



# Efficacy of Fungicides, Botanicals and *Trichoderma viride* against Alternaria Leaf Spot of Okra (*Abelmoschus esculentus* L.)

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## Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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## ABSTRACT

Alternaria leaf spot, caused by *Alternaria alternata*, is a significant fungal disease affecting okra (*Abelmoschus esculentus* L.), leading to considerable yield losses. This study investigates the efficacy of selected fungicides, botanicals, and *Trichoderma viride* in managing this disease, while assessing their effects on plant growth and the economic viability of the treatments. A field experiment was conducted using a randomized block design with eight treatments, including fungicides like mancozeb and carbendazim, botanicals such as neem oil, garlic, ginger extracts, and the biocontrol agent *Trichoderma viride*. The results showed that the combination of mancozeb (12%) and carbendazim (63%) was the most effective, resulting in the tallest plant height of 89.32

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cm at 90 DAS, the lowest disease intensity of 8.10% at 45 DAS, and the highest yield of 14.81 t/ha. This treatment also resulted in the highest cost-benefit ratio of 1:2.94. Among the botanicals, neem oil and garlic extract showed moderate effectiveness in disease management. *Trichoderma viride* also contributed to significant disease suppression and plant growth enhancement. The cost-benefit analysis indicated that chemical fungicides provided the highest economic return, although botanicals and biocontrol agents offer sustainable alternatives. This study demonstrates that integrating chemical, biological, and botanical treatments can effectively manage *Alternaria* leaf spot in okra, with *Trichoderma viride* offering a promising eco-friendly option.

**Keywords:** *Abelmoschus esculentus*; *Alternaria* leaf spot; botanicals; carbendazim; mancozeb; *Trichoderma viride*; yield.

## 1. INTRODUCTION

Okra (*Abelmoschus esculentus* L. Moench), commonly referred to as lady's finger or bhindi, is a significant crop belonging to the Malvaceae family, thought to have originated in present-day Ethiopia. It flourishes in tropical and subtropical regions, particularly in nutrient-rich, well-drained sandy loam soils. Poor drainage and acidic conditions can hinder okra growth and nutrient absorption. For optimal seed germination, temperatures above 16°C are required. India ranks as the largest global producer of okra, with key cultivation areas in Maharashtra, Andhra Pradesh, and West Bengal (Choudhary and Panchouli, 2024; Iderawumi, 2018; Hurule, 2019). Okra is a low-calorie vegetable packed with essential minerals such as potassium, magnesium, calcium, and dietary fiber. Its pods are a rich source of phenolic compounds, including quercetin, hydroxycinnamic acids, and catechin oligomers, which provide various health benefits, such as lowering cholesterol and promoting heart health. Additionally, okra seeds are rich in protein, vitamins A and B, phosphorus, and iodine (Sarangi and Tiwari, 2023; Arain et al., 2012). Despite its benefits, okra cultivation is challenged by biotic and abiotic stresses, notably diseases like *Alternaria* leaf spot, which can reduce yields by up to 50%. The disease begins with brown spots on leaves that expand, causing necrosis and impairing photosynthesis. Effective control measures include fungicide use, crop rotation, and selecting resistant varieties. However, overuse of fungicides can lead to resistance and environmental damage. Eco-friendly alternatives, such as biocontrol agents like *Trichoderma*, along with neem and garlic extracts, help combat pathogens and strengthen plant defenses without the negative side effects of chemical treatments (Gao and Chen, 2020; Mishra and Dubey, 2018; Abbasi

et al., 2003; Rinaldi et al., 2019; Harman et al., 2004).

## 2. MATERIALS AND METHODS

The study was conducted at SHUATS during the 2023 *Kharif* season. The randomized block design (RBD) experiment was set in a semi-arid, subtropical climate with sandy loam soil in Prayagraj, which experiences temperatures ranging from 47°C in summer to 2.5°C in winter, and annual rainfall of 1013 mm.

Laboratory procedures involved cleaning borosilicate glassware, sterilizing equipment, and preparing Potato Dextrose Agar (PDA). Diseased okra leaves were surface sterilized, incubated on PDA medium, and examined microscopically to identify *Alternaria alternata*, which formed fast-growing, velvety colonies.

The experiment included eight treatments (e.g., copper oxychloride, neem oil, *Trichoderma viride*, mancozeb, ginger extract, garlic clove extract and a combination of mancozeb and carbendazim) and a control. Seeds of the VNR Super Green variety were sown in lines with 30 cm row spacing and growth parameters like plant height and disease intensity were measured. Disease intensity was calculated using Percent Disease Incidence (PDI) based on Wheeler's formula.

Disease intensity (%) =

$$\frac{\text{Sum of all numerical rating}}{\text{Number of leaves observed} \times \text{maximum disease grade}} \times 100$$

Statistical analysis using ANOVA was applied to determine the significance of treatment effects with hypotheses testing the differences between treatments and replications.

**Table 1. Detail of treatment**

Sr. No.	Treatment number	Treatment details
1	T <sub>0</sub>	Control (uncheck)
2	T <sub>1</sub>	Copper oxychloride 50% WP @ 4 ml/l (F.S)
3	T <sub>2</sub>	Neem oil 0.3% @ 3ml/l (F.S)
4	T <sub>3</sub>	<i>Trichoderma viride</i> 0.7% @ 7g/l (F.S)
5	T <sub>4</sub>	Mancozeb 75 % WP @ 0.25% (F.S)
6	T <sub>5</sub>	Ginger (Rhizome) extract @ 10% (F.S)
7	T <sub>6</sub>	Garlic clove extract @ 10% (F.S)
8	T <sub>7</sub>	Mancozeb 12% + Carbendazim @ 63 % (WP) 0.2 % (F.S)

WP- Wettable Powder  
F.S- Foliar Spray

**Table 2. Ratings/grade based on percent leaf area infected**

Rating scale	Symptoms description	Severity index
0	No symptoms on the leaves	0
1	Small, brown spots covering > 1 % or less of the leaf area.	0.1-1%
3	Lesions small, scattered, brown to black with concentric rings, covering 1- 10% of the leaf area.	1-10%
5	11-25% of the leaf area affected	11-25%
7	26-50% of leaf area affected with lesions enlarging, slightly sunken in the centre with concentric rings.	26-50%
9	Lesions enlarging (10 mm), coalescing to form bigger patches covering >50 % leaf area	>50%

(Mayee and Datar, 1986)

### 3. RESULTS AND DISCUSSION

The findings of the experiment titled “Effect of Selected Fungicides, Botanicals, and *Trichoderma viride* in Managing Alternaria Leaf Spot of Okra (*Abelmoschus esculentus* L.)” conducted at the Department of Plant Pathology, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, Uttar Pradesh, during the *Kharif* season of 2023. This study aimed to evaluate the efficacy of various

treatments in controlling Alternaria leaf spot disease. The experiment utilized a randomized block design (RBD), comparing the effectiveness of essential oils, bio-agents, and fungicides against a control plot. The VNR super green variety of okra was selected for cultivation, and disease intensity was recorded at regular intervals following the onset of symptoms. The impact of treatments on plant height at 30, 60, and 90 days after sowing (DAS) is summarized.

**Table 3. Effect of treatments on plant height (cm) at 30, 60 and 90 DAS**

Treatments	Plant Height (cm)		
	30 DAS	60 DAS	90 DAS
T <sub>0</sub> Control (untreated check)	19.72 <sup>f</sup>	34.04 <sup>f</sup>	69.98 <sup>f</sup>
T <sub>1</sub> Copper oxychloride 50% WP @ 4 ml/l (F.S)	24.73 <sup>c</sup>	42.82 <sup>b</sup>	80.21 <sup>c</sup>
T <sub>2</sub> Neem oil 0.3% @ 3ml/lit (F.S)	23.20 <sup>d</sup>	41.01 <sup>c</sup>	75.36 <sup>d</sup>
T <sub>3</sub> <i>Trichoderma viride</i> (F.S) 0.7% @ 7g/l	22.36 <sup>de</sup>	38.44 <sup>d</sup>	76.40 <sup>d</sup>
T <sub>4</sub> Mancozeb 75 % WP @ 0.25% (F.S)	26.25 <sup>b</sup>	44.18 <sup>b</sup>	84.03 <sup>b</sup>
T <sub>5</sub> Ginger extract @ 10% (FS)	21.56 <sup>e</sup>	37.29 <sup>e</sup>	72.96 <sup>e</sup>
T <sub>6</sub> Garlic extract @ 10% (F.S)	21.29 <sup>e</sup>	36.69 <sup>e</sup>	72.59 <sup>e</sup>
T <sub>7</sub> Mancozeb 12% + Carbendazim 63% WP @ 0.2% (F.S)	28.12 <sup>a</sup>	46.15 <sup>a</sup>	89.32 <sup>a</sup>
<b>CD (0.05)</b>	<b>1.34</b>	<b>1.37</b>	<b>2.26</b>
<b>CV</b>	<b>3.27</b>	<b>1.95</b>	<b>1.66</b>

WP- Wettable Powder  
F.S- Foliar Spray

At 30 DAS, plant height significantly increased in treatment T<sub>7</sub> (mancozeb 12% + carbendazim 63% WP @ 0.2% F.S), which achieved the tallest average height of 28.12 cm. This was followed by T<sub>4</sub> (mancozeb 75% WP @ 0.25% F.S) at 26.25 cm, T<sub>1</sub> (copper oxychloride 50% WP @ 4 ml/l F.S) at 24.73 cm, T<sub>2</sub> (neem oil 0.3% @ 3 ml/l F.S) at 23.20 cm, T<sub>3</sub> (*T. viride* S.T + F.S 0.7% @ 7 g/l with cfu 2x10<sup>6</sup>) at 22.36 cm, T<sub>5</sub> (ginger @ 10% F.S) at 21.56 cm, and T<sub>6</sub> (garlic clove @ 10% F.S) at 21.29 cm. The control showed the shortest height at 19.72 cm.

Statistical analysis revealed all treatments to be significant compared to the control. Among the treatments, T<sub>1</sub>, T<sub>4</sub>, and T<sub>7</sub> showed significant differences, while T<sub>2</sub>, T<sub>3</sub>, T<sub>5</sub>, and T<sub>6</sub> were non-significant among each other.

At 60 DAS, treatment T<sub>7</sub> recorded a height of 46.15 cm, followed by T<sub>4</sub> (44.18 cm), T<sub>1</sub> (42.82 cm), T<sub>2</sub> (41.01 cm), T<sub>3</sub> (38.44 cm), T<sub>5</sub> (37.29 cm), and T<sub>6</sub> (36.69 cm). The control measured 34.04 cm.

All the treatments were statistically significant over the control (C.D value: 1.37), with T<sub>2</sub>, T<sub>3</sub>, and T<sub>7</sub> showing significant differences. However, treatments T<sub>1</sub> and T<sub>4</sub>, as well as T<sub>5</sub> and T<sub>6</sub>, were non-significant among each other.

At 90 DAS, T<sub>7</sub> achieved the tallest height of 89.32 cm, followed by T<sub>4</sub> (84.03 cm), T<sub>1</sub> (80.21 cm), T<sub>2</sub> (76.40 cm), T<sub>3</sub> (75.36 cm), T<sub>5</sub> (72.96 cm), and T<sub>6</sub> (72.59 cm). The control measured 69.98 cm.

All treatments were statistically significant compared to the control. Treatments T<sub>1</sub>, T<sub>4</sub>, and T<sub>7</sub> were statistically significant among

themselves, while T<sub>2</sub>, T<sub>3</sub>, T<sub>5</sub>, and T<sub>6</sub> showed non-significance. Overall, the findings illustrate that various fungicides, biocontrol agents, and plant extracts significantly influenced the height of okra plants at 30, 60, and 90 DAS. The combination of mancozeb 12% and carbendazim 63% WP (T<sub>7</sub>) resulted in the highest plant heights, attributed to the broad-spectrum activity of these fungicides against various fungal pathogens, including *Alternaria* spp. Mancozeb disrupts enzymatic activities in fungal respiration, while carbendazim interferes with mitosis in fungi by binding to tubulin (Meena et al., 2020; Kantwa et al., 2014).

The application of treatments like mancozeb and carbendazim effectively reduced disease incidence and enhanced both plant height and yield (Gupta and Misra, 2019). Similarly, copper oxychloride (T<sub>1</sub>) and mancozeb (T<sub>4</sub>) also significantly improved plant height by disrupting fungal growth. Although biocontrol agents and plant extracts enhanced plant height, they were less effective than chemical fungicides. *Trichoderma viride* (T<sub>3</sub>) acts through competition and the production of antifungal metabolites, promoting plant growth (Harman et al., 2004), while neem oil (T<sub>2</sub>) inhibits spore germination and disrupts fungal membranes (Srinivasan and Narayanan, 2020). Ginger (T<sub>5</sub>) and garlic (T<sub>6</sub>) extracts, while containing antifungal properties, were less consistent in their effectiveness compared to synthetic fungicides.

The impact of treatments on disease intensity (%) at 45, 60, and 75 DAS is illustrated. At 45 DAS, treatment T<sub>7</sub> exhibited the lowest disease intensity at 8.10%, followed by T<sub>4</sub> (10.24%), T<sub>1</sub> (11.62%), T<sub>2</sub> (16.06%), T<sub>3</sub> (19.06%), T<sub>5</sub> (21.54%), and T<sub>6</sub> (22.64%). The highest disease intensity was recorded in the control at 27.96%.

**Table 4. Effect of treatments on Disease Intensity (%) at 45, 60 and 75 DAS**

Treatments	Disease Intensity (%)		
	45 DAS	60 DAS	75 DAS
T <sub>0</sub> Control (untreated check)	27.24 <sup>a</sup>	36.69 <sup>a</sup>	53.85 <sup>a</sup>
T <sub>1</sub> Copper oxychloride 50% WP @ 4 ml/l (F.S)	11.62 <sup>e</sup>	17.07 <sup>e</sup>	28.49 <sup>f</sup>
T <sub>2</sub> Neem oil 0.3% @ 3ml/lit (F.S)	16.06 <sup>d</sup>	21.46 <sup>d</sup>	33.80 <sup>e</sup>
T <sub>3</sub> <i>Trichoderma viride</i> (F.S) 0.7% @ 7g/l	19.06 <sup>c</sup>	24.36 <sup>c</sup>	37.14 <sup>d</sup>
T <sub>4</sub> Mancozeb 75 % WP @ 0.25% (F.S)	10.24 <sup>f</sup>	16.64 <sup>e</sup>	28.69 <sup>f</sup>
T <sub>5</sub> Ginger extract @ 10% (FS)	21.54 <sup>b</sup>	32.24 <sup>b</sup>	44.07 <sup>c</sup>
T <sub>6</sub> Garlic extract @ 10% (F.S)	22.64 <sup>b</sup>	32.21 <sup>b</sup>	46.24 <sup>b</sup>
T <sub>7</sub> Mancozeb 12% + Carbendazim 63% WP @ 0.2% (F.S)	8.10 <sup>g</sup>	14.36 <sup>f</sup>	26.37 <sup>g</sup>
<b>CD (0.05)</b>	<b>1.28</b>	<b>2.31</b>	<b>1.71</b>
<b>CV</b>	<b>4.26</b>	<b>5.14</b>	<b>2.63</b>

WP- Wettable Powder  
F.S- Foliar Spray

All treatments were statistically significant compared to the control, with T<sub>1</sub>, T<sub>2</sub>, T<sub>3</sub>, and T<sub>7</sub> showing significant differences. However, T<sub>5</sub> and T<sub>6</sub> were non-significant among each other.

At 60 DAS, T<sub>7</sub> again showed the lowest disease intensity at 14.39%. This was followed by T<sub>4</sub> (16.98%), T<sub>1</sub> (17.06%), T<sub>2</sub> (21.46%), T<sub>3</sub> (24.36%), T<sub>5</sub> (32.21%), and T<sub>6</sub> (32.26%). The control had a maximum disease intensity of 36.97%.

All treatments were statistically significant over the control with T<sub>2</sub>, T<sub>3</sub>, and T<sub>7</sub> showing significant differences, while T<sub>1</sub> and T<sub>4</sub>, as well as T<sub>5</sub> and T<sub>7</sub>, were non-significant among each other.

At 75 DAS, treatment T<sub>7</sub> recorded the lowest disease intensity at 25.70%. This was followed by T<sub>4</sub> (28.69%), T<sub>1</sub> (28.49%), T<sub>2</sub> (33.80%), T<sub>3</sub> (37.14%), T<sub>5</sub> (44.07%), and T<sub>6</sub> (46.24%). The control showed the highest disease intensity at 52.85%.

All treatments remained statistically significant compared to the control T<sub>2</sub>, T<sub>3</sub>, T<sub>5</sub>, T<sub>6</sub>, and T<sub>7</sub> demonstrated significant differences, while treatments T<sub>1</sub> and T<sub>4</sub> were non-significant.

The results highlight the significant reduction of disease intensity in okra due to various treatments at different stages (45, 60, and 75 DAS). The combination of mancozeb and carbendazim (T<sub>7</sub>) consistently exhibited the lowest disease intensity, supported by research indicating their effectiveness against fungal pathogens (Meena et al., 2020; Kantwa et al., 2014).

Mancozeb, a multi-site fungicide, inhibits various enzymes within fungi, preventing their growth

and infection (Thind, 2012). Carbendazim's systemic properties disrupt fungal mitosis, significantly lowering disease incidence (Gupta and Misra, 2019). The performance of copper oxychloride (T<sub>1</sub>) also reaffirmed its role in managing *Alternaria* through its ability to inhibit spore germination (Shah et al., 2021), While neem oil (T<sub>2</sub>) showed moderate efficacy.

The impact of different treatments illustrated T<sub>7</sub> showed maximum yield per hectare (14.81 t/ha) followed by T<sub>4</sub> (13.25 t/ha), T<sub>1</sub> (12.21 t/ha), T<sub>2</sub> (10.63 t/ha), T<sub>3</sub> (10.18 t/ha), T<sub>5</sub> (9.23 t/ha) T<sub>6</sub> (8.84 t/ha) minimum fruit yield per hectare (7.41 t/ha) was observe in T<sub>0</sub> (Control).

All the treatments were found to be statistically significant over control. Among the treatments (T<sub>1</sub> and T<sub>4</sub>), (T<sub>2</sub> and T<sub>3</sub>), (T<sub>3</sub> and T<sub>5</sub>) and (T<sub>7</sub> and T<sub>1</sub>) were found statistically non-significant.

Bio-agents such as neem oil (T<sub>2</sub>), *Trichoderma viride* (T<sub>3</sub>), ginger extract (T<sub>5</sub>), and garlic extract (T<sub>6</sub>) demonstrated moderate efficacy compared to chemical fungicides, with yields ranging from 8.84 to 10.63 t/ha. Neem oil contains azadirachtin, a compound that disrupts the hormonal systems of pests and diseases, while *Trichoderma viride* is known for its ability to compete with pathogenic fungi, enhance nutrient availability, and induce systemic resistance in plants (Jayalakshmi et al., 2019). Ginger and garlic extracts contain antifungal compounds such as allicin and zingiberene, which inhibit fungal growth (Kumar and Singh, 2021). However, their effectiveness was lower than synthetic fungicides, indicating that bio-agents may require higher concentrations or more frequent applications to achieve comparable results.

**Table 5. Effect of selected fungicides, botanicals and *Trichoderma viride* on Yield (t/ha) of okra (*Abelmoschus esculentus* L.)**

Treatments	Yield (t/ha)
T <sub>0</sub> Control (untreated check)	7.41 <sup>f</sup>
T <sub>1</sub> Copper oxychloride 50% WP @ 4 ml/l (F.S)	12.21 <sup>b</sup>
T <sub>2</sub> Neem oil 0.3% @ 3ml/lit (F.S)	10.63 <sup>c</sup>
T <sub>3</sub> <i>Trichoderma viride</i> (F.S) 0.7% @ 7g/l	10.18 <sup>cd</sup>
T <sub>4</sub> Mancozeb 75 % WP @ 0.25% (F.S)	13.25 <sup>b</sup>
T <sub>5</sub> Ginger extract @ 10% (FS)	9.25 <sup>de</sup>
T <sub>6</sub> Garlic extract @ 10% (F.S)	8.84 <sup>e</sup>
T <sub>7</sub> Mancozeb 12% + Carbendazim 63% WP @ 0.2% (F.S)	14.81
<b>CD (0.05)</b>	<b>1.04</b>
<b>CV</b>	<b>5.52</b>

WP- Wettable Powder

F.S- Foliar Spray

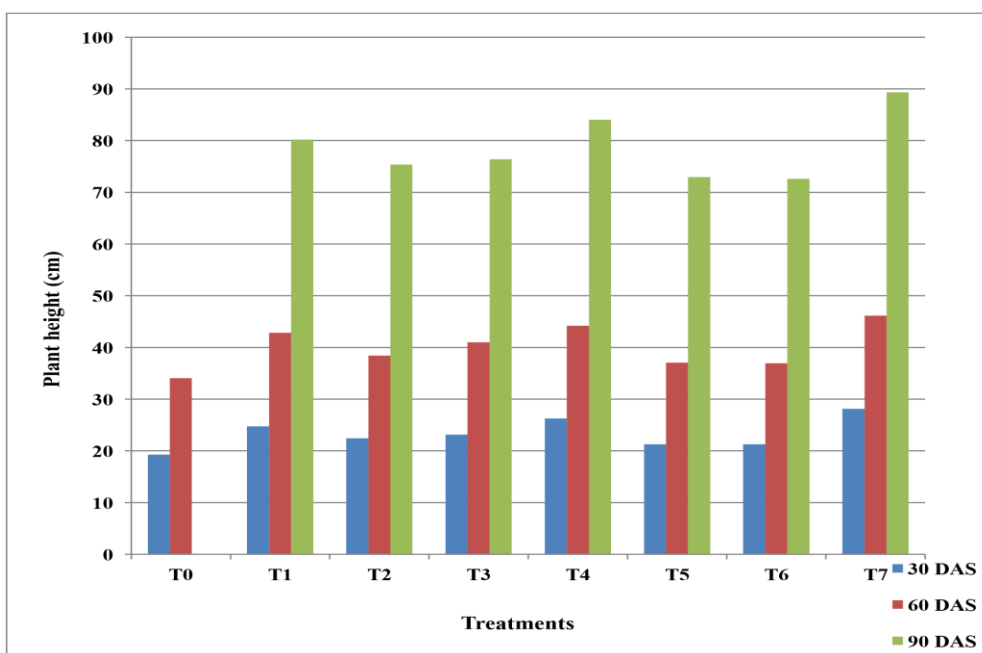


Fig. 1. Effect of the treatments on plant height

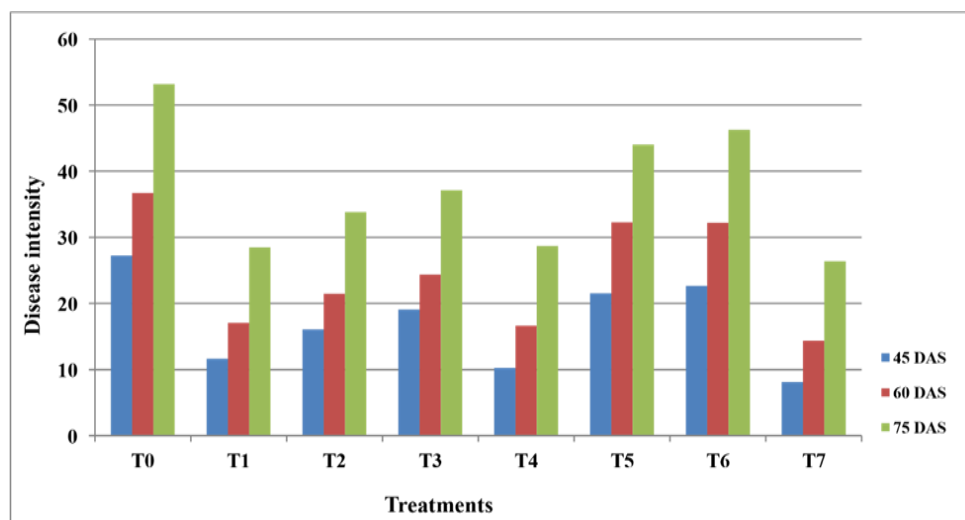


Fig. 2. Effect of the treatments on disease intensity

Table 6. Cost benefit ratio (C:B)

Treatments	Yield (t/ha)	Selling price	Gross return	Total cost of Cultivation	Net profit	C:B ratio
T <sub>0</sub>	7.41	17000	125970	75000	50970	1: 1.67
T <sub>1</sub>	12.21	17000	207570	95600	111970	1: 2.17
T <sub>2</sub>	10.63	17000	180710	90500	90500	1: 1.99
T <sub>3</sub>	10.18	17000	173060	84975	88085	1: 2.03
T <sub>4</sub>	13.25	17000	150033	83300	66733	1: 1.80
T <sub>5</sub>	9.23	17000	156910	82000	74910	1: 1.91
T <sub>6</sub>	8.84	17000	150280	86300	63980	1: 1.74
T <sub>7</sub>	14.81	17380	251770	85400	166370	1: 2.94

Among the treatments the economics of treatments, with higher return value (Rs. 251770) and C: B Ratio (1: 2.94) was observed in T<sub>7</sub> as compared to T<sub>0</sub> – control recorded lowest return value (Rs. 125970) and C: B Ratio (1: 1.67)

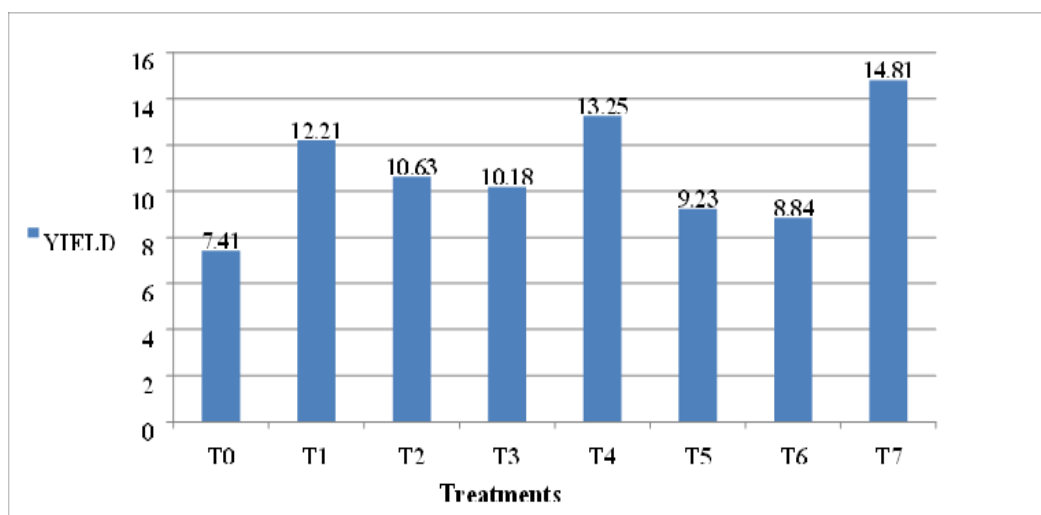


Fig. 3. Effect of the treatments on yield

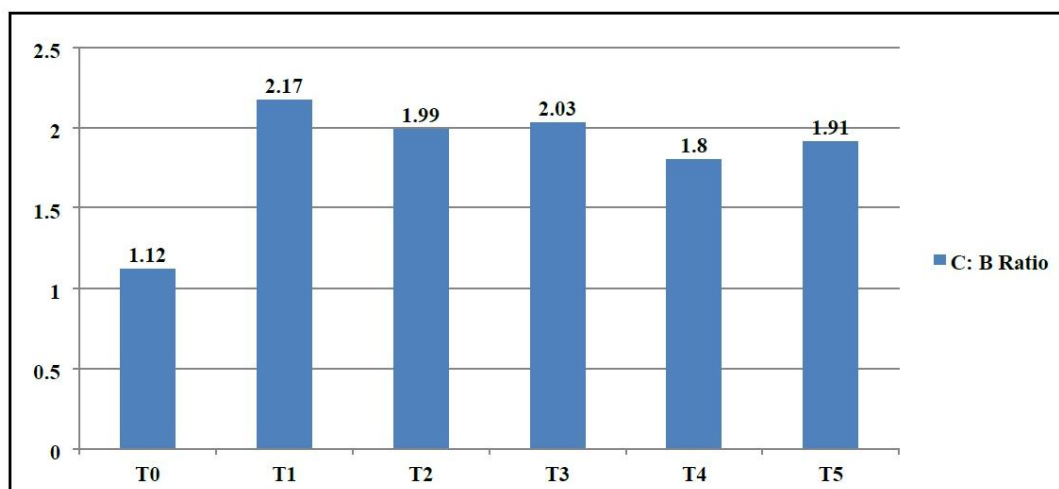


Fig. 4. Cost benefit ratio (C:B)

#### 4. CONCLUSION

This study, titled “Effect of selected fungicides, botanicals and *Trichoderma viride* in managing *Alternaria* leaf spot of okra (*Abelmoschus esculentus* L.)” underscores the vital role of effective disease management in boosting the crop productivity. Among all the treatments, chemical fungicides, particularly mancozeb 12% + carbendazim 63% WP @ 0.2% (F.S), showed the most promising outcomes for okra growth, disease control, and yield. Consistently resulted in the tallest plants, the lowest disease intensity at all observation points, and the highest yield per hectare. The next best-performing treatments were mancozeb 75% WP @ 0.25% (F.S) and copper oxychloride 50% WP @ 4 ml/l (F.S), which also provided significant benefits in terms

of plant height, disease control, and yield. Biological treatments, like *Trichoderma viride* and neem oil, demonstrated moderate effects but were less effective compared to the chemical fungicides.

While also resulted in the highest cost-benefit ratio, suggesting better financial returns compared to other treatments. Bio-agents, though less potent than chemical fungicides, present an eco-friendly alternative that can be further developed to reduce dependency on chemicals. With more research and refinement, bio-agents like *Trichoderma viride* and botanical extracts like neem oil could become viable options for integrated disease management in okra. However, further trials are necessary to optimize their efficacy and understand their

potential as standalone treatments or as part of a broader integrated disease management strategy. It's important to note that further trials are necessary before these treatments can be confidently recommended to farmers. This study provides valuable insights, but more research is required across different seasons, environmental conditions, and disease pressures to ensure consistent and long-term efficacy.

### DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of manuscript.

### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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