this Integrated Nutrient Management (INM) framework. Consistently, the inclusion of *Arbuscular mycorrhiza* (AM, 500 g plant<sup>-1</sup>), Phosphate Solubilizing Bacteria (PSB, 100 g plant<sup>-1</sup>), *Azospirillum* (Az, 100 g plant<sup>-1</sup>) and *Trichoderma harzianum* (Th, 100 g plant<sup>-1</sup>) alongside 75% of the Recommended Dose of Fertilizers (RDF) and 25% Organic Matter (OM) has been reported to enhance fruit yield in 'Kinnow' mandarin

budded on rough lemon in Ludhiana, Punjab, as well as in nucellar seedlings of 'Khasi' mandarin in Tinsukia, Assam (Medhi *et al.*, 2006).

Analysis of fruit quality (Table 3) showed that treatment T<sub>2</sub> yielded a significantly higher juice content (47.76%). This improvement in physical fruit characteristics, including fruit weight and juice content under INM strategies, can be directly correlated with enhanced assimilate accumulation within the plant tissues. These findings corroborate earlier reports by Verma (2010) in phalsa, Lal and Dayal (2014) in acid lime, and Lenka *et al.* (2016) in banana.

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## SHORT NOTE

### Effect of Foliar Nutrition on Growth and Yield of Mungbean Under Rainfed Condition

Grain legumes are generally characterized by the prolific flower production with an extremely low proportion of pod set. Up to 60-94% flowers and young pods abscise under a range of environmental conditions. This is due to the indeterminate growth habit of both vegetative and reproductive fruits, and the consequent competition between them. Moreover, many pods appear with unfilled seeds and grain yield does not increase as plants lacked the capacity for increasing assimilates supply owing to a rapid decline in  $N_2$  fixation following the onset of reproductive development. As a result, nitrogen is rapidly mobilized from the vegetative organs especially leaves to fulfill the demand of grain filling and ultimately lead to a decline in photosynthetic capacity. The decline in photosynthetic rates correlated well with the decline in leaf N and limit yield in legumes, for restricted C and N supply to the seed, may curtail the duration of seed filling period and from reproductive stage crop has often coincide with water stress. Salicylic acid (SA) is a phenolic phytohormone found in plants. It improves the plant growth and development, photosynthesis, transpiration, ion uptake and transport and increase the grain yield of pulses. It induced more flowering at 10 and 100 ppm levels (Anandhi and Ramanujan, 1997). Functionally, it induces flower production and promotes disease resistance. It is ortho-hydroxybenzoic acid and is a secondary metabolite acting as analogous of growth regulating substances. Salicylic acid application may alleviate the toxic effect of salt stress due to its significant role in stomatal regulation, growth yield and photosynthesis (Arfan *et al.*, 2007). Salicylic acid enhancing the endogenous antioxidant levels in plants which resulted in better protection against oxidative stress. Therefore, keeping in view the positive effect of salicylic acid on plants under moisture stress, the present study has aimed to understand the effectiveness of foliar application of Salicylic acid on plants growth, yield, physiological and biochemical characteristics of Mungbean (*Vigna radiata* L.) under moisture stress condition. Potassium maintains the turgor of the plant cell and regulates stomatal functions (Waraich *et al.*, 2011). Potassium application improved the water

content in the broad bean leaves and the plants showed more tolerance to drought stress (Thalooth *et al.*, 1990). Boron has positive effect on growth and development, nitrogen assimilation and root growth. Low level of boron causes negative impact on growth, narrow leave expansion, restricted root elongation and morphological features of greengram plant.

The present investigation was carried out at Sugarcane Research Unit under AICRP on MULLaRP, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during the year 2020. The experiment was laid out in Randomized Block Design comprising of seven treatments replicated thrice. The seeds of greengram varieties were sown separately on 20<sup>th</sup> June at 45x10 cm and harvested on 10<sup>th</sup> September 2020. The gross plot size was 4.5x4.0 m. The soil of the experimental site was medium-deep-black having pH 8.05, medium in available nitrogen and phosphorous and high in potassium. Foliar spray of nutrients was applied at flowering stage. All the fertilizers (20:40:30 kg\_NPK/ha) were applied in a single dose at the time of sowing as basal dose. Greengram crop received enough rainfall during vegetative stage (589.8 mm in 28 rainy days) and during reproductive stage 21.5 mm rainfall received in 2 rainy days.

Vegetative growth namely plant height (cm) and number of branches per plant did not influenced significantly with foliar spray of different foliar spray in greengram plants. However yield contributing character like grain weight per plant and pods per plant influenced significantly with different foliar spray where it was recorded higher with foliar spray of salicylic acid twice at flowering and 7 days after first spray closely followed by 2% urea + salicylic acid @ 75 ppm and 2% foliar spray of 19:19:19::NPK. 100-seed weight was found non-significant difference across all the treatments. Similarly, higher grain yield of greengram was recorded with foliar spray of salicylic acid @ 75 ppm at flowering stage and subsequent at 7 days after first spray. Jeyakumar *et al.*, (2008) reported that application of 125 ppm salicylic acid to blackgram increased seed yield. However, foliar

**Table 1: Effect of different foliar nutrients on yield attributes and grain yield of greengram**

| SN | Treatment                                             | Grain yield<br>(kg ha <sup>-1</sup> ) | Plant<br>height (cm) | Branches<br>plant <sup>-1</sup> | Pods<br>plant <sup>-1</sup> | Grain weight<br>plant <sup>-1</sup> (g) | 100-seed<br>weight(g) |
|----|-------------------------------------------------------|---------------------------------------|----------------------|---------------------------------|-----------------------------|-----------------------------------------|-----------------------|
| T1 | Control                                               | 804                                   | 65.0                 | 4.30                            | 11.0                        | 3.6                                     | 3.44                  |
| T2 | Urea spray 2%                                         | 905                                   | 70.1                 | 4.40                            | 12.2                        | 4.4                                     | 3.60                  |
| T3 | 19:19:19 NPK 2% spray                                 | 1039                                  | 68.3                 | 4.60                            | 15.0                        | 5.0                                     | 3.80                  |
| T4 | Pulse wonder 1% spray                                 | 958                                   | 71.3                 | 4.40                            | 13.6                        | 4.6                                     | 3.65                  |
| T5 | Salicylic acid 75 ppm and 7 days<br>after first spray | 1101                                  | 69.8                 | 5.20                            | 15.8                        | 5.3                                     | 3.95                  |
| T6 | Urea spray 2% + Salicylic acid<br>75 ppm spray        | 1060                                  | 74.8                 | 4.80                            | 15.2                        | 5.2                                     | 3.85                  |
| T7 | Boron 0.25 ppm spray                                  | 1021                                  | 74.2                 | 4.50                            | 14.8                        | 4.9                                     | 3.70                  |
|    | CD at 5%                                              | 150                                   | -                    | -                               | 2.13                        | 0.74                                    | -                     |

application of 2% urea + salicylic acid @ 75 ppm and foliar spray of 19:19:19::NPK @ 2% reported statistically equivalent increased in grain yield.

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