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EFFECT OF *TRICHODERMA HARZIANUM* AND BOTANICAL EXTRACTS ON POST-HARVEST GROWTH PARAMETERS OF GARLIC IN PRAYAGRAJ (U.P.) INDIA

Krushna Mohanrao Solanke*, Sunil Zacharia, Tsukjemnugla Jamir and Rohini Borkar
Department of Plant pathology, Sam Higginbottom University of Agriculture,
Technology and Sciences, Prayagraj – 211007, Uttar Pradesh, India
*Corresponding author E-mail: krishsolanke174@gmail.com
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ABSTRACT

Garlic (*Allium sativum* L.) is an economically important spice and medicinal crop, but its productivity is often constrained by soil-borne pathogens and excessive reliance on chemical inputs. The present study was conducted during the Rabi seasons of 2020–2021 and 2021–2022 at the Research Farm, Department of Plant Pathology, SHUATS, Prayagraj, to evaluate the effect of *Trichoderma harzianum* in combination with various botanical extracts on growth and post-harvest attributes of garlic under field conditions. The experiment was laid out in a Randomized Block Design (RBD) with eight treatments replicated thrice, including seed treatment with *T. harzianum* (10 g kg^{-1} cloves) or Mancozeb (0.25%), followed by foliar sprays of 10% botanical extracts at 45 and 60 days after planting. Significant variations were observed among treatments for clove length, number of cloves per bulb, and bulb weight. The treatment involving *T. harzianum* + neem leaf extract (T_1) recorded superior performance among eco-friendly options, with pooled mean values of 2.89 cm clove length, 24.07 cloves per bulb, and 31.74 g m^{-2} bulb weight, closely approaching the chemical check Mancozeb (T_7). Treatments with eucalyptus (T_4) and *T. harzianum* extract (T_3) also showed promising results. The enhancement in post-harvest traits may be attributed to synergistic effects of *T. harzianum* and bioactive compounds in botanical extracts that improve nutrient uptake, plant vigour, and pathogen suppression. The study concludes that the integrated application of *T. harzianum* and neem extract offers a sustainable, eco-friendly strategy for improving garlic yield and quality while reducing dependence on synthetic fungicides.
Keywords : Bulb weight (g/m^2), Length of cloves (cm), Number of cloves, post-harvest parameters, *T. harzianum*+ neem leaf extract

Introduction

Garlic (*Allium sativum* L.) is one of the oldest known bulbous crops grown and consumed worldwide as a spice, condiment, and medicinal plant. Revered for its pungent flavour and therapeutic properties, garlic is rich in bioactive compounds such as allicin, flavonoids, phenols, and antioxidant enzymes, which contribute to its antimicrobial, antihypertensive, cardioprotective, and immunomodulatory effects (García *et al.*, 2020). It boasts significant nutritional value, including carbohydrates (33%), proteins (6.3%), essential oils, minerals, vitamin C, and trace elements, contributing to its high demand both in fresh and processed forms (Aggarwal *et al.*, 1996; Gavasane *et al.*, 2011). Globally, garlic is cultivated on 1.97 million hectares with a total production of 28.05 million tonnes, of which India accounts for about 16.2% of area and 5.5% of production (FAOSTAT, 2022).

The compound bulb of garlic, consisting of 4–20 cloves depending on variety and environmental conditions, serves as the primary economic and planting unit. Optimal growth of garlic requires well-drained sandy loam to clay loam soils with a pH of 6.5–7.0, a temperature range of 5–25 °C, and moderate humidity with adequate spacing to reduce competition and disease incidence (Dar *et al.*, 2020). In India, the major garlic-growing states are Madhya Pradesh, Rajasthan, Uttar Pradesh, Gujarat, and Punjab, with Madhya Pradesh leading in both area and production (NHB, 2023–24). Despite its profitability, garlic production is constrained by various biotic and abiotic stresses; among them, soil-borne pathogens and post-harvest losses often lead to significant yield and quality degradation.

In recent years, the shift towards eco-friendly and sustainable farming practices has intensified interest in biological agents and natural plant products as alternatives to chemical fertilizers and pesticides. *Trichoderma harzianum*, a well-known bio-control fungus, not only suppresses pathogens through mechanisms such as mycoparasitism and antibiosis but also promotes plant growth by enhancing root development, nutrient solubilisation, and inducing systemic resistance (Singh & Prasad, 2022). Similarly, botanical extracts such as neem (*Azadirachta indica*) and garlic (*A. sativum*) possess antifungal and growth-promoting properties due to the presence of limonoids, azadirachtin, allicin, and sulphur-containing compounds (Arunakumara, 2023; Singh *et al.*, 2021). The integration of *T. harzianum* with botanical extracts holds great potential to improve soil health, reduce disease pressure, and enhance crop productivity in a cost-effective and environmentally benign manner.

Considering the growing demand for organic garlic and the need to minimize chemical inputs, the present investigation was undertaken to evaluate the integrated application of *Trichoderma harzianum* and selected botanical extracts on growth and post-harvest attributes of garlic under field conditions. The study aims to generate scientific evidence for sustainable garlic production through bio-rational approaches, ultimately contributing to enhanced yield, quality, and profitability for farmers while safeguarding environmental and consumer health.

Materials and Methods

Experimental Site

A field experiment was carried out during the Rabi seasons of 2020–2021 and 2021–2022 at the Research Farm, Department of Plant Pathology, SHUATS, Prayagraj (U.P.), to evaluate the effect of *Trichoderma harzianum* and different botanical extracts on growth and post-harvest parameters of garlic. The experiment was laid out in a Randomized Block Design (RBD) with 8 treatments and three replications, using garlic variety 'Bhimomkara'.

The treatments consisted of seed treatment (S.T) with *T. harzianum* @10 g kg^{-1} of cloves or Mancozeb @0.25%, followed by foliar spray (F.S) of botanical extracts at 45 and 60 days after planting @10% concentration, except for the chemical check. The treatment details were as follows:

Table 1: Details of treatments

Treatment No.	Treatment	Concentration
T_0	Control (Untreated check)	—
T_1	*T. harzianum* (10 g/kg, S.T) + Neem leaf extract (F.S)	10%
T_2	*T. harzianum* (10 g/kg, S.T) + Lantana leaf extract (F.S)	10%
T_3	*T. harzianum* (10 g/kg, S.T) + *T. harzianum*(F.S)	10 %
T_4	*T. harzianum* (10 g/kg, S.T) + Eucalyptus leaf extract (F.S)	10%
T_5	*T. harzianum* (10 g/kg, S.T) + Mentha leaf extract (F.S)	10%
T_6	*T. harzianum* (10 g/kg, S.T) + Aloe vera leaf extract (F.S)	10%
T_7	Mancozeb (0.25%, S.T+ F.S)	0.25%

The field was prepared with one deep ploughing followed by two harrowing and leveling. Healthy, uniform garlic cloves were treated as per treatment schedule and planted at a spacing of 10 cm × 15 cm using a seed rate of 100 kg ha^{-1}. Standard agronomic practices such as gap filling, thinning, manual weeding, and irrigations (four to five at critical stages) were adopted uniformly across treatments.

Five randomly selected plants from each plot were tagged for observations. Growth parameters recorded at appropriate intervals included plant height (cm), number of leaves per plant, and leaf length (cm). Post-harvest attributes such as number of cloves per bulb, clove length (cm), bulb diameter (cm), bulb weight (g m^{-2}), and total yield (t ha^{-1}) were measured after harvesting and shade-curing of bulbs for 7–10 days.

Post - harvest observations

Length of cloves (cm) of garlic: To assess the effect of various treatments on the development of garlic cloves, the length of individual cloves was recorded. Five cloves were randomly selected from each of the five bulbs sampled under each treatment. Measurements were taken from the base to the apex of each clove using a standard measuring scale. The results were noted in centimeters (cm). The mean clove length for each treatment was computed and considered a significant parameter for evaluating bulb quality and commercial value.

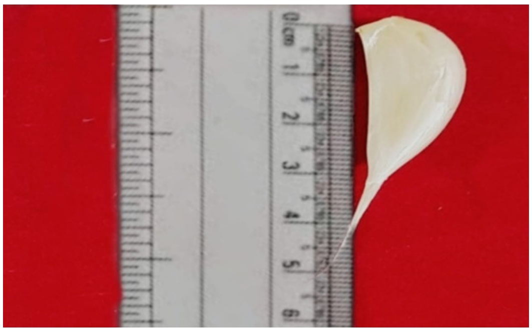

Plate 1: Measuring length of cloves (cm)

Number of cloves per bulb of garlic The number of cloves per bulb was recorded by carefully separating and counting all individual cloves from fully matured garlic bulbs. Observations were made on five randomly selected bulbs from each treatment within every replication. Only well-formed and distinguishable cloves were included in the count, while malformed or undeveloped ones were excluded. The average number of cloves per bulb was then calculated to assess the effect of different treatments on bulb development and clove formation, which is a key yield-contributing trait in garlic

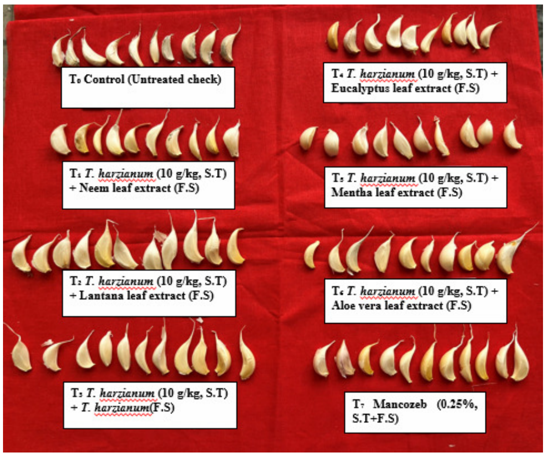

Plate 2: Counting number of garlic cloves per treatment after harvest

Bulb weight (g/m^2) of garlic: The weight of garlic bulbs was recorded to assess yield performance under different treatment conditions. After harvesting, both marketable and non-marketable bulbs were collected from each plot. The total weight was measured using a digital weighing balance and expressed in grams per square meter (g/m²). This parameter served as a direct indicator of productivity and was used to compare the effectiveness of various integrated management practices on garlic yield. Plate- 3 Weighing of bulb (gm) of garlic

Plate 3: Weighing of bulb (gm) of garlic

The pooled observations over two seasons were subjected to Analysis of Variance (ANOVA) as per the method suggested by Gomez and Gomez (1984). Treatment means were compared using critical difference (CD) at 5% level of significance ($p \leq 0.05$) to determine the efficacy of *T. harzianum* and botanical extracts on garlic growth and post-harvest performance under field conditions.

Results and Discussion

Length of cloves (cm)

Length of cloves (cm) of garlic: The observed data demonstrated that integrating *Trichoderma harzianum* with botanical extracts markedly improved clove length in garlic over the untreated control. The highest clove length was recorded in T_7 (Mancozeb 0.2%), showing a pooled mean of 3.03 cm, which served as the chemical benchmark. However, among the bio-rational treatments, T_1 (*T. harzianum* + neem leaf extract) was most effective, recording a pooled clove length of 2.89 cm, indicating that neem extract in combination with *T. harzianum* may effectively stimulate bulb development in an eco-friendly manner.

Treatments T_4 (*T. harzianum* + eucalyptus extract) and T_3 (*T. harzianum* + garlic extract) also registered considerable increases in clove length (2.68 cm and 2.62 cm, respectively), corroborating earlier findings that essential oils and phenolic compounds in eucalyptus and garlic extracts enhance root proliferation and bulb expansion (Dubey *et al.*, 2020). Moderate responses were obtained under T_2 (lantana) and T_5 (mentha), while T_6 (aloe vera) was less effective among treated plots but still surpassed the control (2.16 cm). These improvements could be ascribed to improved nutrient uptake, hormonal stimulation, and suppression of soil-borne pathogens by *T. harzianum* (Singh and Prasad, 2022).

The strong performance of neem extract may be associated with the presence of growth-regulating and antifungal compounds such as azadirachtin, salannin, and nimbin, which may have synergistically acted with *T. harzianum* to enhance clove size and bulb quality (Singh *et al.*, 2021). Thus, the results highlight that *T. harzianum* + neem leaf extract (T_1) is a promising eco-friendly option for improving the post-harvest traits of garlic, aligning with sustainable crop production goals.

Number of cloves

The number of cloves per bulb is an important post-harvest attribute directly influencing bulb yield and market value of garlic. The present investigation revealed significant differences among treatments in both seasons highlighting the positive influence of *Trichoderma harzianum* and botanical extracts on clove multiplication. The highest pooled number of cloves was produced by the chemical check T_7 (Mancozeb), with a mean of 27.26 cloves bulb^{-1}, followed by the eco-friendly treatment T_1 (*T. harzianum* + neem leaf extract), which recorded a pooled mean of 24.07 cloves bulb^{-1}. The increase in clove number under T_1 could be attributed to the synergistic effect of *T. harzianum*, which is known to stimulate plant growth and enhance nutrient uptake (Singh and Prasad, 2022) along with bioactive compounds of neem that improve physiological efficiency and reduce pathogen stress (Arunakumara, 2023).

Other combinations such as *T. harzianum* with eucalyptus (T_4: 22.16), *T. harzianum* with *T. harzianum* extract (T_3: 20.24), and *T. harzianum* with lantana (T_2: 18.77) also enhanced clove numbers significantly compared to the untreated control (T_0: 15.43). Treatments with mentha (T_5: 16.92) and aloe vera (T_6: 16.75) showed moderate improvement. The variability among botanical treatments indicated that the efficacy depended on the type of plant extract used and its bioactive constituents. The superior performance of neem-based treatment is consistent with earlier findings which reported positive effects of neem formulations on clove multiplication and garlic bulb development under field conditions (Singh *et al.*, 2021). Although the chemical fungicide Mancozeb resulted in the highest clove number, the comparable efficacy of *T. harzianum* + neem extract highlights its potential as an eco-friendly alternative to conventional chemicals for sustainable garlic production.

Bulb weight (g/m^2) of garlic

The application of *Trichoderma harzianum* in combination with botanical extracts exerted a significant positive influence on bulb weight of garlic during both growing seasons. Among the eco-friendly treatments, T_1 (*T. harzianum* + neem leaf extract) produced the highest bulb weight with a pooled mean of 31.74 g, recording a substantial increase over the untreated control (20.19 g). This improvement may be attributed to the plant growth-promoting ability of *T. harzianum*, which enhances nutrient uptake, root growth, and hormonal stimulation in plants (Harman *et al.*, 2004) along with the beneficial effects of neem phyto-chemicals like azadirachtin and limonoids that improve bulb filling and impart protection against soil-borne pathogens (Kumar and Poehling, 2006).

The next best performance was observed under T_4 (*T. harzianum* + eucalyptus extract), which recorded a pooled mean bulb weight of 29.53 g, followed closely by T_3 (*T. harzianum* + *Trichoderma* extract) with 27.33 g. Treatments involving lantana (T_2: 25.41 g), mentha (T_5: 23.97 g), and aloe vera extracts (T_6: 22.16 g) also exhibited improvement over the control, though the magnitude of enhancement was comparatively lower, indicating that efficacy may vary based on the type and concentration of active constituents present in different botanicals (Bhatt *et al.*, 2020).

The results clearly suggested that integrating *T. harzianum* with neem extract is the most promising eco-friendly strategy for increasing bulb weight of garlic, followed by eucalyptus and *Trichoderma* extract combinations. Enhanced bulb development under these treatments highlights their potential role in sustainable garlic production by boosting soil health and improving crop physiology, while reducing dependency on chemical inputs (Singh *et al.*, 2021).

Conclusion

The present investigation clearly demonstrated that the integrated use of *Trichoderma harzianum* with botanical extracts has a substantial positive impact on the post-harvest attributes of garlic. Among the eco-friendly treatments, *T. harzianum* + neem leaf extract (T_1) proved to be the most effective, significantly enhancing clove length, number of cloves per bulb, and bulb weight while closely matching the performance of the chemical standard Mancozeb. Treatments involving eucalyptus (T_4) and garlic extract (T_3) also performed considerably well, highlighting their potential as bio-rational alternatives. The observed improvements may be attributed to the synergistic effects of *T. harzianum*, which promotes nutrient availability and plant vigour, and the bioactive compounds present in botanicals that stimulate physiological growth and suppress pathogen activity. These findings suggest that the combination of *T. harzianum* and neem extract offers a promising, eco-friendly strategy for enhancing garlic yield and quality. Adoption of such sustainable management practices could help reduce dependence on chemical fungicides while maintaining productivity, thus contributing to safer food, environmental health, and profitable garlic cultivation.

Table 2: Effect of different treatments on Length of cloves (cm)and Number of cloves, Bulb weight (g/m^2) of garlic (2020-21 and 2021-22) (pooled mean)

Treatment		Length of cloves (cm)			Number of cloves			Bulb weight (g/m^2)		
		length of cloves (cm) *Rabi*-2020-21	**length of cloves (cm) *Rabi*-2021-22**	**Mean**	**Number of cloves *Rabi*-2020-21**	**Number of cloves *Rabi*-2021-22**	**Mean**	**Bulb weight (g/m^2) 2020-21**	**Bulb weight (g/m^2) 2021-22**	**Mean**
T_0	Control (untreated check)	2.15	2.16	2.16	15.47	15.40	15.43	19.91	20.47	20.19
T_1	*T.harzianum*+Neem leaf extract 10g/kg(S.T)+10%(F.S)	2.87	2.91	2.89	23.87	24.27	24.07	30.98	32.51	31.74
T_2	*T.harzianum* +Lantana leaf extract 10g/kg(S.T)+10%(F.S)	2.49	2.56	2.53	18.91	18.63	18.77	24.78	26.04	25.41
T_3	*Trichoderma harzianum* +*T- harzianum* 10g/kg(S.T)+10% (F.S)	2.61	2.63	2.62	20.38	20.10	20.24	27.14	27.52	27.33
T_4	*T.harzianum* + Eucalyptus leaf extract 10g/kg(S.T)+10% (F.S)	2.67	2.68	2.68^{cd}	22.33	22.00	22.16	28.85	30.22	29.53
T_5	*T.harzianum* +Mentha leaf extract 10g/kg(S.T)+10%(F.S)	2.38	2.47	2.43	16.97	16.87	16.92^{fg}	23.61	24.32	23.97
T_6	*T.harzianum* + Aloe vera leaf extract 10g/kg(S.T)+10% (F.S)	2.28	2.40	2.34	16.80	16.70	16.75	22.17	22.14	22.16
T_7	Mancozeb 0.2%(S.T)+(F.S)	3.00	3.05	3.03	27.01	27.52	27.26	35.52	37.85	36.68
SEm (±)		0.06	0.05	0.02	0.63	0.52	0.22	0.27	0.28	0.37
CD (p=0.05)		0.14	0.11	0.06	1.37	1.19	0.53	0.83	0.86	1.28

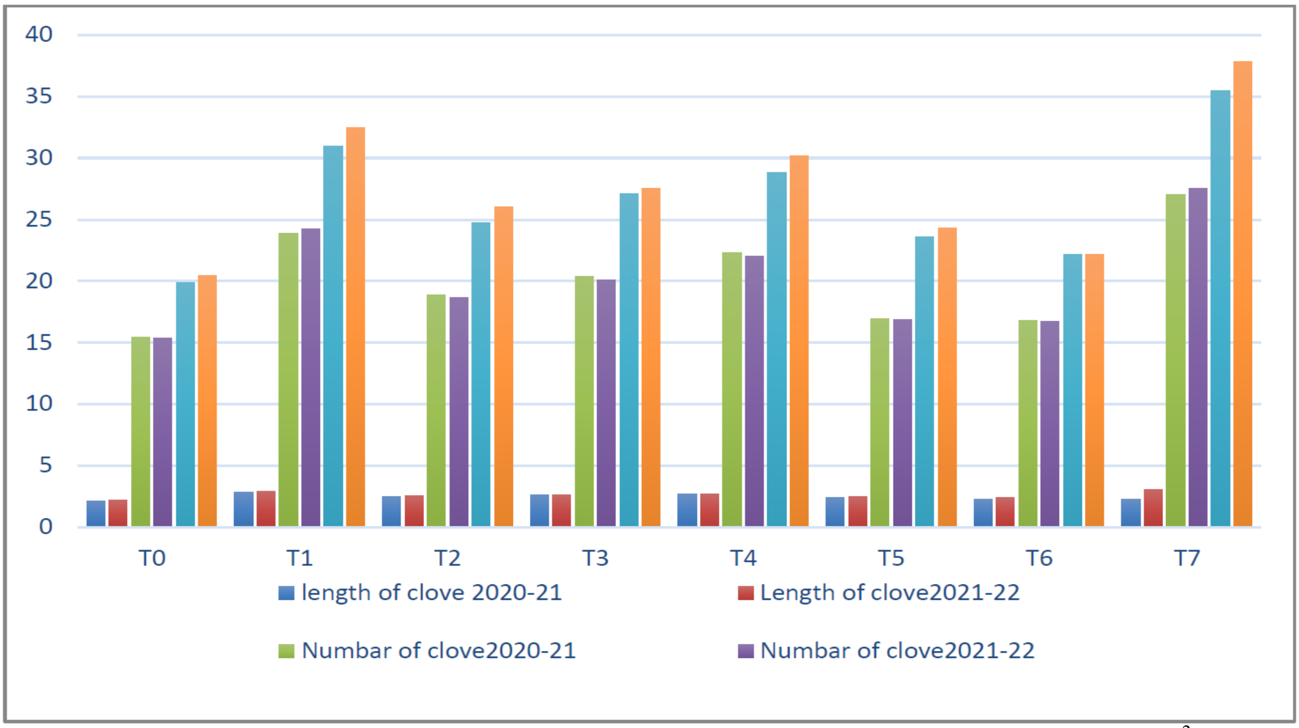

Fig. 1 : Effect of different treatments on Length of cloves (cm) and Number of cloves , Bulb weight (g/m^2) of garlic (2020-21 and 2021-22) (pooled mean)

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