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Physiological and morphological response of *Polianthes tuberosa* to the treatment of bulbs with plant extracts

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Abstract

Objective: The growing application of chemical compounds to combat pests and plant diseases has led to significant environmental contamination. Employing plant compounds, such as plant extracts and essential oils, as alternatives to chemical compounds, can have a positive impact on reducing environmental pollution. Tuberose (*Polianthes tuberosa*) is a significant tropical and semi-tropical ornamental plant commercially cultivated for its cut flowers and the extraction of essential oil from its aromatic blossoms. Fusarium and Alternaria are the prevailing pathogens of tuberose. This research aimed to explore the effects of peppermint, savory, and thyme extracts on important traits of tuberose, as well as their efficacy in inhibiting the growth of *Fusarium proliferatum* and *Alternaria alternata*, as potential replacements for chemical fungicides.

Methods: The extracts of *Mentha piperita*, *Zataria multiflora*, and *Satureja hortensis* at three rates of 12%, 25%, and 50% (v/v), were applied on tuberose plants by immersion. Mancozeb fungicide at a rate of 2 g/L, was used as the control. The fungus cultivation and the experiment about the plant extracts were conducted at a laboratory in Gorgan, Iran. The experiment was carried out in the form of a completely randomized design with three replications. The measured traits were shoot fresh weight, floret number, floret diameter, stem length, stem diameter, spike length, leaf number, leaf area, bulb number, time to flower emergence, commencing of growth, vase life, and catalase (CAT) and peroxidase (POD) enzyme activities.

Results: The comparison of the means indicated that the highest number of florets, floret diameter, shoot fresh weight, and POD was observed in the treatment of savory extract (12 ml/l). The highest leaf number, stem length, and CAT activity was associated with the treatment of peppermint extract (12 ml/l). Also, the lowest growth rates of *F. proliferatum* and *A. alternata* were obtained from the thyme extract (50 ml/l).

Conclusion: Overall, it was found that the plant extracts utilized in this study can serve as viable alternatives for disinfecting tuberose bulbs prior to planting. However, the results for most evaluated characteristics implied that these substances should be applied in lower concentrations. Although the extracts adversely affected the quantity of bulbs, which needs further investigation, the application of plant compounds can be deemed a reasonable approach given the numerous harmful effects of chemical pesticides. It is also recommended to explore the efficacy of other extracts in disinfecting tuberose bulbs.

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Introduction

Due to the perishable nature crops, they are constantly at risk of spoilage from pathogens and pests throughout their growth, harvest, and postharvest stages. In recent years, natural substances like essential oils and plant extracts have been suggested as novel methods for controlling bacterial and fungal infections and minimizing postharvest losses of horticultural products (El Khetabi *et al.* 2022; Mohd Israfi *et al.* 2022). Also, the growing application of chemical compounds to combat pests and plant diseases has led to the significant environmental contamination. Employing plant compounds, such as plant extracts and essential oils, as alternatives to chemical compounds can have a positive impact on reducing environmental pollution. Thus, the discovery and commercial application of biologically active compounds will be extremely beneficial.

Research has indicated that aromatic plants, particularly those from the families of Lamiaceae, Asteraceae, and Apiaceae, contain abundant antimicrobial and antioxidant compounds, which are minimally toxic to humans and other mammals, earning them widespread popularity across various cultures. Owing to their minimal health and environmental risks, essential oils and plant extracts are regarded as some of the most favorable alternatives to synthetic chemicals (Rajendran 2001). Plant extracts have demonstrated a strong inhibitory effect on many pathogenic fungi and bacteria and have historically been utilized in pest and disease management (Sales *et al.* 2016). Riaz *et al.* (2010) investigated the effect of neem, garlic, onion, ginger, and henna extracts on gladiolus corm rot and found that they positively influenced disease control. Garlic, onion, and ginger extracts showed the most effective results.

Research has revealed that plant extracts not only combat pathogens but also enhance the growth characteristics of certain plants. The use of peppermint and rosemary extracts improved the growth characteristics of *Polyanthus tuberosa* (Babarabie *et al.* 2018). Buthelezi *et al*. (2023) reported that moringa leaf and seed extract improved the morphological and physiological traits of *Lessertia* *frutescens L*. plant. The effect of essential oils and plant extracts on enhancing morphological and biochemical traits of ornamental flowers can be ascribed to their antioxidant qualities and the beneficial impact of their secondary metabolites on the photosynthetic system and enzyme activities (Rezvanipour and Hatamzadeh 2016). Vojodi Mehrabani and Valizadeh Kamran (2019) reported that the application of *Ascophyllum nodosum* extract increased the height, number of lateral branches, and biomass of *Coriandrum sativum* L. plants. Some plant growth regulators have been detected in moringa plants (Rehman *et al.* 2014). Also, Desoky *et al.* (2017) noted that immersing bean seeds in moringa extract increased fresh weight, pod number, the activity of antioxidant enzymes, and chlorophyll content.

Tuberose (*Polianthes tuberosa*) is a significant tropical and semi-tropical ornamental plant (Biswas *et al.* 2002), commercially cultivated for its cut flowers and the extraction of essential oil from its aromatic blossoms (Mishra *et al.* 2008). *Alternaria* and *Fusarium* are the prevailing pathogens of tuberose (Nethaji Mariappan *et al.* 1977; Muthukumar 2007). Bharathi and Narayanaswamy (2018) tested both chemical (carbendazim, captan, and hexaconazole) and natural (neem extract and *Trichoderma* fungus) fungicides on tuberose and reported that all treatments inhibited *Sclerotium rolfsii* growth. However, the combination of *Trichoderma* and carbendazim was more effective in reducing fungal growth. Given that certain chemical fungicides may adversely affect the morphological, physiological, and biochemical characteristics while combating fungal diseases, this research aimed to explore the effects of peppermint, savory, and thyme extracts on these traits of tuberose, as well as their efficacy in inhibiting the growth of *Fusarium proliferatum* and *Alternaria alternata*, as potential replacements for chemical fungicides.

Materials and Methods

The research was conducted in the greenhouse of Gorgan University of Agricultural Sciences and Natural Resources at a day/night temperature regime of 26-28/14-16 °C and 70 ± 5% humidity. The greenhouse's light intensity was kept between 4000 and 8000 lux including average shading (60% shading).

Plant extracts used in the research included the extracts of *Mentha piperita*, *Zataria multiflora*, and *Satureja hortensis* at three rates of 12%, 25%, and 50% (v/v), each in three replicates, applied for 20 minutes by immersion. Mancozeb fungicide was applied at a rate of 2 g/L as the control treatment. Pots with a diameter of 26 cm were filled with a prepared soil mixture, and the bulbs were planted on April 20. Identical tuberose 'Pearl' bulbs with a circumference of 10 cm and an approximate weight of 45 g were supplied from the Tuberose Cultivation Center in Dezful, Iran. Two bulbs were planted in each pot. The cultivation bed was a mixture of animal manure (cow manure), sand, leaf compost, and clay in equal proportions. Irrigation was carried out once every three days following the germination of the bulbs. The soil used in the soil cultivation system was sent to Saeedi Soil, Water, and Plant Laboratory, located in Ali-Abad City, Iran, for further analyses (Table 1).

Table 1. The results of soil analysis of the soil culture system used in the research.

Sample location	**Depth (cm)**	**pH**	**EC (S/m)**	**Saturation %**	**Neutralizing material (%)**	**N (%)**	**Organic C (%)**	**Absorbable P (mg/kg)**	**Absorbable K (mg/kg)**
Gorgan	0-30	7.94	1.56	15.30	9.18	0.18	1.8	7.8	296

Clay (%)	**Silt (%)**	**Sand (%)**	**Fe**	**Zn**	**Cu**	**Mn**	**Cl**	**Mg**	**Texture**
18	66	16	9.2	3.3	1.8	9.2	11.6	4.0	Silty-loam

The measured traits included shoot fresh weight, floret number, floret diameter, stem length, stem diameter, spike length, leaf number, leaf area, bulb number, time to flower emergence, commencing of growth, vase life, and catalase (CAT) and peroxidase (POD) enzyme activities.

The flower fresh weight was measured using a digital scale, model FX-300, with an accuracy of 0.001 g. The postharvest stem and floret diameters were measured using a digital vernier caliper. The floret diameter was measured every five days with a digital vernier caliper after the florets became visible and after were completely opened. After separating the leaves from the plants, their area was measured using a DELTA T model leaf area meter.

CAT (EC 1.11.1.6) activity was measured by spectrophotometry according to Chance and Maehly (1955), monitoring the decline in absorbance at 240 nm due to H_2O_2 consumption. In one milliliter of reaction mixture, there was 15 mM H_2O_2 and 50 mM potassium phosphate buffer (pH 7.0). A 50 µL of crude extract was added to the solution, initiating the reaction. CAT activity was expressed as units (µmol of H2O2 consumed per minute) per milligram of protein.

To measure the activity of guaiacol POD, 50 ml of the crude enzyme preparation was added to 2 ml of a solution containing 50 mM potassium phosphate buffer (pH 7.0), 13 mM guaiacol, and 5 mM hydrogen peroxide.

The fungus cultivation and the experiment about the plant extracts were conducted at a laboratory in Gorgan, Iran. The experiment was conducted in the form of a completely randomized design with three replications. After analysis of variance (ANOVA), the means were compared with the LSD test at the 5 and 1 percent probability levels. The data were analyzed using SAS 9.1 software.

Results and Discussion

The ANOVA revealed that plant extracts significantly influenced floret number, floret diameter, stem length, bulblet number, shoot fresh weight, time to flower emergence, time to germination, vase life, and CAT and POD activity at the $p \leq 0.01$ and leaf number at the $p \leq 0.05$. However, it did not have significant effect on stem diameter and spike length (Tables 2 and 3).

Floret number

The comparison of the means indicated that the highest number of florets (26 florets) was obtained by the treatment of savory extract (12 ml/l), which did not differ significantly from the treatment of thyme extract (12 ml/l). On the other hand, the lowest number of florets (12.67 florets) was associated with the treatment of savory extract (50 ml/l), showing a reduction compared to the control treatment (Mancozeb fungicide) (Table 4).

Plant extracts are renowned for their medicinal and antioxidant properties. Additionally, their high levels of minerals and organic compounds, ease of preparation, and environmental adaptation have garnered significant research interest. The application of garlic extract at a rate of 250 mg/g enhanced the flower number in summer squash plants (Helmy 1992). Rezvanypour and Hatamzadeh (2016) reported that treating gladiolus plants with 1000 mg/l of garden thyme essential oil resulted in the highest number of florets. The findings of these studies regarding the increase in flower number with the application of plant extracts align with the results of the current study, likely attributable to the nutrient content of these extracts.

Floret diameter

According to Table 4, the highest floret diameter was observed in the treatment of savory extract (12 ml/l), while the lowest was related to the treatment of thyme extract (50 mg/l), which showed no significant differences from the treatment of thyme extract at a rate of 25 ml/l but was lower than that of the control. Darvishani *et al.* (2011) found that all concentrations of mint, savory (except for its 10% rate), rosemary, and thyme extracts had a positive and significant effect on flower diameter, which is consistent with our findings.

Table 2. Analysis of variance for the effect of plant extracts as bulb disinfectant on the morphological traits of cut tuberose flowers.

Sources of variation	Degrees of freedom	Mean squares					
		Floret number	Floret diameter	Stem diameter	Leaf number	Stem length	Spike length
Treatment	9	59.05**	107.67**	0.16	3.85*	107.86**	12.06
Error	18	0.84	5.63	0.08	1.12	16.60	7.89
CV (%)	-	4.63	6.13	9.68	12.69	6.19	17.78

*,**Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively.

Table 3. Analysis of variance for the effect of plant extracts as bulb disinfectants on various traits of cut tuberose flowers.

Sources of variation	Degrees of freedom	Mean squares						
		Bulblet number	Shoot fresh weight	Time to flower emergence	Time to germination	Vase life	Catalase	Peroxidase
Treatment	9	4.670**	754.28**	123.11**	84.40**	1.57**	0.013**	0.314**
Error	18	0.248	19.04	4.07	3.98	0.26	0.001	0.0008
CV (%)	-	10.17	6.37	2.02	9.22	7.16	20.33	9.79

**Significant at $p \leq 0.01$.

Table 4. The comparison of means for the effect of plant extracts as bulb disinfectants on the morphological traits of cut tuberose flowers.

Treatment	Floret number	Floret diameter (mm)	Stem diameter (mm)	Leaf number	Stem length (cm)	Spike length (cm)
Zataria multiflora extract (12 ml/l)	25.67 a	37.76 de	6.53 a	6.00 c	70.33 abc	19.67 a
Zataria multiflora extract (25 ml/l)	21.337 c	29.19 f	6.55 a	7.67 bc	61.78 e	17.50 ab
Zataria multiflora extract (50 ml/l)	16.67 f	29.06 f	6.44 a	8.33 b	52.75 f	13.17 b
Mentha piperita extract (12 ml/l)	23.337 b	40.88 bcd	6.37 a	10.33 a	73.67 a	19.33 a
Mentha piperita extract (25 ml/l)	20.00 cd	38.92 de	6.40 a	9.33 ab	64.33 cde	18.50 ab
Mentha piperita extract (50 ml/l)	14.67 g	36.18 e	6.30 a	8.00 b	63.00 de	18.00 ab
Satureja hortensis extract (12 ml/l)	26.00 a	46.72 a	6.63 a	9.00 ab	66.00 bcde	18.17 ab
Satureja hortensis extract (25 ml/l)	18.33 e	44.49 ab	6.27 a	8.33 b	71.67 ab	17.50 ab
Satureja hortensis extract (50 ml/l)	12.67 h	44.00 abc	6.24 a	8.00 b	69.00 abcd	15.50 ab
Control (Mancozeb)	19.33 de	40.03 cde	6.21 a	8.33 b	66.00 bcde	19.50 a

Means with similar letters in each column are not significantly different at $p \leq 0.05$ or $p \leq 0.01$ based on LSD test.

Leaf number

Based on the comparison of means, the highest leaf number (10.33) was associated with the treatment of peppermint extract (12 ml/l), and the lowest (6 leaves) with the treatment of thyme extract (12 ml/l), exhibiting a reducing effect on the leaf number versus the control (Table 4). The enhancement of morphological traits in plants by certain plant extracts, including garlic, has been documented in ornamental plants such as narcissus, geranium, and freesia (Gommaa *et al.* 2005; EL-Sayed *et al.* 2015).

Plant compounds can exert a variety of positive or negative effects on growth, flowering, and growth and developmental processes. Research has demonstrated that thyme essential oil can inhibit germination and reduce the growth of plants like radish, lettuce, and garden cress (De Almeida *et al.* 2010). In this study, increasing concentrations of savory and thyme extracts led to a decrease and increase in leaf number, respectively, highlighting the distinct effects of two different plant extracts on tuberose growth. The varying effects of various extracts on growth traits, such as leaf number, may also be attributed to their unique contents and compositions.

Stem and spike length

It was revealed that the highest stem length (73.67) was related to the treatment of peppermint extract (12 ml/l) and the lowest (52.75) to the treatment of thyme extract (50 ml/l). This treatment was associated with shorter stems than the control (Table 4).

An essential characteristic in grading tuberose cut flowers is the stem length. In the present study, the thyme extract at high rates reduced stem length significantly. On the contrary, the plants disinfected with Mancozeb did not have significantly lower plant height than those treated with the plant extracts and were even taller than those treated with the extracts at rates higher than 12%. This effect may be related to the compounds present in thyme, such as camphor, pinene, and linalool (Macias *et al.* 2007; Azirak and Karaman 2008). These compounds have a substantial impact on mitosis and can retard or reduce cell division (Romagni *et al.* 2000). Altaee (2019) reported that the licorice extract increased the flowering stem length of daffodil cut flowers, which is an ornamental bulbous plant. However, in a study by Sadeghizadeh and Zarea (2021) it was found that the length of rice inflorescences increased with foliar application of the *Lathyrus sativus* extract.

Bulblet number

The results of the present study showed that the control (Mancozeb) had the highest number of bulblets (7.33), whereas the lowest number (3.67) was related to the treatment of peppermint extract

(50 ml/l), not differing from the treatments of thyme (12, 25, and 50 ml/l) and peppermint (12 and 25 ml/l) significantly (Table 5). Rezvanypour and Hatamzadeh (2016) reported that the effect of plant essential oils was significant on the daughter corms of gladiolus, but its impact was insignificant on the produced cormlets. They reported that the corms treated with 4000 mg/l eucalyptus essential oil produced no corms or cormlets. However, all corms treated with the thyme essential oil produced two daughter corms, irrespective of the essential oil's rate, whereas the control and 2000 mg/l eucalyptus treatment produced only one daughter corm. Although the treatments did not differ in the number of cormlets significantly, the highest number of cormlets was produced in the treatment of 1000 mg/l garden thyme essential oil. In the present work, it was found that the plant extracts at various rates reduced the number of bulblets, showing their adverse effect and their allelopathic effects on some growth traits of the plants. The number of bulblets is of high economic significance in ornamental bulbous plant species because the more the number of bulbs and bulblets, the higher the profit the grower will gain. Therefore, it is necessary to study concentrations lower than 12% on this trait.

Shoot fresh weight

Based on the comparison of means, the treatment of savory extract (12 ml/l) had the highest, and the treatment of thyme extract (12 ml/l) had the lowest shoot fresh weight (88.55 vs. 41.12 g). The latter treatment had lower shoot fresh weight than the control (61.21 g). In addition to thyme, the peppermint extract (25 ml/l) showed significantly higher shoot fresh weight (84.21 g) than the control (Table 5).

Some plant extracts improve root and stem growth (Zhang and Schmidt 1999). It was reported that savory extract increased the fresh weight of gerbera cut flowers significantly (Mohammadi *et al.* 2019). Similarly, Farhoodi *et al.* (2018) revealed that savory extract improved the fresh weight of lily cut flowers, which is a bulbous plant species just like tuberose. Our findings are consistent with the report of Farhoodi *et al.* (2018).

Time to flower emergence

The longest time to flower emergence was 110.66 days, related to the treatment of thyme extract (50 ml/l), and the shortest was 92.67 days, associated with the treatment of savory extract (50 ml/l), not differing from the treatment of peppermint extract (12 ml/l) significantly. These treatments had a shortening effect on the time to flower emergence (Table 5).

The time to flower emergence is an essential trait in ornamental plants, especially in cut flowers, because delayed flower emergence is significant, given different events and the fluctuations of flower

Table 5. The means for the various traits of cut tuberose flowers, affected by the plant extracts as bulb disinfectants.

Treatment	Bulblet number	Shoot fresh weight (g)	Time from planting to flower emergence (day)	Time from planting to germination (day)	Vase life (day)	CAT (unit/mg protein)	POD (unit/mg protein)
Zataria multiflora extract (12 ml/l)	4.00 c	78.87 bc	95.33 cd	17.67 cd	8.67 a	0.183 cd	0.268 c
Zataria multiflora extract (25 ml/l)	4.33 c	71.46 c	101.33 b	23.67 b	7.33 b	0.225 bc	0.372 b
Zataria multiflora extract (50 ml/l)	4.00 c	41.12 e	110.67 a	30.33 a	6.33 c	0.261 ab	0.459 a
Mentha piperita extract (12 ml/l)	4.00 c	77.94 bc	94.33 d	16.67 d	7.33 b	0.295 a	0.347 b
Mentha piperita extract (25 ml/l)	4.00 c	84.21 ab	98.33 bc	10.67 bc	7.67 b	0.261 ab	0.256 c
Mentha piperita extract (50 ml/l)	3.67 c	75.35 c	111.00 a	30.33 a	6.33 c	0.179 cd	0.165 d
Satureja hortensis extract (12 ml/l)	6.00 b	88.55 a	100.33 b	22.67 b	7.33 b	0.118 de	0.271 c
Satureja hortensis extract (25 ml/l)	6.00 b	59.42 d	98.00 bc	21.00 bc	7.00 bc	0.119 de	0.438 a
Satureja hortensis extract (50 ml/l)	5.67 b	46.68 e	92.67 d	15.00 d	6.33 c	0.177 cd	0.246 c
Control (Mancozeb)	7.33 a	61.21 d	95.67 cd	18.33 cd	7.33 b	0.107 e	0.266 c

POD: peroxidase; CAT: Calalase; Means with similar letters in each column are not significantly different at $p \leq 0.05$ or $p \leq 0.01$ based on LSD test.

prices in the marketplace. Therefore, the compounds that can control this trait in plants, even partially, will be valuable. Given the significant and suitable effect of some plant extracts used in the present research on this trait, they can be valuable in this regard, in addition to functioning as bulb disinfectants.

Time to bulb germination

The longest time to bulb germination (30.33 days) was related to the treatments of thyme and peppermint extracts (50 ml/l), and the shortest was related to the treatment of savory extract (50 ml/l), not differing from the treatment of peppermint extract (12 ml/l) significantly. They had a reducing effect on this trait compared with the control (Table 5).

Thyme extract mainly contains phenolic monoterpene. Thymol and carvacrol are its most important active ingredients (Romagni *et al.* 2000). The monoterpenes of camphor, pinene, linalool, cavacrol, and thymol in thyme essential oil have been reported to affect germination negatively (Macias *et al.* 2007; Azirak and Karaman 2008). Similarly, we observed that the thyme extract at high rates delayed the tuberose bulb germination significantly. However, this negative effect can be greatly avoided by applying a proper extract at a proper concentration. The savory extract at the rate of 50%

shortened the time to bulb germination in the present study. Allelopathic compounds of some plant extracts influence the internal concentration of plant growth regulators and trigger changes like reducing the α-amylase enzyme activity and germination (Bogatek *et al.* 2005).

Vase life

The comparison of means showed that the longest vase life was 8.67 days, related to the treatment of thyme extract (12 ml/l), and the shortest was 6.33 days, related to the treatments of thyme, peppermint, and savory extracts (50 ml/l), which had a shortening effect on tuberose vase life (Table 5). Flower opening requires consuming ATP, whereas supplying ATP requires breaking down of sugar molecules through the respiration process. Therefore, any factor that can reduce plant respiration can retard flower opening and stimulate flower senescence. Similar to our findings, Kaviani *et al.* (2023) stated that the treatment of cut roses with 10% peppermint extract improved their vase life, but as its concentration increased, the vase life started to decrease. Also, Zulfiqar *et al.* (2024) found that the borage extract improved the vase life and some qualitative traits of gladiolus as a bulbous plant.

Activities of catalase and peroxidase enzymes

It was found that the highest CAT activity was associated with the treatment of peppermint extract (12 ml/l) and the lowest with the control (Mancozeb). Also, the highest POD activity (0.46) was obtained from the treatment of thyme extract (50 ml/l), but did not differ from the treatment of savory extract (12 ml/l). The lowest was 0.17, related to the treatment of peppermint extract (50 ml/l), which was lower than that of the control (Table 5).

Plants possess a variety of antioxidants that safeguard cells against oxidative damage by trapping reactive oxygen species (ROS). These include ascorbate, glutathione, hydrophilic molecules (e.g., tocopherols, carotenoids, and xanthophylls), and detoxifying enzymes that operate across various cell organs. These detoxifying enzymes, which include superoxide dismutase (SOD), CAT, and POD, collaborate with one another and other ascorbate/glutathione cycles to scavenge ROS (Hernandez *et al.* 2001).

Antioxidant enzymes defend the cellular milieu from the detrimental impacts of radicals by eliminating oxygen free radicals. Also, similar to other protein-containing compounds, their activity is diminished by high concentrations of allelochemicals (Yu *et al.* 2003; Oracz *et al.* 2007). In this study, we observed a decline in POD enzyme activity with increasing concentrations of peppermint extract. Akhtar *et al.* (2021) demonstrated that the CAT and POD activities of cut gladiolus flowers were enhanced by the peppermint extract at a rate of 2%, corroborating the findings of our investigation. Mousavizadeh and Sedaghathoor (2011) noted that thyme essential oil at concentrations of 500 and 750 mg/l and rosemary essential oil at 2000 mg/l had the greatest impact on reducing POD activity.

Fusarium and Alternaria growth rate

According to ANOVA, the effect of plant extracts was significant ($p \leq 0.01$) on the growth rate of *Fusarium proliferatum* and *Alternaria alternate* (Table 6). The comparison of means showed that the highest and lowest growth rates of *F. proliferatum* were obtained from the treatments of savory extract (12 ml/l) and thyme extract (50 ml/l) (Table 7). The highest growth rate of *A. alternate* was obtained from the peppermint extract at a rate of 50 ml/l, and the lowest was obtained from the treatment of peppermint extract at a rate of 12 ml/l, insignificantly differing from the thyme extracts at rates of 25 and 50 ml/l (Table 7).

Table 6. Analysis of variance for the effect of plant extracts on the growth of the studied fungi.

Sources of variations	Degrees of freedom	The growth rate of *Alternaria alternate*	The growth rate of *Fusarium proliferatum*
Treatment	9	710.54**	182.23**
Error	18	4.92	3.91
Cv (%)	-	4.72	8.23

**Significant at $p \leq 0.01$.

Table 7. The comparison of means for the effect of plant extracts on the growth of the studied fungi.

Treatment	The growth rate of *Alternaria alternate* (%)	The growth rate of *Fusarium proliferatum* (%)
Thyme extract (12 ml/l)	41.437 e	24.603 d
Zataria multiflora extract (25 ml/l)	36.600 f	19.177 e
Zataria multiflora extract (50 ml/l)	34.647 f	10.197 f
Mentha piperita extract (12 ml/l)	55.010 c	30.080 bc
Mentha piperita extract (25 ml/l)	33.017 f	27.827 cd
Mentha piperita extract (50 ml/l)	72.797 a	18.893 e
Satureja hortensis extract (12 ml/l)	65.107 b	36.740 a
Satureja hortensis extract (25 ml/l)	40.850 e	20.833 e
Satureja hortensis extract (50 ml/l)	40.567 e	19.973 e
Control (Mancozeb)	50.193 d	32.050 b

Means with similar letters in each column are not significantly different at $p \leq 0.05$ or $p \leq 0.01$ based on LSD test.

Root and bulb rot, a prevalent disease in tuberose growing regions, is attributed to the *Fusarium* fungus (Muthukumar 2007). Additionally, tuberose faces the challenge of leaf spot disease instigated by the *Alternaria* fungus (Naga Lakshmi *et al.* 2018). Mazumder *et al.* (2016) observed that

Mancozeb mitigated approximately 50% of the disease caused by *Alternaria* in tuberose, which is consistent with our findings.

Research indicates that garlic extract at a concentration of 51 ml/l curtails the proliferation of *Alternaria* and *F. oxysporum* (Amrollahi *et al.* 2010). Also, Abdolmaleki *et al.* (2011) discovered that an aqueous extract of peppermint at 20 ml/l effectively hampered the growth of *F. oxysporum*, implying the potent impact of plant extracts on curtailing the growth of certain pathogens. Ghazalbash *et al.* (2013) revealed that thyme extract reduced the mycelial growth of *F. oxysporum* by 68%, which agrees with our findings. Extracts of savory, mint, and rosemary (20 ml/l) have been shown to significantly impede the growth rate of *F. oxysporum* under *in vitro* conditions. Furthermore, Riaz *et al.* (2010) reported the suppressive influence of eucalyptus extract on the *Fusarium* infection in gladiolus bulbs.

Conclusion

Overall, it was found that the plant extracts utilized in this study can be used to fight disease-causing pathogens. However, the results for most evaluated characteristics implied that these substances should be applied in minimal concentrations. Although the extracts adversely affected the quantity of bulbs produced, which needs further investigation, the application of plant compounds can be deemed a reasonable approach given the numerous harmful effects of chemical pesticides. It is also recommended to explore the efficacy of other extracts in disinfecting tuberose bulbs.

Conflict of Interest

The authors declare that they do not have any relevant financial or non-financial competing interests.

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