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INFLUENCE OF ESSENTIAL OILS AND *TRICHODERMA VIRIDE* ON VEGETATIVE GROWTH PARAMETERS OF PUMPKIN (*CUCURBITA MOSCHATA* DUCH.)

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ABSTRACT

The use of plant-based bioinputs has emerged as a sustainable strategy for enhancing crop growth and productivity while minimizing environmental impact. This study aimed to evaluate the influence of selected essential oils in combination with *Trichoderma viride* on the vegetative growth and yield parameters of pumpkin (*Cucurbita moschata* Duch.). A field experiment was conducted during the *Kharif* season of 2022 at the Central Research Farm, SHUATS, Prayagraj, using a randomized block design with seven treatments replicated thrice. Treatments included seed treatment with *Trichoderma viride* and foliar sprays of five essential oils Lemongrass, Lavender, Tea tree, Peppermint, and Orange alongside a chemical control (Carbendazim) and an untreated check. Results revealed that the combination of *Trichoderma viride* and Lemongrass oil significantly enhanced vine length (396.4 cm), number of leaves per plant (42.0), number of flowers (11.0), and dry shoot weight (30.33 g). Lavender oil showed moderate improvements, while Tea tree, Peppermint, and Orange oils exhibited variable or lesser effects. The untreated control consistently showed the lowest growth performance. These findings suggest that specific essential oils, particularly lemongrass oil, when integrated with *Trichoderma viride*, can effectively promote vegetative growth and yield in pumpkin and may serve as eco-friendly alternatives to chemical inputs.

Keywords **:** essential oils, pumpkin growth, *Trichoderma viride*, vegetative parameters, yield enhancement

Introduction

Pumpkin is an important cucurbitaceous crop in India, widely cultivated across tropical and subtropical regions since its introduction from South America around the ninth century. At present, pumpkin is grown over approximately 78,000 hectares in India, with an annual production of about 17.14 lakh metric tonnes, positioning the country as the second-largest producer globally after China. The crop is predominantly cultivated during the kharif and summer seasons, with significant production concentrated in states such as Tamil Nadu, where it occupies nearly 1,530 hectares and yields around 37,340 tonnes annually (Umesh *et al*., 2020; Marxmathi *et al*., 2018). Its agronomic adaptability, high yield potential, and health-promoting phytochemicals such as carotenoids, flavonoids, and antioxidants contribute to its wide cultivation in India and abroad (Jahan *et al*., 2012; Suresh *et al*., 2020). Despite these advantages, pumpkin productivity is often limited by both biotic and abiotic stresses, including foliar fungal diseases, which indirectly affect vegetative growth, fruit set, and yield potential.

While synthetic fungicides are commonly used to control disease and maintain crop vigor, their overuse can lead to phytotoxic effects, soil degradation, and negative impacts on beneficial soil microbiota (Sharma *et al*., 2015). The extensive reliance on chemical fertilizers poses serious environmental and human health risks, underscoring the urgent need for sustainable agricultural alternatives. Adverse effects of synthetic fertilizers, including soil degradation, water contamination, and associated health hazards, have been well documented (Chittora, 2023). In this context, plant-derived essential oils and beneficial microorganisms such as *Trichoderma* spp. are increasingly recognized as eco-friendly inputs due to their biodegradability, low environmental persistence, and ability to promote plant growth, enhance nutrient availability, improve soil health, and suppress phytopathogens, thereby contributing to sustainable crop production.

Trichoderma is a potent plant growth-promoting fungus that enhances plant development through a range of intricate biological mechanisms. Substantial evidence indicates that Trichoderma stimulates plant growth via direct processes such as improved nutrient uptake, phosphate solubilization, and the production of phytohormones, particularly indole-3-acetic acid (IAA) (Contreras-Cornejo *et al*., 2024). In addition, it operates through indirect mechanisms by suppressing plant pathogens and inducing tolerance to abiotic stresses (Mendoza-Mendoza *et al*., 2017). At the molecular level, studies have shown that *Trichoderma* activates complex signaling pathways that regulate phytohormone balance, promote nutrient accumulation, and enhance soil nutrient bioavailability, thereby contributing to improved plant growth and resilience (Khan *et al*., 2023).

Essential oils (EOs) are volatile secondary metabolites obtained mainly from aromatic and medicinal plants. They are rich in biologically active compounds and have been reported to influence plant growth and development, in addition to exhibiting antimicrobial, insecticidal, nematicidal, herbicidal, antioxidant, and anti-inflammatory activities. Chemically, EOs consist primarily of volatile terpenes and generally contain 20–60 constituents, with two or three major compounds present at relatively high concentrations and the remaining components occurring in trace amounts, contributing to their overall biological activity (Kesraoui *et al*., 2022).

Accordingly, essential oils from Lemongrass (*Cymbopogon citratus*) (Irkin *et al*.,2008), Lavender (*Lavandula dentata*) (Abdali *et al*.,2022), Tea tree (*Melaleuca alternifolia*) (Alves *et al*., 2019), Peppermint (*Mentha piperita*) (Franka *et al*., 2018) and Orange (*Citrus sinensis*) (de Lima *et al*., 2016) were selected for the present investigation based on comparative evidence from previous studies demonstrating their bioactive secondary metabolites and documented disease-suppressive properties, which indirectly contribute to enhanced plant vigor and improved growth performance.

Despite extensive documentation of their antifungal activity, the influence of essential oils on vegetative growth and reproductive parameters in crop plants remains underexplored. This study aimed to evaluate the effect of foliar application of essential oils, in combination with *Trichoderma viride*, on key growth and yield attributes of pumpkin under field conditions.

Materials and Methods

Experimental Site and Design

The field experiment was conducted during the *Kharif* season of 2022 at the Central Research Farm, Department of Plant Pathology, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Prayagraj, Uttar Pradesh, India. The site lies in the semi-arid Indo-Gangetic plains and is characterized by sandy loam soil with moderate fertility and good drainage. The experiment comprised seven treatments laid out in RBD with three replications, and each replication plot contained nine uniformly spaced plants. Each plot measured 2.0 × 1.0 meters, with plants spaced at 60 × 80 cm. Seeds of the indigenous pumpkin variety 'Sadabahar' were procured from the Department of Horticulture, SHUATS, and served as the plant material for the experiment.

Treatment Details

The experimental treatments included a combination of biological and chemical inputs as follows:

T0 – Untreated control
T1– *Trichoderma viride* + Lemongrass oil (*Cymbopogon citratus*)
T2– *Trichoderma viride* + Lavender oil (*Lavandula dentata*)
T3– *Trichoderma viride* + Tea tree oil (*Melaleuca alternifolia*)
T4– *Trichoderma viride* + Peppermint oil (*Mentha piperita*)
T5– *Trichoderma viride* + Orange oil (*Citrus sinensis*)
T6 – Carbendazim @ 1 g/L (chemical control)

Seeds were treated with *Trichoderma viride* at 4 g/kg of seed prior to sowing. Essential oils were applied as foliar sprays.

Preparation of Essential Oil Emulsions

The essential oils utilized in this study were obtained from a commercial online supplier and were claimed by the manufacturer to be 100% pure, natural, and undiluted. For foliar application, each essential oil was emulsified by mixing 2.5 mL of the oil with 1.0 mL of Tween 20 (as a surfactant) in 100 mL of sterilized distilled water. The mixture was thoroughly stirred to achieve homogeneity and then diluted with distilled water to a final volume of 1 L, resulting in a working concentration of 2.5 mL/L. All emulsions were freshly prepared before use and applied immediately. Control plots were treated with distilled water instead of essential oils.

Experimental Procedure

Foliar sprays were administered after the initial appearance of disease symptoms, around 45 days after sowing. Each treatment was sprayed twice at weekly intervals using a hand-operated sprayer. For consistent data collection, three healthy plants were randomly selected and tagged in each plot at the early vegetative stage. Growth and yield observations were recorded from these tagged plants at 50, 75, and 100 days after sowing (DAS). Data collected at these intervals allowed the monitoring of developmental trends throughout the crop cycle.

Measurement of Growth Parameters

The following vegetative parameters were systematically recorded to assess plant growth and development:

- **Vine length (cm):** Determined by measuring the distance from the stem base to the apex of the shoot at each designated observation interval, providing an indicator of overall plant vigor.
- **Number of leaves per plant:** Counted manually on each tagged plant to evaluate foliar development and canopy expansion.
- **Number of flowers per plant:** Recorded during the flowering phase to monitor reproductive development and potential yield.
- **Dry shoot weight (g):** Shoots were harvested at maturity, sun-dried until a constant weight was achieved, and then weighed to quantify biomass accumulation.

To ensure consistency and reliability of data, all observations were conducted on the three pre-tagged plants within each experimental plot. This approach facilitated uniformity in measurements and minimized variability due to plant-to-plant differences.

Statistical Analysis

Data obtained from each parameter were subjected to statistical analysis using ANOVA to assess the significance of treatment effects. Means were compared using the Critical Difference (CD) test at the 5% level of significance. Statistical analysis was conducted using standard software and methods appropriate for field-based agronomic trials (Fisher, 1925).

Results

Effect on Vine Length

Vine length, a key indicator of vegetative vigor and canopy development in cucurbit crops, was markedly affected by the different treatments applied in the study. The treated check (chemical control) recorded the maximum vine elongation across all observation stages (50, 75, and 100 DAS), reaching 412.3 cm at 100 DAS, indicating superior vegetative growth under protected conditions. Among the essential oil treatments combined with Trichoderma viride, lemongrass oil (T1) proved most effective, resulting in a vine length of 396.4 cm at 100 DAS, followed by lavender oil (T2) with 376.2 cm. In contrast, the untreated control (T0) consistently exhibited the shortest vines, with a final length of 287.5 cm at 100 DAS, reflecting restricted growth under natural stress conditions and highlighting the positive influence of both chemical and bio-based treatments on vine development.

Table 1: Effect of selected essential oils and *Trichoderma viride* on vine length (cm) of pumpkin

SN.	Treatments	Treatment Details	50 DAS (Mean)	75 DAS (Mean)	100 DAS (Mean)
1.	T_0	Control (untreated check)	161.8	252.4	287.5
2.	T_1	*Trichoderma viride* + Lemongrass essential oil	172.8	310.9	396.4
3.	T_2	*Trichoderma viride* + Lavender essential oil	170.6	302.4	376.2
4.	T_3	*Trichoderma viride* + Tea Tree essential oil	168.7	264.1	297.4
5.	T_4	*Trichoderma viride* +Peppermint essential oil	165.3	288.4	329.8
6.	T_5	*Trichoderma viride* + Orange essential oil	160.9	291.7	343.6
7.	T_6	Control (treated Check)Carbendazim	176.4	321.7	412.3
CD at 5%			**39.432**		
CV%			**8.236**		

Effect on Number of Leaves per Plant

The number of leaves per plant, a crucial determinant of photosynthetic efficiency and nutrient assimilation, was significantly influenced by the various treatments applied during the crop cycle. The treated check (chemical control) recorded the highest leaf production, with an average of 45.7 leaves at 100 DAS, indicating enhanced vegetative growth. Among the essential oil treatments in combination with *Trichoderma viride*, lemongrass oil (T1) proved most effective, producing an average of 42.0 leaves per plant, followed closely by lavender oil (T2) with 41.7 leaves. In contrast, the untreated control (T0) registered the lowest leaf count (38.7 leaves), reflecting reduced photosynthetic potential under untreated conditions and underscoring the beneficial impact of both chemical and bio-based treatments on leaf development.

Table 2: Effect of selected essential oils and *Trichoderma viride* on number of leaves of pumpkin

SN.	Treatments	Treatment Details	50 DAS (Mean)	75 DAS (Mean)	100 DAS (Mean)
1.	T_0	Control (untreated check)	17.3	26.3	38.7
2.	T_1	*Trichoderma viride* + Lemongrass essential oil	19.3	27.3	42
3.	T_2	*Trichoderma viride* + Lavender essential oil	18.7	27	41.7
4.	T_3	*Trichoderma viride* + Tea Tree essential oil	17.7	25.3	37.7
5.	T_4	*Trichoderma viride* +Peppermint essential oil	17.7	26.7	39.3
6.	T_5	*Trichoderma viride* + Orange essential oil	18.7	26.3	36.7
7.	T_6	Control (treated check)Carbendazim	23	28.7	45.7
CD at 5%			**2.200**		
CV%			**4.315**		

Effect on Number of Flowers per Plant

Floral development per plant was significantly influenced by the different treatments applied, as presented in Table 2. The treated check (chemical control) recorded the highest average number of flowers per plant (13.7), indicating enhanced reproductive growth under chemical protection. Among the essential oil treatments combined with *Trichoderma viride*, lemongrass oil (T1) was the most effective, producing an average of 11.0 flowers per plant, followed by lavender oil (T2) with 10.7 flowers. In contrast, the untreated control (T0) exhibited the lowest floral production (average of 7.3 flowers per plant), reflecting reduced reproductive potential under untreated conditions and emphasizing the positive role of both chemical and bio-based treatments in improving flowering.

Table 3: Effect of selected essential oils and *Trichoderma viride* on number of flowers of pumpkin

SN.	Treatments	Treatment Details	50 DAS (Mean)	75 DAS (Mean)	100 DAS (Mean)
1.	T_0	Control (untreated check)	0.6	6	7.3
2.	T_1	*Trichoderma viride* + Lemongrass essential oil	1.3	8.7	11
3.	T_2	*Trichoderma viride* + Lavender essential oil	0.6	8.3	10.7
4.	T_3	*Trichoderma viride* + Tea Tree essential oil	0.6	7.7	9.3
5.	T_4	*Trichoderma viride* +Peppermint essential oil	0.6	8	8.7
6.	T_5	*Trichoderma viride* +Orange essential Oil	0.6	6.7	8.3
7.	T_6	Control (treated check)Carbendazim	2	9.7	13.7
CD at 5%			**1.553**		
CV%			**13.949**		

Effect on Dry Shoot Weight

Dry shoot weight at harvest, a reliable indicator of cumulative biomass accumulation and overall plant vigor, was significantly influenced by the different treatments. The treated check (chemical control) recorded the highest dry shoot weight (34.40 g), reflecting enhanced biomass accumulation under chemical protection. Among the essential oil treatments combined with *Trichoderma viride*, lemongrass oil (T1) proved most effective, registering a dry shoot weight of 30.33 g, followed by lavender oil (T2) with 29.20 g. In contrast, the untreated control (T0) showed the lowest biomass accumulation (23.13 g), indicating suppressed vegetative growth under natural disease pressure and underscoring the beneficial effects of both chemical and bio-based treatments on plant vigor.

Table 4: Effect of selected essential oils and *Trichoderma viride* on dry weight (g) of pumpkin

SN.	Treatments	Treatment Details	R1	R2	R3	Mean
1.	T_0	Control (untreated check)	22.4	22.5	24.5	23.13
2.	T_1	*Trichoderma viride* + Lemongrass essential oil	29.6	31.7	29.7	30.33
3.	T_2	*Trichoderma viride* + Lavender essential oil	32.3	28.1	27.2	29.20
4.	T_3	*Trichoderma viride* + Tea Tree essential oil	29.1	29.2	28.3	28.87
5.	T_4	*Trichoderma viride* +Peppermint essential oil	27.1	26.1	27.5	26.90
6.	T_5	*Trichoderma viride* +Orange essential Oil	24.2	30.7	30.8	28.57
7.	T_6	Control (treated check)Carbendazim	32.2	35.8	35.2	34.40
CD at 5%			**3.760**			
CV%			**7.346**			

Discussion

The observed increase in plant biomass following essential oil treatment supports their effectiveness in controlling powdery mildew pathogens and reducing disease severity. As a result, the pumpkin plants remained healthy and free from infection, allowing them to carry out normal physiological functions and achieve standard growth parameters. Furthermore, the normal development of the treated plants indicates that essential oils exhibit minimal phytotoxicity when applied at appropriate concentrations (2.5 mL/L in this study). The notable increase in the number of flowers per plant following essential oil application also suggests a potential enhancement in yield. This overall improvement in plant growth can reasonably be attributed to: (1) suppression of fungal pathogens, (2) the direct action of bioactive growth-promoting compounds, such as phenolic constituents present in the essential oils, and (3) induction of plant resistance mechanisms against pathogenic attacks.

The enhanced leaf proliferation may result from improved physiological performance due to reduced disease pressure, enhanced root development, and possible stimulation of endogenous phytohormones. These findings align with earlier reports that essential oils can influence plant morphogenesis and stress response pathways (De Clerck *et al.*, 2020), while *Trichoderma viride* facilitates nutrient uptake and promotes vegetative growth under field conditions (Tyskiewicz *et al*., 2022).

The biocontrol mechanisms exhibited by beneficial fungi can be broadly classified into five categories: (i) competition with pathogens for space and nutrients, (ii) mycoparasitism, (iii) antibiosis, (iv) mycovirus-mediated cross protection (MMCP), and (v) induction of systemic resistance (ISR). By employing these mechanisms, beneficial fungi like *Trichoderma* effectively suppress disease-causing pathogens, which in turn reduce infection pressure on the host plant. This alleviation of disease stress allows the plant to maintain normal physiological processes, ultimately leading to enhanced vigor, improved growth, and increased biomass accumulation (Ghorbanpour *et al.*, 2018).

These results support the hypothesis that disease suppression and physiological enhancement through biostimulants can translate into measurable growth and yield gains. The combined bioactivity of *Trichoderma viride* and bioactive oils such as citral-rich lemongrass may improve sink strength, fruit setting, and translocation of photosynthates, resulting in better fruit development.

Conclusion

The present study demonstrates that foliar application of essential oils, particularly Lemongrass and Lavender, in combination with *Trichoderma viride*, significantly enhances vegetative growth and yield parameters in pumpkin (*Cucurbita moschata* Duch.). The treatment combining *Trichoderma viride* with lemongrass oil consistently recorded the highest vine length, number of leaves, flowers and shoot biomass, outperforming both the untreated and chemically treated controls. These effects can be attributed to the synergistic interaction between the biocontrol agent and the bioactive compounds present in essential oils, which together appear to improve plant metabolism, hormonal balance, and resistance to biotic stress. Given the growing demand for sustainable and eco-friendly agricultural practices, this integrated approach presents a promising alternative to synthetic inputs for enhancing pumpkin productivity. Future work may explore its scalability and effectiveness under diverse agro ecological conditions.

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